·专家笔谈·

自酸蚀类树脂水门汀的临床应用与未来展望

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【摘要】 自酸蚀类树脂水门汀是一种兼具美观与性能的口腔修复材料,近年来凭借着操作简便、较低的技术敏感性和低术后敏感发生率等独特优势,在口腔修复学领域备受关注,并广泛应用于临床间接修复体的粘固操作。本文梳理了自酸蚀类树脂水门汀的化学组成及粘接机制,归纳不同临床场景下的注意事项,并对其未来发展趋势进行探讨。口腔医师应充分了解材料特性,熟悉各类应用场景的操作要点,并关注相关研究,以提供更精准与规范的临床操作。伴随临床对高效操作的追求和粘接技术的更新迭代,如何在简化操作的同时保证粘接强度有望成为未来的发展方向。

【关键词】 自酸蚀类树脂水门汀; 口腔修复材料; 粘接机制; 临床应用; 粘接强度

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Clinical applications and future prospects of self-etch resin cements

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【Abstract】 Self-etch resin cements are dental restorative materials that combine aesthetic appeal with outstanding performance. In recent years, they have gained significant attention in the field of prosthodontics owing to their unique advantages, such as simplified procedures, low technique sensitivity, and a reduced incidence of postoperative sensitivity. Consequently, they have been widely adopted for the cementation of indirect restorations clinically. This review systematically analyzes the chemical composition and bonding mechanisms of self-etch resin cements, summarizes clinical considerations across various situations, and discusses future development trends. Dental clinicians should thoroughly understand the material properties, master the operational essentials for different applications, and stay informed about relevant research to ensure precise and standardized clinical practice. With the increasing demand for clinical efficiency and the iteration and updating of bonding technology, balancing simplified procedures with the maintenance of optimal bonding performance remains a key direction for future advancement.

【Key words】 Self-etch resin cement; Dental restorative material; Mechanism of bonding; Clinical application; Bonding performance

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理想的牙科粘固材料应兼具良好生物相容性、易操作性、低溶解性、良好的边缘封闭性及适宜的操作和固化时间等优点[1]。自酸蚀类树脂水门汀涵盖以上诸多优势,近年来在口腔修复领域备受青睐应用广泛[2-3]。

一、树脂水门汀的分类

树脂水门汀诞生于20世纪60年代,历经迭代已成为现代口腔临床间接修复体粘固的核心材料之一。根据应用步骤,树脂水门汀可分为全酸蚀类(total-etch)树脂水门汀或称酸蚀-冲洗类(etch-and-

rinse)树脂水门汀、自酸蚀类(self-etch)树脂水门汀和自粘接类(self-adhesive)树脂水门汀3类[4],见表1。全酸蚀类树脂水门汀需与全酸蚀粘接系统联合应用;自酸蚀类树脂水门汀则需与自酸蚀粘接系统或通用型粘接剂联合使用;自粘接类树脂水门汀因自身含有酸性功能单体,可直接用于基牙与修复体之间的粘固,临床操作最为简便。

树脂粘接系统根据简化的程度不同可进一步分类。全酸蚀粘接系统分为三步法和两步法;自酸蚀粘接系统无需单独的酸蚀步骤,分为两步法和一步法[18-19]。该系统根据产品剂型又进一步划分为两瓶装混合后使用和一瓶装(all-in-one)两种形式。

二、自酸蚀类树脂水门汀概述

1. 自酸蚀类树脂水门汀的发展历程:1955年,Buonocore[20]首次提出磷酸处理牙体组织,奠定了全酸蚀理论的基础。1979年,Fusayama等[21]提出全酸蚀粘接系统。1981年日本Kuraray公司成功研发并推出酸性功能单体10-甲基丙烯酰氧基癸基磷酸二氢酯(10-methacryloyloxydecyl dihydrogen phosphate,10-MDP),至今被誉为行业的"金标准"[22]。1982年,Nakabayashi研发出基于甲基丙烯酸甲酯(methyl methacrylate,MMA)的超级粘接剂(Super-Bond C & B),首次实现牙本质粘接,奠定了自酸蚀类树脂水门汀的理论基础[23]。

1989年,Chigira等[24]突破性地取消了传统的独立酸蚀与冲洗步骤,正式提出自酸蚀粘接概念。1993年,两步法自酸蚀系统(第六代)问世,标志着简化操作成为明确的发展方向[25]。2002年,一步法自酸蚀系统(第七代)将酸蚀、底漆与粘接3个步骤合而为一,极大简化了操作步骤[26]。2012年,10-MDP专利到期后,以3M™(Solventum,舒万诺,美国)Scotchbond™ Universal为代表的通用型粘接剂(第八代)正式发行[27]。尽管通用型粘接剂在分类上仍归属于一步法自酸蚀粘接系统,但其卓越的普适性使其成为目前同行评审文献中应用最广泛的粘接解决方案[18]。

近年来,通用型粘接剂因操作简便而被广泛用于自酸蚀类树脂水门汀的组合,但仍存在易吸水水解、耐久性不足等问题[28]。为此,研究者从材料改性、涂布工艺优化、针对龋损牙本质的特殊处理、添加生物活性成分及抗菌纳米颗粒等多个方向进行改进,在提高粘接强度的同时增强了长期稳定性和抗菌性能[29-32]。

2. 自酸蚀类树脂水门汀的化学组成与特性:自酸蚀类树脂水门汀需配合通用型粘接剂或专用处理剂使用。该体系主要由酸性功能单体、树脂基质、无机填料与引发剂4部分组成,各组分主要功能见表2。

3. 自酸蚀类树脂水门汀的粘接机制

(1)功能单体:10-MDP作为已被广泛用于通用

表1 全酸蚀类、自酸蚀类与自粘接类树脂水门汀的比较

树脂水门汀类型	操作步骤	粘接机制	性能特点	边缘封闭性	抗水解性与耐久性	常见问题
全酸蚀类树脂水门汀	需单独使用酸蚀剂处理基牙表面,釉质冲洗后吹干;牙本质表面需保持一定湿度,再涂布底漆处理剂与粘接剂,最后使用树脂水门汀[5]。	微机械嵌合+化学结合:通过磷酸蚀使牙釉质脱矿形成微机械嵌合;去除牙本质表面玷污层,暴露胶原纤维网形成混合层[4]。	粘接强度最高,技术敏感性最高,操作步骤最繁琐,长期稳定性最高[6-7]。	优[8]	高(推荐在磷酸处理面涂布氯己定)[9]	操作繁琐,易受污染,牙本质"湿粘接"技术具有高度技术敏感性[10]。
自酸蚀类树脂水门汀	无需单独酸蚀;使用含酸性功能单体的通用型粘接剂或专用处理剂处理基牙,再使用树脂水门汀[5]。	微机械嵌合+化学结合:处理剂或粘接剂中酸性功能单体部分溶解玷污层,渗入牙本质形成混合层[4]。	粘接强度居中,技术敏感性较低,操作复杂性居中,对牙髓刺激性较低,术后敏感较少,长期稳定性较高[11]。	良好[8]	中[12]	需使用"选择性酸蚀"技术处理牙釉质粘接界面[13]。
自粘接类树脂水门汀	无需在基牙表面使用粘接剂;直接将树脂水门汀用于修复体与基牙之间即可[14]。	主要依赖化学结合,含酸性单体轻度脱矿釉质和牙本质,形成一定程度的微机械嵌合[4]。	粘接强度最低,技术敏感性最低,操作最简便,对牙髓刺激性低,但边缘封闭性略差,长期稳定性差[11]。	一般(具有材料依赖性)[15]	一般(具有材料依赖性)[16]	粘接强度波动较大,对粘接基底敏感[17]。

表2 自酸蚀类树脂水门汀及其粘接系统的主要化学组成

组成	主要成分	功能
酸性功能单体(粘接系统)	10-MDP、PENTA、6-MPHA、4-META和4-MET等	粘接能力的主要体现,10-MDP能与牙齿基质羟基磷灰石形成不溶于水的10-MDP-Ca盐,使牙基体脱矿,树脂得以渗入,从而实现粘接[33]。
树脂基质	MMA、Bis-GMA、UDMA、TEGDMA和HEMA等	作为自酸蚀类树脂水门汀的基本骨架,承载和分散酸性功能单体与填料,并保证美学性能;其中亲水性功能单体HEMA可作为助溶剂并改善表面润湿性[34]。
无机填料	硅烷化钡玻璃、BAFSG、BFG、SiO_2和YbF_3等	提升机械性能并中和酸性功能单体的残余酸度,与材料的收缩率呈负相关[35-36]。
引发剂	BPO、CQ、TA和芳香族亚磺酸盐(如SBS、STS)等	使树脂水门汀固化,包括光固化、化学固化与双固化;双固化中芳香族亚磺酸盐充当促进剂,抑制酸性功能单体与叔胺的反应进而保护叔胺[37]。

注:10-MDP为10-甲基丙烯酰氧基癸基磷酸二氢酯;PENTA为二季戊四醇五丙烯酸磷酸酯;6-MPHA为6-甲基丙烯酰氧己基膦酰乙酸酯;4-META为4-甲基丙烯酰氧乙基偏苯三酸酐;4-MET为4-甲基丙烯酰氧乙基偏苯三酸;MMA为甲基丙烯酸甲酯;Bis-GMA为双酚A-二甲基丙烯酸缩水甘油酯;UDMA为二甲基丙烯酸氨基甲酸酯;TEGDMA为三乙二醇二甲基丙烯酸酯;HEMA为甲基丙烯酸β-羟乙酯;BAFSG为钡-铝-氟硅酸盐玻璃;BFG为氟铝硼硅酸钡玻璃;SiO_2为二氧化硅;YbF_3为镱氟化物;BPO为过氧化苯甲酰;CQ为樟脑醌;TA为叔胺;SBS为苯亚磺酸钠;STS为对甲苯亚磺酸钠。

型粘接剂中的磷酸酯类功能单体,可使牙本质界面部分脱矿,并与玷污层中的Ca^{2+}结合发生螯合反应,形成纳米级MDP-Ca复合物和可渗透的混合层[38](图1)。

10-MDP的含量是影响粘接性能的关键因素。10-MDP含量过低的粘接剂脱矿能力欠佳,与牙本质的微机械嵌合和化学结合效果减弱;但过多的10-MDP会增加粘接剂的吸水性,且使渗透性降低[39]。有文献表明,一步法自酸蚀粘接剂功能单体最适宜的质量分数为10%[40]。

(2)溶剂:自酸蚀类树脂水门汀的常见溶剂有水、乙醇和丙酮等。适量的溶剂可促进酸性功能单体的官能团电离活化,但过多时则稀释单体浓度,影响聚合物链的形成[41]。理想情况下,溶剂应在聚合前完全蒸发以形成高质量的粘接剂层,通常粘接系统中溶剂含量约为8%~49%[42]。

(3)树脂基质:在酸性功能单体使牙本质小管脱矿的同时,树脂单体应渗透入牙本质小管内,在混合层中形成树脂-胶原-矿物复合体,与牙本质形成微机械嵌合[43-44]。常见的树脂基质单体包括双酚A-二甲基丙烯酸缩水甘油酯(bisphenol A-glycidyl methacrylate, Bis-GMA)、二甲基丙烯酸氨基甲酸酯

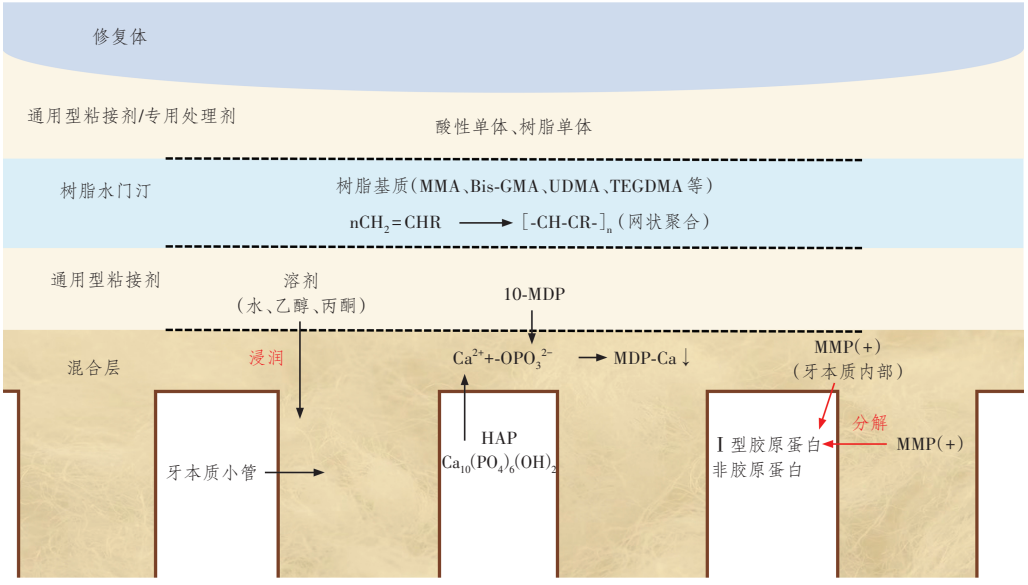

图1 自酸蚀类树脂水门汀粘接界面分层示意图 MMA:甲基丙烯酸甲酯;Bis-GMA:双酚A-二甲基丙烯酸缩水甘油酯;UDMA:二甲基丙烯酸氨基甲酸酯;TEGDMA:三乙二醇二甲基丙烯酸酯;10-MDP:10-甲基丙烯酰氧基癸基磷酸二氢酯;HAP:羟基磷灰石;MMP:基质金属蛋白酶。

(urethane dimethacrylate, UDMA)和三乙二醇二甲基丙烯酸酯(triethylene glycol dimethacrylate, TEGDMA)等。

4. 性能评价方法:自酸蚀类树脂水门汀的粘接性能主要通过临床体内研究和体外实验数据综合评估。临床研究主要评价修复体的存留率、边缘密合度、牙髓刺激性及是否出现继发龋等[45]。体外实验对自酸蚀类树脂水门汀的评价则主要基于粘接强度测试、耐久性和边缘封闭性,为临床材料选择提供了重要参考依据。

粘接强度测试是衡量材料与牙体组织结合效果的直接手段,包括微拉伸粘接强度测试(micro-tensile bond strength test, μTBS)与剪切粘接强度测试(shear bond strength test, SBS)[46]。μTBS是目前评价复合树脂修复与牙体组织粘接效果的重要指标[47];SBS操作简便,常用于粘接强度的初步评价。然而,由于μTBS受样本制备方式、界面应力分布、试件面积及操作者等因素影响,在评价时需结合多篇文献报道综合考量[48]。

耐久性评价用于评估材料在口腔功能环境下的抗老化能力。冷热循环是最经典的体外加速模拟方法,通常设置5和55 ℃的冷热交替环境,以10 000次循环模拟1年的老化[49]。研究普遍显示,不同产品的耐久性存在明显区别[50-52]。

边缘封闭性关乎修复体的远期成功率,主要通过染料渗漏法、扫描电镜(scanning electron microscopy, SEM)和微计算机断层扫描(micro-computed tomography, Micro-CT)进行评价[53-55]。相关研究表明,当粘接边缘位于牙釉质时,若不配合选择性酸蚀,自酸蚀类树脂水门汀的边缘封闭效果通常弱于全酸蚀类树脂水门汀[56]。

上述评价手段共同构成了自酸蚀类树脂水门汀实验测试的基础,为材料的性能评估及临床应用提供了重要参考依据。

三、自酸蚀类树脂水门汀的临床应用

自酸蚀类树脂水门汀需与通用型粘接剂或专用处理剂联合使用,其中通用型粘接剂适用于各类酸蚀模式及直接、间接修复中的多种基材粘接,可显著简化操作流程[13,50]。粘接的临床决策应从产品成分、基牙条件、修复体类型、固位形、膜厚度及患者对美观的要求等各方面考虑,进行个体化产品选择。表3系统性梳理了目前临床常用的自酸蚀粘接系统、通用型粘接剂与配套树脂水门汀的功能单体、膜厚度、颜色选择、pH值及适应证。

1. 适应证与选择原则:自酸蚀类树脂水门汀自问世以来广泛应用于临床。其适应证可从基牙牙髓状态、预备体与修复体3个方面加以考量。

(1)牙髓状态:对于活髓牙的牙本质粘接,自酸蚀类树脂水门汀无需磷酸酸蚀,因此规避了全酸蚀粘接系统中技术敏感性较高的牙本质"湿粘接"技术(wet bonding technique),在简化操作的同时降低了术后敏感的发生率,从而提升患者的短期满意度[57]。经过根管治疗的牙齿虽无需考虑牙髓源性术后敏感的发生,但由于自酸蚀类树脂水门汀具有操作简便、对牙本质粘接性能良好等优势,仍可作为优先考虑的方案之一。

此外,酸性过强的自酸蚀粘接剂(如Adper Prompt, pH<1)虽然可对牙本质产生较深的脱矿效应,但由于脱矿深度与树脂渗透程度不匹配,在粘接耐久性和修复寿命方面并不可靠,在临床操作中应避免使用[58]。临床操作时建议选用pH值为2.3~2.5的自酸蚀粘接剂(表3)[59]。

(2)预备体固位条件:自酸蚀类树脂水门汀适用于预备体固位条件一般,需借助一定粘接力的临床情形。修复体边缘位置是影响粘接效果的重要因素。当边缘主要位于牙本质时,自酸蚀能有效提升边缘封闭性并降低术后敏感风险[45,60]。若预备体存在大面积釉质边缘,则建议结合选择性酸蚀技术:先用35%~37.5%磷酸酸蚀釉质边缘15~30 s,充分冲洗干燥后,再使用自酸蚀类树脂水门汀完成粘接,以达到更好的耐久性与边缘封闭效果[61-62]。需要注意的是,自酸蚀单体对硬化牙本质的渗透能力相较于正常牙本质显著下降[63]。在应用自酸蚀类树脂水门汀粘接硬化牙本质前,应采取适当的预处理措施,如使用选择性酸蚀技术结合喷砂[64-65]。

(3)修复体材质:自酸蚀系统中酸性功能单体(如10-MDP)能与金属氧化物和氧化锆表面形成化学结合[66],是临床粘接金属修复体与氧化锆全瓷修复体的理想选择。对于硅基陶瓷类修复体,氢氟酸酸蚀与硅烷偶联剂的联合使用效果最为稳定[67-68]。

2. 具体应用场景

(1)全冠/固定桥:传统的全冠与冠固位体主要与基牙牙本质粘接。临床研究表明,由于自酸蚀类树脂水门汀无需磷酸酸蚀牙本质,从而显著降低了活髓牙术后敏感风险[69]。粘接桥(如翼式固定桥)作为一种微创修复手段,在基牙严重倾斜时可避免磨除过

表3 临床常见的自酸蚀类树脂水门汀(粘接剂/处理剂+水门汀)

厂家	产品	主要组分	膜厚度	颜色选择	pH值	适应证
BISCO, 美国	All-Bond Universal® 通用型粘接剂	Bis-GMA、MMA、HEMA、10-MDP	<10 μm	淡黄色(Pale Yellow)	2.5~3.5	①直接修复:树脂基复合树脂、树脂改性玻璃离子、桩核核成形修复等;②间接修复体粘接:金属、玻璃陶瓷、氧化锆/氧化铝等材质修复体;③牙本质脱敏治疗、牙体封闭处理;④口内修补修复:崩瓷修补、现有直接修复体追加充填修补等;⑤玻璃离子充填体的护洞漆/保护涂层应用;⑥正畸托槽粘接;⑦根管纤维桩粘接固位。
	DUO-Link Universal™ Resin Luting Cement 双固化树脂水门汀	Bis-GMA、TEGDMA、UDMA	12~15 μm	通用色(Universal),乳白色(Milky White)	–	①间接修复体:金属/复合材料/瓷/陶瓷/氧化锆/氧化铝/全冠、固定桥、嵌体、高嵌体;②纤维桩、复合材料桩、金属桩或氧化锆桩;③种植体基台、种植体支持的全冠和固定桥;④复合材料贴面、全瓷贴面和氧化锆贴面。
GC, 日本	G-Multi Primer 粘接剂增强底漆	10-MDP、硅烷偶联剂	单分子层	无色(Colorless)	–	①玻璃陶瓷、混合陶瓷、氧化锆、氧化铝、复合树脂及金属材质间接修复体的粘接面进行底涂预处理;②破损/折裂的陶瓷、混合陶瓷、氧化锆、氧化铝、复合树脂材质间接修复体口内、口外修补。
	G-CEM ONE™ 双固化树脂水门汀	PAE、SiO_2、UDMA	5 μm	A2,半透明(Translucent),AO3,BO1白色不透明(White Opaque)	–	①各类全瓷、树脂、金属材质嵌体、高嵌体、全冠、固定桥的粘接固位;②金属桩、陶瓷桩、纤维桩、铸造桩核的粘接固位;③全瓷贴面、树脂贴面的粘接固位;④种植基台上方全冠、固定桥的最终粘接固位。
沪鸽 Huge, 中国	美益汀® 光固化牙体粘接剂	–	–	透明	–	①树脂充填粘接;②隐形矫治器附件粘接;③光固化复合树脂粘接;④纤维桩粘接;⑤全瓷修复体粘接;⑥与树脂水门汀配套使用。
	美益汀® 粘固用树脂水门汀(双固化)	–	–	透明,白色不透明	–	
Ivoclar Vivadent, 列支敦士登	Multilink®N Primer A/B 自酸蚀粘接剂	HEMA、膦酸丙烯酸酯	–	透明	–	全瓷/金属/复合树脂等多种材料的嵌体、高嵌体、全冠、固定桥和根管桩的粘接。
	Multilink®N 双固化树脂水门汀	UDMA、HEMA、Bis-GMA	–	透明,黄色(Yellow)	–	①玻璃陶瓷、二硅酸锂玻璃陶瓷、复合树脂修复体(嵌体、高嵌体、部分冠、全冠、固定桥)的永久粘接固位;②氧化锆等氧化物陶瓷、金属材质不透光修复体的永久粘接固位;③根管桩的永久粘接固位。
Kerr, 美国	OptiBond™ eXTRa Universal 通用型粘接剂	HEMA、GPDM、GDMA	–	淡黄色	>2	①所有间接修复应用(包括贴面、CAD/CAM修复体、陶瓷、瓷、树脂、金属修复体);②贴面粘接(可使用双固化或光固化型);③需要无限操作时间的多单位修复(推荐使用光固化型);④适用于自酸蚀或全酸蚀粘接技术。
	NX3 Nexus™ Third Generation 光固化树脂水门汀	Bis-EMA、TEGDMA、UDMA、HEMA	9 μm	透明,白色,黄色,漂白色(Bleach),白色不透明	–	
Kuraray Noritake, 日本	可乐丽菲露™ SE ONE 自酸蚀粘接剂	Bis-GMA、HEMA、10-MDP	–	黄色	≤2.5	①配合光固化复合树脂进行牙体直接修复;②间接修复体粘接前的窝洞封闭预处理;③暴露牙根面的牙体脱敏与封闭治疗;④牙本质敏感牙的脱敏治疗;⑤口内折裂修复体的口内修补修复;⑥配合双固化或自固化复合树脂完成根管桩粘接固位;⑦配合光固化、双固化或自固化核成型材料进行桩核核体构筑修复;⑧配合复合树脂水门汀,完成嵌体、高嵌体、全冠、固定桥及贴面的粘接固位。

续表3

厂家	产品	主要组分	膜厚度	颜色选择	pH值	适应证
	可乐丽菲露™ DC CORE ONE 双固化复合树脂	Bis-GMA、钡玻璃粉、氧化铝填料	-	牙本质色(Dentin),白色	-	①使用直接法进行基牙构筑;②使用间接法进行基牙构筑。
	可乐丽菲露™ SE BOND 两步法自酸蚀粘接剂	Bis-GMA、HEMA、10-MDP	40~80 μm	黄色	≤2.5	①使用光固化复合树脂或复合体的直接充填修复;②间接修复体的预处理;③窝洞封闭;④过敏性和/或暴露根面的脱敏治疗;⑤使用光固化复合树脂进行瓷、混合陶瓷或复合树脂制贴面冠的崩裂修补;⑥瓷、混合陶瓷及已固化复合树脂制成的修复体(修复器械)的表面处理。
	帕娜碧亚™ V5牙质粘合处理剂	10-MDP、HEMA	-	透明	<2.3	①冠、桥、嵌体及高嵌体的粘接;②贴面的粘接;③桩核的粘接;④氧化锆的粘接。
	帕娜碧亚™ V5修复体处理剂	硅烷偶联剂、10-MDP	-	透明	-	
	帕娜碧亚™ V5糊剂双固化树脂水门汀(不透明色仅为化学固化)	Bis-GMA、TEGDMA、HEMA	12 μm	通用色,透明,白色,褐色(Brown),不透明	-	
Shofu,日本	AZ-Primer	6-MPHA	-	透明(Clear)	-	①氧化铝或氧化锆修复体的树脂粘接;②使用树脂水门汀进行修复体的粘固;③使用复合树脂对碎裂的修复体进行修补。
	ResiCem® 双固化树脂水门汀	UDMA、TEGDMA、HEMA、4-AET、羧酸单体	9 μm	通用色,透明,象牙色(Ivory),不透明	-	①氧化铝或氧化锆修复体的粘接性粘固;②瓷或间接复合树脂材料制作的贴面、牙冠、牙桥、嵌体、高嵌体及金属增强型间接修复体的粘固;③各类桩及核材料的粘固。
Solventum,美国(原3M)	Scotchbond™ Universal 通用型粘接剂	Bis-GMA、硅烷化SiO_2、HEMA	5~10 μm	黄色	2.7	①配合光固化复合树脂或复合体材料,进行各类窝洞的充填;②配合其他产品进行间接修复体粘固;③粘接由光固化复合树脂或专用核材料制作的核;④修补复合树脂充填体、复合体充填体;口内修复复合树脂修复体、烤瓷熔附金属冠及全瓷修复体(无需额外预处理剂);⑤银汞合金修复前窝洞封闭,间接修复体临时粘固前窝洞封闭及牙体预备面封闭;⑥根面脱敏处理;⑦作为玻璃离子充填体的保护性漆;⑧粘接窝沟封闭剂。
	RelyX™ Ultimate 双固化树脂水门汀	TEGDMA、硅烷化处理剂、Bis-EMA	12 μm	半透明,漂白色(B0.5),A1,A3不透明	-	
Tokuyama,日本	BONDMER Lightless Ⅱ通用型粘接剂	Bis-GMA、TEGDMA、HEMA、3D-SR Monomer、MTU-6	5~10 μm	绿色(固化前)	-	①前后牙直接修复;②口内修复复合树脂修复体、烤瓷熔附金属修复体、金属修复体及全瓷修复体,无需额外使用预处理剂;③配合光固化、双固化及自固化树脂水门汀进行间接修复体及贴面的粘固;④核充填材料的核成型粘接;⑤义齿树脂与金属基托、卡环或附着体的粘接;⑥带有金属基托、卡环或附着体的义齿修补;⑦遮色树脂与金属基底粘接。
	ESTECEM Ⅱ PLUS 双固化树脂水门汀	Bis-GMA、TEGDMA、HEMA、MTU-6	10 μm	通用色,透明,褐色,白色不透明	-	①玻璃/瓷/氧化锆/氧化铝/金属/贵金属/非贵金属/树脂材料等制成的冠、桥、嵌体和高嵌体;②折裂的饰面冠和所有陶瓷修复体;③贴面、粘接桥、金属/树脂核、金属或玻璃纤维桩的粘接。

注:Bis-GMA:双酚A-二甲基丙烯酸缩水甘油酯;MMA:甲基丙烯酸甲酯;HEMA为甲基丙烯酸β-羟乙酯;10-MDP:10-甲基丙烯酰氧基癸基磷酸二氢酯;TEGDMA为三乙二醇二甲基丙烯酸酯;UDMA为二甲基丙烯酸氨基甲酸酯;CAD/CAM为计算机辅助设计与制作;PAE为磷酸酯单体;SiO_2为二氧化硅;GPDM为甘油磷酸二甲基丙烯酸酯;GDMA为双甲基丙烯酸乙二醇酯;Bis-EMA为乙氧基化双酚A-二甲基丙烯酸酯;6-MPHA为6-甲基丙烯酰氧己基膦酰乙酸酯;4-AET为4-丙烯酰氧乙基偏苯三酸;3D-SR Monomer为三维自增强单体;MTU-6为硫代尿嘧啶单体。主要组分来自厂家官网使用说明;膜厚度数据来自各厂商官网披露的数值;颜色命名参考VITA Classic比色体系及各厂家专有美学比色指南;pH值均为厂商官网披露的固化前酸碱值;"-"为不适用或无数据。

多牙体组织。部分临床随机对照试验表明,将自酸蚀类树脂水门汀应用于氧化锆后牙粘接桥短期随访期内在边缘密合度、粘接强度与美学性能方面均维持良好[70-73]。

(2)嵌体/高嵌体/髓腔固位冠:嵌体常用于活髓牙,且洞壁以牙本质为主,自酸蚀系统可有效减少术后敏感的发生。不同材料的嵌体(如玻璃陶瓷、氧化锆和树脂)在粘接前应采取相应的表面处理方式,以增强粘接强度[74]。高嵌体和髓腔固位冠(endocrown)在牙体预备时较全冠更为保守,有利于维持根管治疗后牙齿的抗力。体外研究表明,自酸蚀系统可为髓腔固位冠提供与全酸蚀系统同等的耐久性,但老化处理后的边缘封闭性略低[12]。因此,当基牙边缘为牙釉质时推荐使用选择性酸蚀技术处理釉质边缘。

(3)桩核冠/纤维桩:根管内粘接环境具有冲洗剂化学污染、操作视野受限、湿度难以控制、玷污层复杂和聚合收缩压力(C-因子)高等不利因素[75]。研究表明,除了机械嵌合外,自酸蚀系统凭借10-MDP与根管内牙本质产生的化学结合,可提供比全酸蚀系统更强的长期抗水解性能,尤其在根管冠部表现优异[76-77]。由于根管内部无法充分光照,建议选择自固化或双固化自酸蚀类树脂水门汀完成粘接[78],如G-CEM ONE™等(表3)。在涂布技巧上,为促进粘接剂渗透进入牙本质小管,可使用旋转刷在根管内进行机械涂布,并在光照前用吸潮纸尖蘸除根尖区域残留的粘接剂[79]。现有研究结果显示,自酸蚀类树脂水门汀与自粘接类树脂水门汀在根管内的粘接强度及长期稳定性尚存分歧[77,80],仍需更多临床研究予以验证。

(4)贴面:当预备后的牙体粘接面全为釉质结构时,应使用全酸蚀类树脂水门汀[57]。经5年临床随访证实,当预备体粘接面有部分位于牙本质时,采用自酸蚀类树脂水门汀配合选择性酸蚀技术进行贴面粘接,可取得与全酸蚀类树脂水门汀相当的临床表现[81]。

(5)特殊应用:成人正畸患者口内全瓷修复体与正畸托槽的粘固是临床诊疗的一大难点。修复体在口内永久粘固后,其表面预处理手段明显受限。临床医师需在确保全瓷修复体完整性和表面形态不受损的前提下,实现正畸临床要求的粘接强度(6~8 MPa[82])。实验室老化试验结果表明,自酸蚀类树脂水门汀G-CEM ONE™、RelyX™ Ultimate等(表3)可以保证正畸托槽在全瓷修复体上维持至少3~6个月的有效粘接[52,83]。正畸治疗结束取下托槽后,可使用钨钢车针去除修复体表面残余的粘接剂与水门汀。

3. 常见失败原因及应对策略

(1)修复体脱落:修复体脱落是粘接失败的常见形式,其主要原因可归结为初始粘接强度不足、粘接界面降解与应力集中3个方面。

为获得良好的初始粘接强度,可对修复体进行适当的表面处理、使用主动涂布技术、保证适当的风吹时间(5~15 s),以及做好粘接环境的严格隔湿[84-85]。在此基础上,进一步结合夹层技术、双层涂覆技术和选择性酸蚀技术等,有助于提升长期粘接效果[86-87]。

延长粘接界面的耐久性可以通过抑制内源性降解和外源性水解来实现。内源性降解主要源于在选择性酸蚀牙釉质时,难以避免磷酸接触部分的牙本质,导致牙本质小管内的基质金属蛋白酶(matrix metalloproteinase,MMP)激活[88]。建议在牙本质磷酸酸蚀后使用浓度为0.2%~2%的氯己定处理30 s,以抑制MMP的活性[9]。外源性降解主要是由于亲水性单体吸水与化学键的水解[89]。研究表明,不含亲水单体甲基丙烯酸β-羟乙酯(2-hydroxyethyl methacrylate,HEMA)的粘接剂在延缓界面水解、耐久性维持上表现更好[90-92]。

此外,修复体设计应分散𬌗力,避免应力集中导致粘接失败或牙体折裂。尤其对于嵌体、高嵌体等修复形式,应确保修复体和牙体组织具备合理的抗力形[93]。在修复体粘固后需确认咬合并适当调𬌗,以消除由于粘固后咬合抬高而出现的早接触点。

(2)边缘着色与继发龋:当修复体边缘位于牙釉质时,单独使用自酸蚀类树脂水门汀易导致边缘不密合,从而产生微渗漏(microleakage)[56]。边缘着色是微渗漏的早期表现,细菌及其代谢产物沿缝隙渗入进一步发展为继发龋[94]。继发龋是影响修复体寿命的主要因素之一[95]。

研究表明,选择性酸蚀策略配合自酸蚀类树脂水门汀有助于提高边缘封闭性,减少微渗漏与边缘着色[8]。此外,在修复体粘固后应嘱患者定期复查,早期发现并处理边缘着色问题。

前牙修复对美观要求较高,操作中应严格控制多余水门汀的清除时机,避免因过早清胶破坏边缘封闭,进而导致边缘着色[96]。对光固化或双固化水

门汀应进行点固化(tack-cure)1~2 s后再用探针轻轻去除多余水门汀,以免在完全未固化前清胶造成边缘缺陷[55,97]。对于自固化水门汀而言,应在固化前的凝胶期(gel phase)去除。

(3)咬合痛:有时可见部分全冠试戴时咬合接触良好,但粘固到基牙后出现咬合抬高,进而引发咬合痛甚至咬合创伤[98]。这一现象的主要原因是修复体未完全就位,如粘接材料成膜过厚、水门汀用量过多、就位压力不足或操作时间延误导致水门汀流动性下降,修复体无法完全就位于预备体上,致使粘固后咬合抬高[99-101]。

对于双固化和自固化水门汀(如表3中G-CEM ONE™和ESTECEM Ⅱ PLUS等),其操作时间有限,涂布后应尽快使修复体就位。水门汀在固化的过程中应配合医师稳定的手指压力(finger pressure)[101],以保证修复体完全就位[1,102-103]。

此外,固定修复体通常需要25~50 μm的均匀水门汀厚度[104]。为避免粘固后咬合抬高的发生,技师在制作过程中应在基牙与修复体之间预留一定的间隙。同时,临床医师也应根据患者情况灵活选择不同膜厚度的粘接材料。需要注意的是,可乐丽菲露™ SE BOND可形成缓冲层以抵抗树脂的聚合收缩应力,提升边缘封闭性[105],但其膜厚度明显高于其他自酸蚀粘接剂。

4. 进一步省略临床操作步骤的可行性

(1)不同固化模式的反应动力学:光固化体系通过光引发剂(如樟脑醌)在光照下快速产生活性自由基,聚合反应速率高,能在数秒内达到较高的转化率[106]。化学固化水门汀主要通过叔胺(tertiary amine)和过氧化苯甲酰(benzoyl peroxide,BPO)发生氧化还原反应产生自由基并聚合,实现无需光照的自主固化[107]。此外,化学固化硼酸引发体系(如表3双固化树脂水门汀ESTECEM Ⅱ PLUS)利用芳基硼酸盐催化剂与酸性单体反应,引发氧化还原聚合,表现出优异的耐久性和边缘密合性[108-109]。

双固化体系则兼具以上两种机制的特点,既可通过光照射快速引发聚合反应,又能在光线无法到达的区域(如深部牙本质、根管内)依靠化学固化完成聚合[110]。自酸蚀类树脂水门汀通常为双固化,操作灵活且固化效果可靠,如表3中可乐丽菲露™ DC CORE ONE、ResiCem®和RelyX™ Ultimate等。

(2)省略光照的原因及依据:近年来,关于是否省略双固化自酸蚀类树脂水门汀光照步骤的讨论逐渐增多,其原因主要包括两方面:一是主观意愿,减少医师操作环节,提高效率。例如,将G-CEM ONE™搭配Adhesive Enhancing Primer,在涂布、风吹后无需光照即可启动化学固化反应,具有良好的临床适用性[90]。二是客观限制,在光线无法充分到达的区域,如后牙远中、根管和桥体遮挡区等,光照难以进行有效固化[91]。

省略光照的科学依据在于,在光照受限时,通过延长固化时间和选用高效化学引发体系,可在达到临床可接受粘接强度的同时,避免聚合不完全和界面应力集中[111],从而保持粘接界面的完整性[112]。BONDMER Lightless Ⅱ采用含3D-SR单体与硼酸盐的双瓶自固化体系,与ESTECEM Ⅱ PLUS联用时,“接触固化”技术使二者接触后化学活化,10 s内开始产生自由基,24 h内实现完全固化[113]。省略光照步骤可简化操作流程、降低操作误差、减少对设备的依赖,在基层医疗单位及儿童乳牙修复中具有实用价值[114]。

然而,近年来亦有诸多研究指出,省略光照步骤可能对粘接强度及长期耐久性产生不利影响,增加修复体脱落等临床风险[115-116]。

(3)临床操作的具体建议:临床操作中,是否省略双固化树脂水门汀光照步骤应基于产品性能、修复体厚度、透光性及所在位置综合考虑。

对于厚度小于2 mm且透光性良好的修复体(如玻璃陶瓷贴面、高透氧化锆冠等),可选择光固化或不含叔胺成分的双固化树脂水门汀产品并充分光照以获得最大聚合度和粘接强度[117]。而对于修复体厚度在2~3 mm以上、不透光以及光照无法到达时(如根管内、固定桥连接体下方和磨牙远中面等),则应选用化学固化树脂水门汀或化学固化效果良好的双固化树脂水门汀[44,78]。对于双固化树脂水门汀而言,建议必须光照的情况包括:前牙瓷贴面、薄边缘修复体及需要高即刻粘接强度的修复体[118-119]。

此外,不同品牌的双固化材料省略光照后的强度存在显著差异。一些双固化树脂水门汀的聚合度在无光照时显著降低,如RelyX Ultimate与Scotchbond™ Universal配合使用[78]。截至目前,SuperBond C&B是临床中完全依靠化学固化并实现良好粘接耐久性的系统[52,120]。

综上所述,粘接材料的临床决策应综合修复体材料、修复体类型及透光性等因素全面考量(图2)。

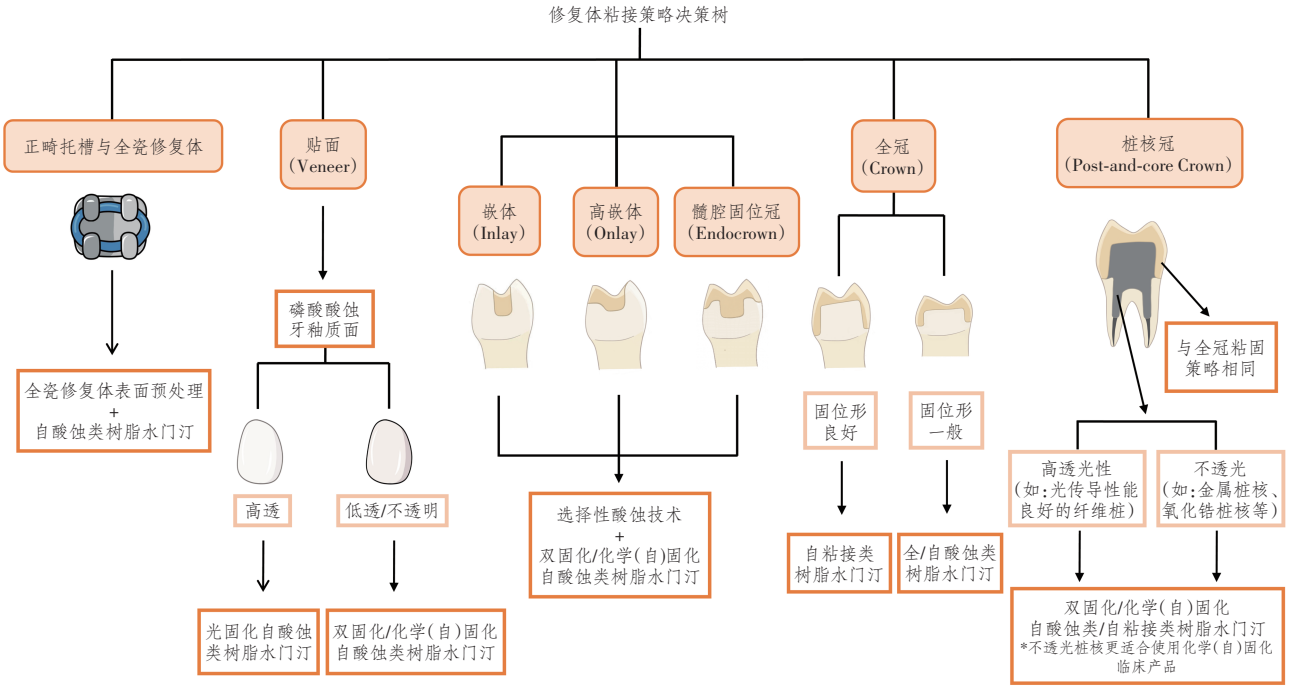

图2 修复体粘接策略决策树

在所选材料属于双固化系统时,若修复体透明度及位置允许光透,则建议通过延长光照时间代偿修复体过厚的不利影响,以提升粘接强度。反之,在厚度大、透光差、光照不可及或临床证据显示光照不能明显提升粘接效果的情况下,可优先选择化学(自)固化树脂水门汀。

四、总结与展望

自酸蚀类树脂水门汀能满足多数临床需求,是一种适应证广泛的口腔修复材料。其临床应用局限性在于:(1)多数随机对照试验随访时间较短;(2)用于粘接桥等特殊病例的临床报告有限;(3)不同品牌产品间缺乏直接比较研究。

根据近5年的系统综述和Meta分析可明确以下几点:首先,10-MDP是目前公认具有良好牙本质长期粘接性能的酸性功能单体[33,60]。其次,选择性酸蚀技术对于牙釉质边缘封闭的有效性得到广泛认同[3,121],且在楔状缺损的修复中效果良好[64,122]。此外,自酸蚀类树脂水门汀与自粘接类树脂水门汀在间接单冠修复体的失败率上差异无统计学意义[123]。但自粘接类树脂水门汀由于对釉质的粘接强度较弱,其在非机械固位形为主的修复体如贴面和后牙粘接桥的修复中,表现出更高的失败率[7,124]。

有研究发现,在树脂水门汀中加入生物活性填料可促进脱矿牙本质再矿化,预防继发龋[125-126]。目前被广泛研究的生物活性填料包括无定形磷酸钙、生物活性玻璃、纳米羟基磷灰石、钙磷复合填料及硅酸盐微填料等[127-130]。未来,生物活性填料对长期粘接稳定性的影响有待进一步探索。

复杂的粘接操作流程旨在确保粘接的可靠性和稳定性,否则将失去价值,例如:采用选择性酸蚀技术处理牙釉质粘接界面与双层涂覆技术等,均可改善自酸蚀类树脂水门汀的粘接效果[131-132]。另一方面,理想的临床产品应在简化操作步骤的同时提供可预测的临床效果。G-CEM ONE™和Tokuyama Universal Bond的推出,体现了当前自酸蚀类树脂水门汀向这一目标迈进的发展趋势。

利益冲突 所有作者均声明不存在利益冲突

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