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临床常用根管冲洗液去除根管玷污层的研究进展

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摘 要

根管治疗的核心在于彻底清除感染与玷污层，提升根管消毒及充填效果。玷污层为根管机械预备后形成的有机－无机结构复合层，可阻碍消毒药物渗透并影响封闭剂粘接效果。根管冲洗是去除玷污层的关键手段，不同类型冲洗液的作用机制与效果存在明显差异：乙二胺四乙酸(EDTA)、次氯酸钠为临床常用传统根管冲洗液，前者可螯合钙离子，去除无机成分，后者能溶解有机组织，但单一溶液难以实现全面清洁；MTAD、QMiX、SmearClear等复合制剂兼具螯合与抗菌作用，效果稳定且适用性更广；有机酸类冲洗液生物相容性良好，去除根尖1/3区域玷污层优势显著。本文对各类根管冲洗液去除玷污层的效果、特点及临床应用进行综述，为临床合理选择冲洗方案提供参考。

关键词

根管冲洗液，玷污层，EDTA，次氯酸钠，有机酸

Research Progress on Removal of Root Canal Smear Layer by Clinical Common Root Canal Irrigants

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Abstract

The core of root canal therapy lies in thoroughly eliminating infections and smear layers to improve the efficacy of root canal disinfection and obturation. The smear layer is an organic-inorganic composite layer formed after mechanical root canal preparation, which hinders the penetration of disinfectants and impairs the bonding effect of sealers. Root canal irrigation serves as a key method to remove the smear layer, and distinct differences exist in the mechanisms and effects of different irrigants. Ethylenediaminetetraacetic acid (EDTA) and sodium hypochlorite are conventional clinically used root canal irrigants. EDTA chelates calcium ions to remove inorganic components, while sodium hypochlorite dissolves organic tissues, yet a single irrigant fails to achieve thorough cleansing. Compound preparations such as MTAD, QMiX and SmearClear possess both chelating and antibacterial properties with stable effects and wide applicability. Organic acid irrigants feature favorable biocompatibility and exert prominent advantages in removing the smear layer in the apical one-third region. This paper reviews the efficacy, characteristics and clinical applications of various root canal irrigants in smear layer removal, aiming to provide references for rational selection of irrigation protocols in clinical practice.

Keywords

Root Canal Irrigants, Smear Layer, EDTA, Sodium Hypochlorite, Organic Acids

1. 引言

机械预备过程中形成的玷污层是一层有机–无机复合层，包含牙本质碎屑、牙髓组织残渣及细菌[1] [2]，会阻碍冲洗液与牙本质表面及牙本质小管的直接接触，影响消毒效果，同时改变根管充填材料与根管壁的粘接性能[3]。有报道指出，根尖切除术中去除玷污层可能导致玻璃离子水门汀逆行充填失败[4]；另有研究认为，玷污层去除后根管封闭剂渗入牙本质小管，与粘接强度提升无关[5]。Kokkas 等发现，玷污层降解后，封闭剂渗入深度存在差异[6]；玷污层存在可能有助于部分封闭剂与根管壁粘接，但 Gettleman 等研究显示，Sealapex 与 Sultan 封闭剂的粘接强度不受玷污层影响[7]。牙髓治疗的效果依赖于化学机械预备对根管系统内微生物的彻底清除，该技术结合了机械预备与化学消毒手段实现根管清洁，但根管系统解剖结构复杂，存在形态变异、弯曲等特征，为有效消毒带来了巨大挑战。根管清洁不彻底将导致微生物残留，引起根管再感染[8]，因此冲洗液在牙髓治疗中发挥着关键作用，本文将按传统冲洗液、复合冲洗液、有机酸类冲洗液三类进行综述。

2. 冲洗液的类型

2.1. 传统冲洗液

2.1.1. 乙二胺四乙酸(EDTA)

EDTA 是一种氨基酸，具有螯合作用，其羧基和氨基是与金属离子结合的关键基团，能与多种金属形成稳定的螯合物[9]。Wu 等人的研究表明，17% EDTA 去除玷污层的效果显著优于 20%柠檬酸、MTAD 及 SmearClear [10]。Prado 等人的研究证实，磷酸去除玷污层的效果与 EDTA 相近，具备良好效能[11]。

多项研究均验证了 EDTA 去除玷污层的有效性。Caron 等人的研究发现，17% EDTA 与 3% NaOCl 复配后，经声波和超声波激活，去除玷污层的效果更优[12]。一项扫描电子显微镜研究显示，以 5 mL EDTA 持续冲洗 3 分钟，可有效清除根管壁的玷污层[13]。原子吸收光谱和扫描电子显微镜检测结果显示，与其他螯合剂相比，15% EDTA 的钙离子螯合效果最佳，且去除玷污层能力最强[14]。一项研究发现，17% EDTA 经 1 分钟超声波激活后，可有效清除根管根尖部的玷污层和碎屑[15]。

Saito 等人的研究表明，根管预备后，将 17% EDTA 的冲洗时间从 30 秒延长至 1 分钟，可提升玷污层的去除效果[16]，EDTA 与 NaOCl 复配液分别冲洗 1、3、5 分钟，在直根管壁的玷污层去除效果上无显著差异[17]。Sen 等人的研究显示，不同浓度的 EDTA 去除玷污层能力无显著差异[18]。Perez 等人发现，根管预备过程中，15% EDTA 冲洗 1 分钟与 8% EDTA 冲洗 3 分钟，去除玷污层的效果相当[19]；还有研究发现，EDTA 冲洗 3 分钟的效果在统计学上显著优于冲洗 15 分钟；而使用 EDTA-T 冲洗时，不同时间组的效果无显著差异[20]。Adigüzel 等人的研究表明，使用自调整锉并持续 EDTA 冲洗后，根管冠方、根中、根尖 1/3 区域的玷污层清除率分别为 85%、60%及 50%，碎屑清除率分别为 95%、90%及 85% [21]，表明 EDTA 对玷污层的清除效果在根尖区域存在缺陷，且只靠机械锉配合 EDTA 进行冲洗，无法完全实现根管系统的清洁。

2.1.2. 次氯酸钠(NaOCl)

次氯酸钠为浅绿黄色透明液体，具有明显的氯味，遇光易分解，且易溶于水[22]。全球多项调查显示，次氯酸钠是牙髓病临床中应用最广泛的根管冲洗液，临床建议在根管清洁和成形的整个过程中，使用浓度为 2.5%~6%的次氯酸钠[23]。在根管治疗中，次氯酸钠具备多种优异特性：它不仅能溶解根管内的感染牙髓、胶原蛋白等有机组织[24] [25]，还可作为根管内的有效润滑剂，助力机械方式清除根管内的碎屑和其他污染物，实现更彻底的清洁[26]。此外，次氯酸钠的酸碱度具有独特的变化特征：其初始状态为碱性，这一特性有利于发挥抗菌和组织溶解作用，但随着时间推移，其碱性会逐渐减弱[27]。治疗过程中这种动态的酸碱度变化，可能会对次氯酸钠的整体疗效及根管内化学环境的变化产生影响。次氯酸钠也存在明显缺点，包括具有毒性、无法有效去除玷污层、腐蚀性强，还可能导致牙齿变色，并伴有刺激性气味。若将其作为最终冲洗液，会降低根管封闭剂与牙本质的结合力。

2.2. 复合冲洗液

2.2.1. 四环素－酸－清洁剂混合物(MTAD)

BioPure (MTAD)由 Torabinejad 等于 2003 年推出，组成为 4.25%柠檬酸、3%多西环素及 0.5%聚山梨酯[28]。Torabinejad 等首次提出，MTAD 可有效去除玷污层且对牙本质小管结构影响极小，尤其适用于 NaOCl 冲洗后的终末冲洗。其后续研究显示，MTAD 可清除大部分玷污层，但根管壁仍可能残留少量有机成分[29]。先用稀释 NaOCl 冲洗，再以 MTAD 终末冲洗，可增强 MTAD 的玷污层去除效果；但也有研究认为 MTAD 无法完全清除玷污层[30]。

Tay 等发现，EDTA 与 MTAD 均可在牙本质小管周围及侵蚀牙本质中形成脱矿胶原基质带，且酸性 MTAD 的作用强于 EDTA[31]；其超微结构研究显示，MTAD 形成的脱矿牙本质基质厚于 EDTA。De-Deus 等证实，MTAD 诱导的牙本质脱矿动力学显著快于 17% EDTA [32]。

2.2.2. QMiX

QMiX 为新型根管复配冲洗液，推荐用于 NaOCl 冲洗后的预备终末阶段，组成为氯己定、EDTA 与清洁剂，为即用型澄清溶液。虽未见 QMiX 与 NaOCl 复配产生沉淀的报道，但全程使用 NaOCl 清洁预备后，建议先用生理盐水冲洗，避免形成沉淀物[33]-[35]。Stojicic 等扫描电镜研究显示，QMiX 去除玷污

层效果与 EDTA 相当[33]；另一研究证实，经 5.25% NaOCl 初洗后，QMiX 与 17% EDTA 效果一致[34]。

2.2.3. SmearClear

SmearClear 为专用玷污层去除剂，是含阴/阳离子表面活性剂的 17% EDTA 溶液。研究显示，17% EDTA、SmearClear、10%柠檬酸的玷污层去除效果无显著差异[36]；Silva 等证实，SmearClear 去除恒牙根管玷污层的效果与 14.3% EDTA 相当[37]；其在乳牙根管中的效果与 EDTA 无差异[38]。相关研究指出，17% EDTA 效果优于 SmearClear；另有研究显示，SmearClear 对粪肠球菌生物膜的效果显著弱于 1%、6% NaOCl [39]。

2.3. 有机酸类冲洗液

2.3.1. 柠檬酸

柠檬酸是一种有机弱酸，室温下为白色结晶状粉末，分为一水合物和无水物两种形式，温度高于 78℃时两者可相互转化，可通过对牙根表面脱毒处理暴露胶原纤维，从而达到去除玷污层的效果[40]。临床所用柠檬酸的浓度范围为 1%~50%，其中 10%柠檬酸作为最终冲洗液，清除玷污层的效果良好，与临床金标准 17% EDTA 相当，且远优于 HEDP 类螯合剂，在根管中 1/3 区域，玷污层去除效果尤为显著，在根管各区域表现稳定[41]；同时，研究证实，10%柠檬酸溶液的生物相容性优于 17% EDTA 溶液[42]，是临床根管治疗中去除玷污层的优质选择。Olivieri 等人对手动动态激活技术进行了评估，发现 5%或 10%柠檬酸冲洗联合手动动态激活时，玷污层的去除效果最佳[43]。

Prado 等人将冲洗时间作为研究参数，发现冲洗 30 s 后，柠檬酸在根管冠方 1/3 段的玷污层去除效果显著更优，冲洗 1 min 后冠方和根中 1/3 段的效果优于根尖 1/3 段[43]。Turk 等人和 Silva 等人得到了相似的结果，证实柠檬酸冲洗后牙本质壁上的玷污层残留极少[44] [45]。Pitoni 等人的研究发现，柠檬酸冲洗后大部分样本无玷污层，仅少数样本存在牙本质小管轻微堵塞，无完全闭塞的情况[46]。也有研究发现，40%柠檬酸冲洗 30 s 和 60 s 的效果最佳，且在根管三个区段间无统计学差异[47]。

然而柠檬酸去除玷污层的效果仍存在一定局限，现有研究证实，10%、40%浓度的柠檬酸均无法完全清除根管玷污层，尤其是根尖 1/3 区域[48]，Vlad 等人证实该区域玷污层清除效果略逊于 17% EDTA [49]；且柠檬酸溶液作用 60 s 后将会导致牙本质小管管间和管周的脱矿与管腔扩大[50]。此外，6%柠檬酸虽能有效去除玷污层并暴露牙本质小管[51]，且在去除乳牙玷污层方面的效果优于生理盐水、5.25%次氯酸钠等溶液[52]，但其表面张力较高，冲洗液难以渗透至根管根尖段深部[53]。

不同研究中柠檬酸与 EDTA 的效果对比存在差异，Liolios 等人的研究发现，市售 EDTA 制剂的玷污层去除效果优于 50%柠檬酸[54]，另有两项研究表明，15% EDTA 与柠檬酸的玷污层去除效果无显著差异或仅有轻微差异[55]，这可能与试剂浓度、冲洗时间、样本类型及评估方法不同相关。

2.3.2. 马来酸

马来酸因能有效去除根尖 1/3 区域的玷污层，细胞毒性较低，且可通过提高牙本质表面粗糙度和湿润性增强封闭剂的黏附性，成为极具潜力的根管冲洗剂[56] [57]，多项研究以 7%马来酸作为对照，评估不同冲洗剂在根管不同区域的玷污层去除效果[58]。研究表明，7%马来酸在根尖 1/3 区域去除玷污层的效果优于 5%乙醇酸、0.5%过氧乙酸和 10%柠檬酸等冲洗剂[59]；Ballal 等人观察到，在根管冠方和中部 1/3 区域，7%马来酸和 17% EDTA 的玷污层去除效果无显著差异[60]；Ulusoy 等研究显示，7%马来酸、SmearClear、17% EDTA、MTAD、在根管冠方和中部 1/3 区域的玷污层去除效果良好，而 7%马来酸在根尖 1/3 区域形成的牙本质小管更洁净[61]；Nabi 等研究了二极管激光联合马来酸和 EDTA 对玷污层的去除效果，发现前者效果显著优于 17% EDTA [62]。然而，Attur 等人认为，在根管各区域，17% EDTA 去

除玷污层的效果均优于 7%马来酸[58]，该结果差异可能与实验操作、样本解剖特征不同有关。

马来酸的 pH 值低至 1.05，酸性极强，能在短时间内发挥较好的脱矿效果，脱矿能力优于 EDTA。Varghese 等研究了 7%马来酸在 1 分钟和 3 分钟作用时间下的效果，发现两种时间条件均能有效去除玷污层[63]。由于根尖区的牙本质高度硬化，而 7%马来酸的 pH 值不会升高，能长期保持高酸性，因此可有效去除牙根所有区域的玷污层，并对管间和管周牙本质进行脱矿[64]。研究证实，在去除根尖 1/3 处的玷污层方面，7%马来酸的效果优于 17% EDTA 和 18%依替膦酸[62]，这一结果与 Ballal 等人和 Prabhu 等人[65]的研究分析一致，这可能是因为 17% EDTA 的表面张力(0.0783 N/m)高于 7%马来酸(0.06345 N/m)；同时，EDTA 去除玷污层的效果会随 pH 值降低和时间推移而下降，而马来酸酸性更强，能在更短时间内发挥更强的脱矿作用[66]。

2.3.3. 乙醇酸

乙醇酸分子量小、酸解离常数低且为有机成分[67]，是牙釉质、牙本质等矿物表面处理的潜在替代试剂[68]。乙醇酸天然存在于甘蔗和甜味蔬菜中，无毒性且可生物降解[69]。高浓度乙醇酸溶液的表面张力较低，作用于牙本质时，牙本质中的磷灰石与胶原蛋白比例会随乙醇酸浓度升高而降低，而牙本质的弯曲强度不会因乙醇酸浓度的变化受到影响[70]。乙醇酸的 pH 值可稳定 90 天，这一特性使其能够安全、有效地应用于临床，且逐渐替代磷酸，作为牙釉质和牙本质的表面酸蚀剂[71]。5%浓度的乙醇酸能有效去除玷污层，与 EDTA、柠檬酸的效果无统计学差异，且不同浓度的乙醇酸在根管中、尖 1/3 区域去除玷污层效果也无差异，说明即使是 5%的低浓度乙醇酸，也具备去除玷污层能力；5%和 10%乙醇酸去除玷污层的效果相近，且两种浓度的乙醇酸均比 17%EDTA 的玷污层评分更低[69]。

研究认为，乙醇酸联合超声激活是一种具有应用前景的根管终末冲洗方案，既能提升牙体牙髓治疗的根管清洁效果，又能保护牙本质结构，为后续修复治疗奠定基础[72]。近年来，药物递送系统发展迅速，其中聚乳酸－乙醇酸共聚物备受关注。作为乳酸和乙醇酸的共聚物，其具有生物相容性良好、可生物降解、能实现包埋药物的缓释和控释等优良特性，乙醇酸还已成功用作纳米载体分子。聚乳酸－乙醇酸纳米粒已在牙髓治疗领域开展试验性应用，且已发现其多个应用方向。纳米粒的粒径优势使其能轻松穿过牙本质小管、根管峡部、盲端、侧支根管、根尖分叉及其他根管解剖形态变异区域，这些区域是器械难以预备到的[73]。研究表明，载莫西沙星的聚乳酸－乙醇酸纳米粒即使在低剂量下，对粪肠球菌也能保持稳定的抗菌活性，其程序化的药物释放方式和良好的抗菌效果，使其成为理想的根管内药物[74]。

2.3.4. 植酸

植酸是一种高负电性分子，对钙具有高亲和力和强螯合能力，作为天然物质，植酸具有良好的生物相容性，是理想的终末冲洗液候选试剂[75]。近期一项文献综述指出，浓度为 0.5%~1%的植酸玷污层去除效果与 17% EDTA 相近或更优[76]，这可能是由于植酸处理后的牙本质表面无玷污层和管内残留，牙本质小管口开放，管间胶原纤维暴露；且植酸蚀刻组的树脂——牙本质粘接强度显著高于磷酸蚀刻组。Nassar 等人[77] [78]的研究发现，在经次氯酸钠处理的冠方平整牙本质表面和器械预备后的根管中，植酸去除玷污层的效果优于 EDTA，且对牙髓细胞无损伤作用。Gandhi 等人[79]将 5%、10%、17%三种浓度的自制植酸溶液与 17% EDTA、5%、10%、17%柠檬酸溶液对比，评估其作为终末冲洗液的效能。结果显示，17% EDTA 组和 10%植酸组分别在根管冠段、中段和尖段的玷污层评分最低；17%植酸组在根管冠段和中段的玷污层清除效果优异，但在尖段的效果逊于 10%植酸组。1%植酸溶液的 pH 值约为 1.2，这可能是其钙离子提取效果更佳的原因。Nikhil 等人[80]的研究表明，植酸会降低牙本质显微硬度，其作用程度与壳聚糖相当，但低于 EDTA。

已有多项研究探讨了植酸的玷污层清除能力，并提出植酸可作为 EDTA 的替代物用于玷污层处理，植酸在牙本质平片上的清除效果优于 EDTA，而在闭合式根管系统中与 EDTA 效果相当[77]。多种植物提取物已被尝试用作牙髓冲洗剂或根管内用药[81]，与 EDTA、四环素类抗生素等螯合剂相比，植物冲洗剂去除玷污层的能力相对较弱。但也有研究表明，天然冲洗剂在有效去除玷污层的同时，对根管牙本质的力学和化学性能造成的损伤极小，这与合成冲洗剂形成鲜明对比——天然冲洗剂对牙本质力学性能的不利影响更小[77]，这一特点凸显了天然冲洗剂在维持牙本质完整性方面的潜在优势，尽管其去除玷污层的能力不如合成冲洗剂，但也说明植物冲洗剂具备独特的应用价值，值得进一步探索其在优化牙髓治疗中的潜力。

3. 冲洗液活化方法

3.1. 超声活化(25~40 kHz)

利用声流效应剧烈搅动冲洗液，提升抗菌与组织溶解效果；缺点为需保持被动操作(器械不接触管壁)、可能导致冲洗液超出根尖孔。所谓“被动”，是指工作尖需在根管内自由运动，避免与管壁大量接触。若工作尖不仅接触管壁，且表面粗糙、尖端尖锐，情况会进一步恶化[82]。

3.2. 声波活化(<20 kHz)

清洁效果良好，强度略低于超声，长时间使用优势更明显；根尖孔外溢更少[83]。

3.3. 激光活化

清洁效果良好，但设备成本高、存在冲洗液超根尖孔风险；常用激光包括二极管激光、Nd:YAG 激光、Er:YAG 激光、Er,Cr:YSGG 激光。活化方式分激光尖置根管内(LAI)与仅置髓腔(PIPS)，多用 Er:YAG 激光[84]。

3.4. 根尖负压

根尖段清洁效果优于正压系统，几乎无超根尖孔外溢；要求根尖预备直径 ≥0.35 ISO、锥度 ≥0.4，狭窄弯曲根管难以满足[85]。

3.5. 手动动态活化(MDA)

牙胶尖距工作长度 1 mm 处小幅泵动(100 次/分钟，幅度 2 mm)，提升根管内压力、解除气锁、提高冲洗液更新率；操作简便，但效果弱于上述技术[86]。

4. 结论

本文系统综述了传统、复合及有机酸三类根管冲洗液去除玷污层的研究进展。结果表明，尚无单一冲洗液能满足所有临床需求：EDTA 与 NaOCl 需联合使用以兼顾无机与有机成分的去除；复合制剂功能整合但成本较高；有机酸类在根尖 1/3 区域优势显著，且生物相容性更佳。冲洗液的清洁效果高度依赖于活化技术。超声与激光活化效能强，但设备成本高且存在冲洗液超根尖孔风险；声波与手动动态活化安全性好、操作简便，在基层医疗机构中更具实用性。从成本效益看，EDTA/NaOCl 基础方案价格低廉但步骤繁琐，复合制剂及部分有机酸效果优越但可获得性有限，柠檬酸则性价比适中。此外，针对引言中提及的争议，玷污层对封闭剂粘接的影响因材料而异，临床应根据所选封闭剂特性制定冲洗策略，而非盲目追求玷污层的完全去除。综上，根管冲洗策略应综合根管解剖、感染状态、设备条件及经济成本进行个体化选择。未来研究需进一步探索活化技术的协同优化及新型天然制剂的临床转化。

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