[DOI]10.12016/j.issn.2096-1456.202550458

· 综述 ·

牙膏功效成分的作用及研究进展

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【摘要】　随着大众口腔健康意识的不断提升，功效型牙膏已逐渐成为市场主流产品，通过化学活性成分与机械清洁的协同作用，实现防龋、抗炎、抗牙本质敏感及美白等多重功效。本文系统梳理了近年来牙膏功效成分的研究进展，重点分析四大核心功能领域关键成分及其作用机制：在防龋方面，以氟化物为核心，钙磷类协同促进牙体再矿化，益生菌与草本制剂辅助调节口腔微生态；在抗菌抗炎方面，依赖多种成分的协同作用，抑制致病菌并减轻炎症反应；在抗牙本质敏感方面，通过物理封闭和神经抑制双路径发挥作用，草本制剂提供了天然替代方案；在美白方面，依托机械摩擦、化学美白和光学修饰三重机制重塑色泽。当前研究仍存在碎片化、重复性高的问题，难以形成系统的科学证据体系，导致消费者难以基于充分证据选择合适产品，且牙膏的精准化与个性化研究尚显不足。未来研究应致力于构建更加完整的功效评价体系，深化多组分协同机制研究，并推动针对不同口腔微生态特征及个体需求的精准牙膏研发。本文通过综述牙膏成分、作用机制、临床效果及安全性，旨在为功效型牙膏的研发优化与临床推荐提供理论依据，助力精准口腔医学的发展。

【关键词】　牙膏；　功效成分；　防龋；　再矿化；　抗炎；　抗菌；　抗牙本质敏感；　美白

【中图分类号】　R78　**【文献标志码】**　A　**【文章编号】**　2096-1456（2026）05-0518-11

微信公众号

【引用著录格式】　安佳琪，张琛，李韶容. 牙膏功效成分的作用及研究进展[J]. 口腔疾病防治, 2026, 34(5): 518-528. doi:10.12016/j.issn.2096-1456.202550458.

The functions and research progress of toothpaste efficacy ingredients

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【Abstract】　With a growing public emphasis on oral health, efficacy-focused toothpastes have become mainstream. By combining chemical active ingredients with mechanical cleaning, these products deliver multifunctional benefits, such as caries prevention, dentin hypersensitivity relief, whitening, and anti-inflammation. This article systematically reviews recent advances in key efficacious ingredients across four functional domains: fluoride, often supplemented with calcium-phosphorus compounds, probiotics, and herbal preparations, primarily prevents caries; antibacterial and anti-inflammatory effects arise from multi-ingredient synergy; anti-hypersensitivity works via physical occlusion and nerve inhibition, with herbal extracts as natural alternatives; and whitening involves mechanical abrasion, chemical action, and optical modification. However, current research remains fragmented and repetitive, lacking a systematic evidence base. This complicates evidence-based consumer choice, while studies on precision and personalized formulations are still limited. Future efforts should establish comprehensive efficacy evaluation systems, investigate multi-component synergies, and advance precision toothpaste development tailored to individual oral microbiomes and needs. By summarizing ingredients, mechanisms, efficacy, and safety elements, this review aims to support optimized toothpaste formulation and clinical application, thereby contributing to oral healthcare precision.

【Key words】　toothpaste;　efficacy ingredients;　caries prevention;　remineralization;　anti-inflammatory;　antibacterial;　anti-dentin hypersensitivity;　whitening

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【收稿日期】2025-10-09；　**【修回日期】**2025-11-18
【基金项目】北京市自然科学基金项目（7232070）；中华口腔医学会青年临床科研基金项目（CSA-F2024-03）

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J Prev Treat Stomatol Dis, 2026, 34(5): 518-528.

【Competing interests】 The authors declare no competing interests.

This study was supported by the grants from Beijing Municipal Natural Science Foundation (No. 7232070) and Young Clinical Research Fund of the Chinese Stomatological Association(No. CSA-F2024-03).

牙膏是兼具清洁与护理功能的口腔日常护理剂[1]。通过去除口腔内食物残渣、牙菌斑，以特定配方预防口腔疾病、改善口腔组织健康，如防龋、抗菌抗炎、抗牙本质敏感，部分产品还具备美学或个性化功效。牙膏通常分为普通型牙膏和功效型牙膏。从成分构成分析，牙膏包含基质、功能性及辅助成分。基质成分是牙膏的主体，决定牙膏的形态、稳定性和基础清洁能力[2]，主要包括摩擦剂、保湿剂、黏合剂等[3-4]；功能性成分是功效型牙膏的核心，根据不同需求予以添加；辅助成分能提升牙膏的使用感受和保质期，如调味剂、防腐剂等[5-6]。

随着大众口腔健康意识的提升，对牙膏功效成分的研究日趋深入。大量研究不仅聚焦于氟化物、抗菌剂等经典成分的机制、功效与安全性，也涌现出多种新型活性成分，为牙膏的功能拓展提供新可能[7-9]。但研究存在碎片化、重复性高的问题，人们难以依据科学证据做出选择，也限制了口腔护理产品的精准化、个性化发展。本文系统总结近年功效型牙膏的成分及机制，为研发与临床推荐提供思路。

1　牙膏防龋及促进再矿化功效成分

龋病是以细菌为主的多种因素作用下牙体硬组织发生慢性进行性破坏的一种疾病[10]。口腔内复杂微生物群落中，变形链球菌等[11]水平升高与龋病发生直接相关[12]。世界卫生组织将龋齿列为危害人类健康的第三大疾病[13]。防龋牙膏作为个体抗龋的关键防线，通过局部再矿化、抑制细菌产酸及逆转早期龋损[14]，从源头减少龋齿发生。

1.1　核心成分——氟化物

防龋牙膏的核心是调节脱矿/再矿化平衡[15]。牙釉质主要成分是羟基磷灰石（hydroxyapatite，HAP），抗酸能力较弱，易被细菌产生的有机酸腐蚀[16]。氟化物释放氟离子（F^-）到牙釉质表层，与HAP中羟基替换，形成氟磷灰石[17-18]，氟磷灰石抗酸能力是HAP的5～10倍，可直接抵御细菌产酸的腐蚀，减少脱矿风险；同时，氟化物能加速游离的钙、磷离子向脱矿区沉积，促进再矿化，修复早期龋损[19-20]；F^-还可抑制致龋菌代谢，减少酸性产物[21-22]。几乎所有上市的防龋牙膏均以氟化物为主要活性物质[23]。含氟牙膏常见的氟化物有氟化钠、单氟磷酸钠、氟化亚锡（SnF_2）等，氟浓度需达到1 000～1 450 ppm[24]。对于龋易感高风险人群，建议选用更高浓度的含氟牙膏[25]，研究显示氟浓度越高，防龋效果越强[19]。

含氟牙膏具有双面性，一方面预防龋齿促进再矿化；另一方面过量摄入有氟蓄积风险[26]。我国国家标准规定成人含氟牙膏的氟含量为0.05%～0.15%，儿童含氟牙膏的氟含量为0.05%～0.11%。3岁以内婴幼儿每次牙膏用量为米粒大小，约0.2 g；3岁以上儿童每次用量为豌豆大小，约0.5 g[27]。

1.2　协同增效剂——钙磷类成分

防龋牙膏中常添加钙磷类成分，如HAP、酪蛋白磷酸肽-无定形磷酸钙（casein phosphopeptide-amorphous calcium phosphate，CPP-ACP）、磷硅酸钠钙（calcium sodium phosphosilicate，CSPS）或β-三钙磷酸盐等[23，28-29]。此类成分补充牙釉质矿化所需的Ca^{2+}、PO_4^{3-}，与氟化物协同增效，尤其适合氟斑牙高风险人群或氟不耐受者[30]。

HAP在牙膏中多以微晶、纳米晶和离子取代形式存在。微晶HAP颗粒（5～10 μm）可驻留牙面控制菌斑及维持表面光滑度；纳米晶HAP颗粒（20～100 nm）可渗透至龋损深处释放钙磷，抑制脱矿；离子取代型（含锌、氟或锶）HAP颗粒可增强抗菌活性或再矿化潜力[31-33]。

研究显示无氟离子取代型HAP牙膏能实现牙釉质深层的均匀再矿化，防龋效果与含氟牙膏相当[31-32，34]，且可规避6岁以下儿童因误吞导致的氟斑牙风险，实现均匀、平滑的牙釉质修复，降低表面粗糙度，可作为含氟牙膏的有效替代方案[34-36]。

钙磷类成分与氟化物复配可发挥协同增效作用，其再矿化效果优于传统单一含氟牙膏。Cocco等[33]研究表明，含仿生羟基磷灰石-氟化物的牙膏在儿童乳牙活性龋病干预中，能更有效地阻断龋损进展并增强牙釉质再矿化程度，效果优于标准

含氟牙膏。Gonçalves等[23]研究表明，含氟化物、CPP-ACP和三偏磷酸钠组成的新型复合牙膏，再矿化效果优于传统含氟牙膏，三种成分共同作用可提升再矿化效率和深度。

1.3　辅助成分——益生菌及草本成分

除上述核心成分外，部分防龋牙膏还添加益生菌、天然草本抗菌成分，改善口腔微生态，减少龋齿风险[37]。Tahir等[38]研究表明，副干酪乳杆菌可抑制致病菌并恢复微生态平衡，但在菌斑控制方面并未显示出优于普通牙膏的效果，难以达到理想的防龋效果。Pørksen等[39]将含2%精氨酸与益生菌的含片与1 450 ppm含氟牙膏联合使用，在10~12个月的观察期内发现龋病进展及活动性病变指标有所改善，提示含氟牙膏中添加益生菌成分可能成为未来防龋牙膏的研发方向之一。

随着人们对“天然无添加”的追求，草本牙膏日益受到关注。Qi等[40]研究表明，含积雪草、虎杖根、黄芩根等8种草本提取物的天然产物混合物（a natural product mixture of eight ingredients，NPM-8）的含氟牙膏，有更优更快的抑菌杀菌作用，其抗菌性能优于常规含氟牙膏，且生物安全性良好。Biria等[12]研究显示，含竹盐的草本牙膏可降低唾液中变形链球菌和乳酸杆菌水平，其抗菌能力与常规牙膏相当，可作为防龋的又一可行选择。

综上，氟化物通过促进氟磷灰石形成、增强再矿化、抑制致龋菌三重作用，构成防龋牙膏的核心成分，但需严格控制浓度；钙磷类成分可补充矿化所需离子，与氟化物协同增效，为儿童、氟不耐受人群提供了安全替代方案；益生菌与草本成分通过调节口腔微生态辅助防龋。基于现有研究，临床应用推荐如表1所示。

表1　防龋及促进再矿化牙膏临床应用推荐

Table 1　Clinical recommendations of caries prevention and remineralization toothpaste

Categories	Core needs	Toothpaste types	Key ingredients
Children under 3 years old	Caries prevention, avoid fluoride accumulation risk	Children's caries prevention toothpaste	Fluoride content: 0.05%-0.11%, or fluoride-free HAP toothpaste
Children over 3 years old	Caries prevention	Children's fluoride toothpaste	Fluoride content: 0.05%-0.11%
Adults susceptible to caries	Powerful caries prevention	High-fluoride toothpaste	Fluoride concentration ≥ 1 450 ppm or synergistic formulations combining fluoride with calcium phosphate compounds (CPP-ACP, HAP)
Fluoride-intolerant individuals	Caries prevention, fluoride-free safety	Fluoride-free toothpaste	HAP (especially nanocrystalline HAP) and CSPS

HAP: hydroxyapatite; CPP-ACP: casein phosphopeptide-amorphic calcium phosphate; CSPS: calcium sodium phosphosilicate

2　牙膏抗菌抗炎功效成分

牙周病是以牙周支持组织破坏为特征的慢性感染性疾病，涵盖了从早期轻度炎症到晚期组织严重破坏的连续病变过程[41-42]。牙龈炎是牙周病的初始阶段，若未及时控制可进展为牙周炎[43]。牙菌斑是牙周病的主要始动因素，其主要由链球菌、放线菌等微生物构成[40, 44]。使用具有抗菌功能的牙膏能有效减少牙菌斑，控制龋齿和牙周病[45]。因此，有效管理牙龈炎、减少牙龈出血已成为消费者对牙膏功能的重要诉求之一[46]。目前，抗炎抗菌牙膏成分主要可分为抗菌类、抗炎类及止血修复类，它们通过不同机制共同缓解牙龈炎症状。

2.1　抗菌类成分

抗菌类成分主要通过直接清除或抑制致炎细菌，减少炎症介质释放，从而达到控制牙龈炎症的目的。常用核心成分包括氯化十六烷基吡啶（cetylpyridinium chloride，CPC）、胺类化合物等。

CPC能破坏细菌细胞膜结构，抑制生物膜形成，减少细菌在牙面的定植。Iniesta等[22]研究表明，使用含CPC的牙膏可针对性减少部分潜在致病菌，并增加与健康相关的有益菌。胺类化合物可破坏细菌细胞壁，抑制生物膜形成；锌离子可干扰细菌酶活性，减轻牙龈炎症。Seriwatanachai等[47]研究表明，含有胺类化合物、0.5%乳酸锌及1 400 ppm氟化钠的新型牙膏，在减少牙菌斑和改

善牙龈炎方面显著优于普通含氟牙膏。

天然抗菌成分亦具有一定优势，如连翘、山银花以及NPM-8等多种中草药含有的黄酮类、生物碱类、酚类及挥发油等活性成分，具有抑菌、抗炎、抗氧化及抗病毒等作用[48]。胡椒薄荷精油—壳聚糖纳米凝胶在牙膏及漱口水配方中也展现出良好的应用前景[49]。研究发现，含芦荟提取物的牙膏，其抑菌活性显著强于含野草莓提取物的牙膏[50]。

2.2　抗炎类成分

抗炎类成分通过抑制炎症通路、减少炎症介质释放，从而缓解牙龈炎症[51]，包括甘草酸二钾（dipotassium glycyrrhizinate，DPG）、姜黄素等。DPG是甘草提取物活性成分，抗炎机制与糖皮质激素相似，但无免疫抑制副作用。Ohara等[52]研究表明，DPG有选择性抗菌作用，可通过调节口腔微生物群，发挥抗炎作用，有助于牙周疾病的预防。姜黄素是姜黄的活性成分，兼具抗炎与抗氧化作用[53]，适合慢性牙龈炎患者。其核心机制为调控巨噬细胞极化过程，降低肿瘤坏死因子α（tumor necrosis factor-α，TNF-α）、白细胞介素-1β（interleukin-1β，IL-1β）、白细胞介素-6（interleukin-6，IL-6）等促炎因子表达水平。Wang等[54]研究发现，姜黄素可显著缓解结扎诱导的小鼠牙周炎进展，有效减轻牙龈炎症并保护牙槽骨，为牙周炎治疗提供新靶点和策略，其具体作用机制仍有待进一步深入研究。

2.3　止血修复成分

止血修复成分通过加速凝血过程、促进组织修复[55]，有效缓解牙龈出血症状，包括氨甲环酸（tranexamic acid，AMCA）等。AMCA是抗纤溶药物，可快速止血[56]，适合急性牙龈炎或出血明显的患者。其作用机制在于通过与纤溶酶原结合，阻止其转化为纤溶酶，减少纤维蛋白降解，加速凝血块形成，并增强牙龈毛细血管的完整性，降低出血风险[57]。相关研究也证实，含AMCA牙膏具有显著的止血作用[58]。

综上，在抗菌抗炎牙膏领域，化学抗菌、抗炎、止血及天然草本成分各具优势，但单一成分难以满足综合需求。未来研究应致力于通过标准化实验与临床验证，优化复方配伍策略，在保障疗效的同时维护口腔微生态平衡。Rajendiran等[59]研究表明，针对牙周炎患者推荐的牙膏功效成分主要包括：抗牙菌斑的氯己定，安全性较高的氯化十六烷基吡啶，兼具抗菌斑、抗牙龈炎、防龋及改善微环境的氟化物，辅助控制菌斑与促再矿化的锌类成分，以及具备抑菌与抗炎潜力的草本提取物。上述成分为牙周炎的日常维护提供辅助支持。

3　牙膏抗牙本质敏感功效成分

牙本质敏感症（dentin hypersensitivity，DH）是指牙齿受外界刺激时，出现短暂、尖锐的疼痛或不适的现象[60]。其发生机制目前主要采用“流体动力学说”进行解释，即外界刺激引起牙本质小管内液体流动，进而激活神经末梢产生疼痛[61]。抗牙本质敏感牙膏作为常用的日常护理手段，主要通过物理封闭牙本质小管及降低神经对疼痛刺激的反应两大路径缓解敏感[62]。

3.1　物理封闭牙本质小管成分

此类物质通过在牙本质表面或小管内形成致密屏障，减少液体流动，是长效抗敏感的主流选择，主要活性成分包含[63]锶类化合物、CSPS、SnF_2、HAP、精氨酸等。

锶类化合物是最早应用于抗敏感牙膏的封闭剂之一，其效果也已得到临床验证[64]。研究表明，锶类化合物可进入牙本质小管，与钙反应形成锶磷灰石并沉积，从而封闭小管[62]。Kun等[65]通过高分辨率显微放射照相术、电子探针分析和X射线衍射技术等方法验证了这一结论。

CSPS自2000年后逐步进入牙膏市场[66]，其与唾液中Ca^{2+}、HPO_4^{2-}反应形成类HAP的无定形钙磷层，封闭牙本质小管开口及深层，阻断刺激传导；同时，其释放的Ca^{2+}、PO_4^{3-}浓度是唾液的10倍，在酸性环境中促进矿化，修复牙釉质并减少牙本质暴露。CSPS对冷刺激的缓解效果显著，是缓解冷刺激最佳脱敏成分之一[67]。

SnF_2通过在牙本质表面化学沉积不溶性亚锡盐层，阻断小管内液体流动，减少刺激引发的疼痛信号传导[68]，且不易被唾液冲刷脱落。但其稳定性较差，若配方未添加稳定剂，Sn^{2+}易被氧化为Sn^{4+}，与口腔内蛋白质结合形成棕褐色沉积物，导致牙齿染色[69]。

精氨酸作为载体将Ca^{2+}和PO_4^{3-}转运至牙本质小管口，与唾液糖蛋白结合形成致密的钙磷-糖蛋白保护层，实现封闭作用[70]。其效果高度依赖唾液钙磷浓度，是缓解空气刺激效果最佳的成分之一[63，67]。

HAP与天然牙本质主要成分一致，可在牙本质小管口形成薄层HAP结晶，物理性覆盖、充填牙

本质小管口[71-72]。但其对深层小管封闭能力较弱，故多作为辅助成分增强效果[63，73]。

Martins 等[63]开展了一项回顾性研究，通过视觉模拟量表综合分析评估，锶类化合物对冷刺激痛和空气刺激痛缓解效果有限；CSPS 核心优势在于缓解冷刺激痛；SnF_2对空气和触觉刺激引发的敏感痛改善显著；精氨酸对空气刺激痛缓解效果最为显著。各活性成分的有效性比较及临床应用推荐如表2所示。

表2 抗牙本质敏感牙膏活性成分的有效性及临床应用推荐

Table 2 Efficacy of active ingredients in anti-dentin sensitivity toothpaste and clinical application recommendations

Active ingredients	Effectiveness	Recommended applicable patients
Strontium compounds	Significant alleviation of pain from tactile stimulation	Patients with tooth sensitivity triggered by tooth contact (such as when brushing teeth or biting hard objects)
CSPS	Significant alleviation of pain from cold stimulation	Patients with cold stimulus sensitivity (such as pain when drinking ice water), root surface sensitivity after periodontal treatment, and early enamel demineralization
Stannous fluoride	Significant alleviation of pain from air and tactile stimulation	Patients with cold stimulus sensitivity (such as pain when drinking ice water), root surface sensitivity after periodontal treatment, and early enamel demineralization
Arginine	Significant alleviation of pain from air stimulation	Non-all-round desensitizing ingredients, suitable for patients with air stimulus pain in autumn and winter, airflow sensitivity after dental examination, or intolerance to chemical ingredients (such as stannous fluoride or potassium)

CSPS: calcium sodium phosphosilicate

3.2 牙髓神经抑制成分

神经抑制型抗敏感牙膏主要活性成分为钾化合物。钾离子通过牙本质小管渗透至牙髓神经末梢，降低神经细胞膜兴奋性，减少疼痛信号的产生[74]，从信号源头缓解疼痛。其安全性高，无黏膜刺激、牙齿染色等副作用，适合儿童、孕妇等人群[62-63]。但也有研究表明，长期使用神经去极化剂可能会降低神经末梢的敏感性[75]。钾化合物对触觉刺激痛的缓解效果显著，但对冷刺激痛、空气刺激痛的缓解效果不佳[63]，故建议选择复合配方，以提升综合脱敏效果。

3.3 草本成分

蜂胶是蜜蜂的产物，研究表明其在口腔领域具有促进组织再生、加速伤口愈合、减少菌斑形成等作用[76-77]，安全有效且低成本[77-78]。其作用机制包括两个方面[79]，一方面，其所含树脂和黄酮类成分可物理封闭牙本质小管；另一方面，蜂胶可刺激转化生长因子-β1（transforming growth factor-β1，TGF-β1）表达，诱导修复性牙本质形成。Naghsh 等[79]研究表明，蜂胶基草本牙膏在减少开放牙本质小管比例方面效果优于氟化钠牙膏，提示其可用于牙本质敏感的辅助治疗。

五倍子是中草药常用收敛剂，其活性成分单宁酸和没食子酸可与牙本质胶原交联，并结合 Ca^{2+} 促进HAP沉积，封闭牙本质小管。Xia 等[80]研究表明，含2%五倍子提取物与1 450 ppm氟化钠的牙膏，抗敏感效果显著优于单一含氟牙膏，且安全性良好。除蜂胶与五倍子外，传统中医药中多种草药（如两面针、丹皮酚、胡椒等）[81]亦被报道可缓解牙本质敏感。其活性成分中，生物碱具有抗炎、镇痛及轻度局部麻醉作用；鞣质可收敛蛋白质、封闭小管并麻痹神经；挥发油兼具镇痛、麻醉及抗炎功效[82]。此外，中药采集与生产简便，不易产生耐药性，安全性较高[80]。

综上，物理封闭类成分是长效脱敏的核心，其中锶类化合物针对触觉痛有一定效果，CSPS侧重缓解冷刺激痛，SnF_2兼顾脱敏与防龋抗菌功能，精氨酸则在改善空气刺激痛方面表现突出；神经抑制类成分安全性高，但需与物理封闭剂联用；草本成分来源天然、作用多样，为开发新型脱敏产品提供了重要思路。

4 牙膏美白功效成分

牙齿颜色受固有颜色及外在色素共同影响[83]，固有颜色主要由牙本质决定[84-85]，外在色素与物质吸附到获得性薄膜有关[86-87]，主要源于食物、烟渍等[88]。美白牙膏通过多重机制改善牙齿颜色，包括摩擦剂物理摩擦作用、过氧化物化学氧

化作用及光学修饰等[89]。

4.1　摩擦剂机械美白

此类成分是牙膏实现基础美白功能的物理途径，主要依赖微细磨料的摩擦作用以去除牙齿表层色素。为最大限度降低对牙釉质的磨损，磨料的粒径与硬度需严格控制[90]。常用磨料为水合二氧化硅、碳酸钙、二水合磷酸氢钙、焦磷酸钙和碳酸氢钠等[91-92]。

4.1.1　二氧化硅　二氧化硅是当前应用最广泛的牙膏磨料，主要通过机械摩擦直接去除牙齿表面色素，需控制粒径<20 μm，避免划痕[93]。Kim等[93]研究表明，使用含二氧化硅的美白牙膏刷牙10 000次后，对咖啡染色牙齿的亮度恢复率超过70%，效果显著优于常规牙膏；但随着刷牙次数增加，牙釉质表面粗糙度亦有所上升，提示长期使用需关注其磨损风险。

4.1.2　羟基磷灰石　纳米级HAP兼具美白与修复功能，通过微观研磨去除深层附着的色素，同时释放Ca^{2+}、PO_4^{3-}形成致密矿化层，阻止色素渗透至牙釉质深层[32, 94]。Shang等[94]研究表明，含纳米级HAP的牙膏有显著的美白效果，且效果随浓度增加而提升，其中质量分数为10%的纳米级HAP美白牙膏可作为传统美白产品的替代选择。

4.1.3　碳酸氢钠　碳酸氢钠硬度较低，颗粒的多孔结构可增加与牙面接触面积，有助于剥离表面色素，同时提供弱碱环境，中和酸性物质，减少色素在酸性条件下的附着，避免过氧化物酸性降解[93]。Shang等[94]研究表明，含20%碳酸氢钠的牙膏对咖啡渍的颜色恢复率为71.67%，效果虽低于六偏磷酸钠（sodium hexametaphosphate，SHMP），但优于过氧化氢；其磨损深度也低于SHMP牙膏，更适合牙齿敏感人群使用。

4.2　化学美白

化学美白成分通过释放活性氧，氧化分解牙齿表面及浅层色素，从而实现美白效果。该类成分以过氧化物（如过氧化氢）为主，也包括非过氧化物类物质（如六偏磷酸钠）。含过氧化氢美白牙膏浓度多为0.1% ~ 1.5%；对于美白需求较高的人群，可选择浓度范围为2% ~ 5%的产品，但需注意高浓度可能带来的口腔刺激风险[95-96]。其主要机制为过氧化氢分解为羟自由基，破坏色素分子共轭双键，使其变为无色小分子，羟自由基也可渗透至牙齿浅层，去除部分内源性色素[97]。Kim等[97]研究表明，含2.8%过氧化氢的牙膏在漂白效果上优于含0.75%过氧化氢的牙膏且未增加牙齿敏感风险，在效果与安全性方面表现均衡。

SHMP是一种多聚磷酸钠，可通过螯合金属离子阻止色素结合位点与色素结合，破坏已形成的色素聚集体，使其易被刷牙去除[93]。Kim等[93]研究表明，含SHMP的牙膏是去除外源性色素、恢复牙齿颜色的较优选择。

4.3　光学修饰

光学修饰是牙齿美白的重要方法之一[7]。蓝色素通过视觉颜色调和实现美白效果，其核心原理为色光互补[98]。牙齿视觉发黄，本质是黄色色素反射黄色光[99]。蓝色素在牙面形成一层极薄的蓝色光学膜，反射的蓝色光可中和牙齿自身反射的黄色光，让牙齿在视觉上呈现更接近白色的效果[100]。含蓝色素的美白牙膏常搭配硅基磨料，两者形成光学修饰及机械研磨的协同效应[101]；临床研究证实，使用含蓝色素的牙膏单次刷牙后，牙齿白度指数显著提升，黄度值即时降低，说明其光学美白效果可快速显现[102]。

在美白牙膏中，不同成分通过多种机制协同发挥美白作用：机械摩擦类成分通过物理研磨去除外源性色素；化学氧化类成分分解色素、预防色素附着，但不建议长期使用；SHMP对外源性色素去除效果较强；光学修饰成分通过色光互补实现即时视觉美白，与磨料协同增效。

5　小　结

本文系统梳理了牙膏四大功效的成分机制、效果与安全性，明确不同成分在牙膏应用中的作用（图1）。单一成分难以满足复杂口腔护理需求，未来牙膏将趋向于开发多成分协同复合配方，并结合人群特征与口腔问题实现精准化成分选择，兼顾功效与安全。未来，随着研究技术的进步与市场需求的升级，牙膏功效成分将朝着“天然化、精准化”方向发展，为人们提供更高效、安全、个性化的口腔护理解决方案，同时推动全民口腔健康管理升级。

【Author contributions】 An JQ collected the references and wrote the article. Zhang C reviewed the article. Li SR conceptualized and reviewed the article. All authors read and approved the final manuscript as submitted.

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Figure 1 Main efficacy ingredients of toothpaste and their functions
图1 牙膏主要功效成分及其作用

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