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· 临床研究 ·

基于 micro-CT 评估 3 种去龋方法清除龋损组织效果及微创潜力的研究

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【摘要】 目的 使用微型计算机断层扫描(micro-computerized tomography, micro-CT)评价传统球钻去龋法、去腐凝胶辅助去龋法和龋显像笔辅助去龋法的清除龋损组织效果和微创潜力。方法 本研究已获得医院生物医学研究伦理委员会审批及患者知情同意。收集 30 颗有牙本质龋的磨牙或前磨牙, 随机分为 3 组, 分别使用传统球钻去龋法(传统球钻组)、去腐凝胶去龋法(去腐凝胶组)和龋显像笔去龋法(龋显像笔组)对样本进行去龋处理, 并记录每个样本的去龋操作时间, 去龋前后均使用 micro-CT 进行扫描并记录每颗牙齿的龋损及健康牙体体积。根据去龋前后的龋损体积及去龋前后的健康牙体体积分别评估 3 种去龋方法的清除龋损组织效果、微创潜能。结果 在去龋时间方面, 去腐凝胶组所用时间(501.7 ± 143.6)s 高于传统球钻组(263.9 ± 121.2)s 和龋显像笔组(284.2 ± 135.6)s, 差异具有统计学意义($P < 0.01$); 传统球钻组和龋显像笔组差异无统计学意义。在清除龋损组织效果方面, 残余龋损体积与初始龋损体积的比值传统球钻组(0.087 ± 0.04)最低, 去腐凝胶组(0.51 ± 0.10)最高, 龋显像笔组(0.36 ± 0.10)介于前两组之间, 差异有统计学意义($P < 0.01$)。在微创潜能方面, 去龋前后健康牙体体积比值传统球钻组(0.87 ± 0.05)低于去腐凝胶组(0.99 ± 0.01)和龋显像笔组(0.98 ± 0.01), 差异有统计学意义($P < 0.01$); 去腐凝胶组和龋显像笔组差异无统计学意义。结论 传统球钻组操作时间最短, 但会过多去除健康牙本质和脱矿牙本质, 微创潜能最差。去腐凝胶组可保留脱矿牙本质和全部健康牙本质, 微创潜能最好, 但清除龋损组织效果不佳, 操作时间较长。龋显像笔组可以保留部分脱矿牙本质和健康牙本质, 具有一定微创潜力, 临床操作时间适中。

【关键词】 龋齿; 矿化牙本质; 牙本质深龋; 化学机械去龋; 荧光辅助去龋; 选择性去龋; 龋齿微创治疗; 微型计算机断层扫描; 去龋效率

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Evaluating the caries excavation effect and minimally invasive potential of three caries excavation methods using micro-CT WANG Ruyan¹, ZHANG Li², LIU Miaomiao³. 1. Department of Stomatology, Suzhou Municipal Hospital, The Affiliated Suzhou Hospital of Nanjing Medical University, Gusu School, Nanjing Medical University, Suzhou 215004, China; 2. Department of Prosthodontics, Nanjing Stomatological Hospital, Affiliated Hospital of Medical School, Institute of Stomatology, Nanjing University, Nanjing 210008, China; 3. Department of Cariology and Endodontics, Nanjing Stomatological Hospital, Affiliated Hospital of Medical School, Institute of Stomatology, Nanjing University, Nanjing 210008, China

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【Abstract】 Objective To evaluate the caries excavation efficacy and minimally invasive potential of three dentine

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caries excavation methods including traditional excavation, chemomechanical excavation, and fluorescence-aided caries excavation using micro-computerized tomography (micro-CT). **Methods** This study was approved by the Biomedical Research Ethics Committee, and all patients provided informed consent. Thirty molars and premolars with dentin caries were collected and randomly divided into three groups. The samples were obtained by traditional excavation (traditional excavation group), chemomechanical excavation (chemomechanical excavation group), and fluorescence-aided caries excavation (fluorescence-aided caries excavation group), and the operation time for each sample was recorded. Micro-CT was used to scan and record the caries volume and healthy tooth volume of each tooth before and after caries excavation. The caries excavation efficacy and minimally invasive potential of the three caries excavation methods were evaluated based on the caries volume and the healthy tooth volume before and after caries excavation. **Results** In terms of caries excavation operation time, the chemomechanical excavation group ($501.7 \text{ s} \pm 143.6 \text{ s}$) had a longer operation time than the traditional excavation group ($263.9 \text{ s} \pm 121.2 \text{ s}$) and the fluorescence-aided caries excavation group ($284.2 \text{ s} \pm 135.6 \text{ s}$), with a statistically significant difference ($P < 0.01$); there was no significant difference between the traditional excavation group and the fluorescence-aided caries excavation group. In terms of caries excavation efficacy, the ratio of residual caries volume to initial caries volume was determined in the traditional excavation group (0.087 ± 0.04), followed by the fluorescence-aided caries excavation group (0.36 ± 0.10), and the chemomechanical excavation group was the highest (0.51 ± 0.10); the observed disparity between the groups exhibited statistical significance ($P < 0.01$). In terms of minimally invasive potential, the ratio of the traditional excavation group (0.87 ± 0.05) was lower than the chemomechanical excavation group (0.99 ± 0.01) and fluorescence-aided caries excavation group (0.98 ± 0.01), with statistically significant differences ($P < 0.01$); the difference between the ratio of the chemomechanical excavation group and the fluorescence-aided caries excavation group was not statistically significant. **Conclusion** The traditional excavation group had the shortest operation time, but the traditional excavation removed too much healthy dentin and demineralized dentin. The chemomechanical excavation group retained demineralized dentin and healthy dentin and had the best minimally invasive potential, but the caries excavation efficacy was poor and the operation time was long. The fluorescence-aided caries excavation preserved part of the demineralized dentin and healthy dentin, had certain minimally invasive potential, and the clinical operation time was moderate.

【Key words】 caries; demineralized dentin; dentine deep caries; chemo-mechanical caries excavation; fluorescence-assisted caries excavation; selective caries excavation; minimally invasive treatment of caries; micro-CT; caries excavation effect

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2020年国际牙科研究协会对龋病定义为一种由生物膜介导、受饮食调节、多因素、非传染性、动态进展的疾病,表现为牙体硬组织矿物质的流失^[1]。在龋病中深龋的诊断和治疗一直备受关注,欧洲牙髓病协会将深龋定义为龋损到达牙本质内1/4及以上,X线片可检测到在龋损透射区和牙髓之间存在矿化区^[2]。传统深龋治疗原则是去尽龋损牙本质,但这样会导致牙髓暴露风险增高,国际龋病共识合作组织(the International Caries Consensus Collaboration, ICCC)专家共识提出深龋治疗可以保留健康和可再矿化的牙体组织,控制风险因素,终止龋损发展,保护牙髓活力^[3-4]。目前基于各种原理的龋检测设备有很多种^[5],去龋的方法也有很多种,其中比较常见的是钻去龋法(如传统球钻

和新型的多聚物钻)、化学机械去龋法(如龋蚀液染色法、去腐凝胶去龋法)、激光辅助去龋法以及荧光辅助去龋法^[6]。对于牙本质深龋的治疗,可以保留髓壁的部分软化牙本质,以保护牙髓-牙本质复合体,防止穿髓^[7]。在这些去龋方法中以龋显像笔为代表的荧光辅助去龋法和以去腐凝胶为代表的化学机械去龋法,因这两种方法具有保护牙本质及脱矿牙本质的能力,近年来被越来越多的学者关注^[8-9]。但未见有文献报道龋显像笔去龋法对于牙本质保留的微创潜力。深龋患牙,特别是年轻恒牙,如果能在髓壁保留少量软化牙本质,以及脱矿牙本质,通过再矿化治疗,可最大限度保留活髓组织并提高牙体的抗折性。本研究通过微型计算机断层扫描(micro-computerized tomography,

micro-CT)评估使用传统球钻、去腐凝胶及龋显像笔3种方法的去龋操作时间、清除龋损组织效果以及微创潜能,为临床提供参考。

1 材料和方法

1.1 主要仪器设备与试剂

超声洁牙机(EN-041,EMS,瑞士);micro-CT(Quantum GX2,PerkinElmer,美国);高速涡轮机(Pana-Max2 M4,NSK,日本);低速涡轮机(FX23,NSK,日本);4号快速球钻(E012334101400,Dentsply,美国);4号慢速钨钢球钻(E012324101400,Dentsply,美国);去腐凝胶(1710313634,朗力生物,中国);龋显像笔(6488949,Dentsply Sirona,德国);0.1%百里酚溶液(69024016,沪试,中国)。

1.2 牙齿的收集和保存

收集苏州市立医院北区口腔科因正畸治疗、龋坏、阻生或其他原因无法保留而拔除的龋坏磨牙及前磨牙。用超声去除牙体表面的牙周膜及牙结石,将牙齿放入0.1%百里酚溶液并置于4℃避光保存。纳入标准如下:①年龄18~60岁;②未进行过磨除、充填或根管治疗的成熟恒牙;③龋损部位为一个殆面或邻殆面的深龋患牙;④通过视诊选择国际龋病检测与评估系统(ICDAS)中被评为5、6级的深龋患牙;⑤通过X线片检查龋损范围达牙本质层1/4以上,距髓腔间距离>1mm的深龋患牙。排除标准如下:①去腐后发生露髓的离体牙;②伴有大面积釉质发育不全的离体牙;③冠部存在大面积非龋坏引起缺损的离体牙。本研究中离体牙的收集工作由同一名口腔科医师完成,最终获取30颗离体牙纳入研究,随机分为传统球钻组、去腐凝胶组及龋显像笔组,每组10个样本。本研究获得苏州市立医院生物医学研究伦理委员会批准,患者均知情同意。

1.3 micro-CT扫描

使用micro-CT,采集参数为88 uA,90 kV,50 μm像素大小。扫描每一颗去龋完成前和完成后的牙齿影像,每颗牙齿前后两次扫描的图像以DICOM文件格式保存。

1.4 去除龋损牙本质

按照各分组要求进行操作,传统球钻组以探诊无软化牙本质为去龋终点,去腐凝胶组严格按照说明书要求以凝胶不再浑浊为去龋终点,龋显像笔组严格按照说明书要求以光照时无红色荧光为去龋终点。所有的去龋操作均由同一个医生完成。

1.4.1 传统球钻组 使用高速涡轮机及4号球钻去除龋洞表面悬空无基釉,随后用4号慢速钨钢球钻以30 000 rpm转速伴喷水降温去除牙本质龋损,去除过程中用探针探查洞侧壁及洞底,直到探诊无软化牙本质,即为本组去龋终点。记录每颗牙齿的去龋所用时间。

1.4.2 去腐凝胶组 使用高速涡轮机及4号球钻去除无基釉,使用去腐凝胶,按照说明书操作,通过注射针头将凝胶滴入龋洞内,确保覆盖所有龋损牙本质面。等待30 s,使凝胶充分软化龋损组织,然后用小挖匙轻柔的刮擦洞内已被软化的龋损组织。不断重复以上操作,直到用小挖匙挖窝洞内时凝胶不再浑浊,即为本组去龋终点。用清水冲净龋洞内残余的凝胶。记录每颗牙齿的去龋所用时间。

1.4.3 龋显像笔组 先使用高速涡轮机及4号球钻去除无基釉,按照产品说明书,使用龋显像笔照射龋洞内,透过橙色滤光片观察,如果显示红色部分则用4号球钻去除,显示绿色部分则保留,注意照射到每个位置。反复上述操作直到照射窝洞内没有红色光点为止,即为本组去龋终点。记录每颗牙齿的去龋所用时间。

1.5 数据记录

1.5.1 龋损及健康牙体体积测量 用micro-CT仪器自带的两个已知密度的羟基磷灰石块进行micro-CT扫描,得出相应的灰度值,通过线性关系计算将micro-CT灰度值与龋损牙本质的矿物密度值相关联。将去龋前后的micro-CT图像导入mimics21.0软件中,按1.11 g/cm³ HAp所对应的灰度值作为龋损牙本质和正常牙本质的界限^[10],将去龋前后牙体分别分割成去龋前后龋损部分以及去龋前后健康牙体,分别记录各部分体积。

1.5.2 龋损组织清除效果 根据去龋前后的龋损体积计算龋损组织清除效果,清除效果=残留龋损体积÷初始龋损体积,结果越接近0,代表龋损组织清除效果越好。

1.5.3 微创潜能 根据去龋前后的健康牙体体积计算微创潜能,微创潜能=去龋后健康牙体体积÷去龋前健康牙体体积,结果越接近1,代表微创潜能越好。

1.6 统计学分析

采用GraphPad Prism9.0软件进行统计分析。定量资料采用均数±标准差表示,组间比较采用单因素方差分析。检验水准取双侧α=0.05。

2 结果

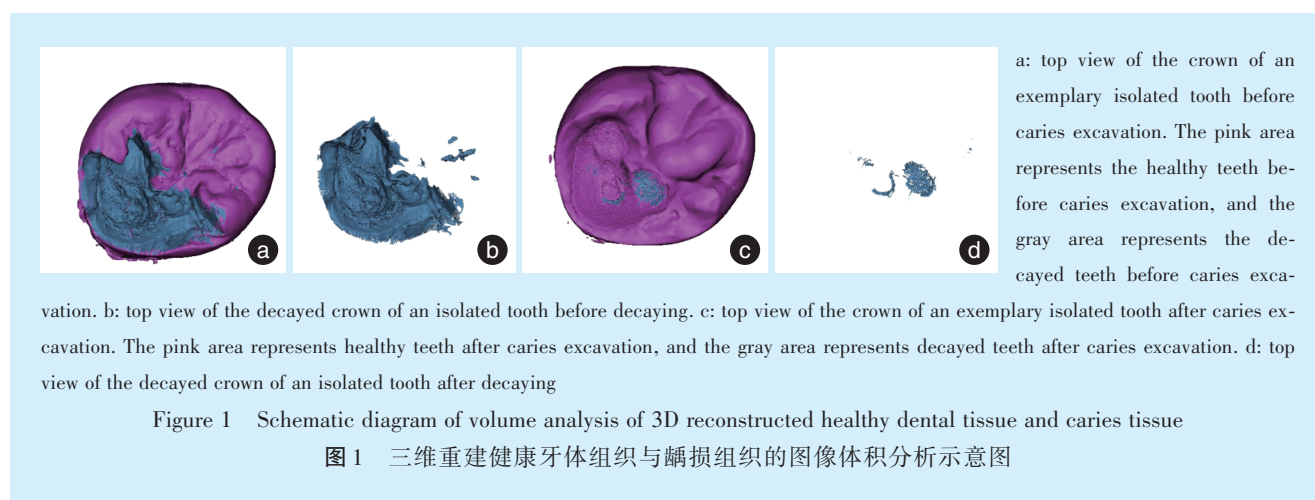
2.1 去龋操作时间比较

3组去龋操作时间分别为传统球钻组(263.9 ± 121.2)s,去腐凝胶组(501.7 ± 143.6)s,龋显像笔组(284.2 ± 135.6)s。去腐凝胶组的操作时间大于传统球钻组和龋显像笔组,差异有统计学意义($P < 0.01$)。传统球钻组和龋显像笔的操作时间差异无统计学意义($P > 0.05$)。说明使用去腐凝胶方法去龋作用时间最长,龋显像笔去龋所需时

间跟传统球钻去龋法接近(表1)。

2.2 micro-CT 图像三维重建体积分析

在mimics软件中,去龋前牙体总体积(图1a)被分割为去龋前龋损牙体即初始龋损体积(图1b)和初始健康牙体即去龋前健康牙体体积(图1a体积减图1b体积);去龋后牙体总体积(图1c)被分割为去龋后残留龋损体积(图1d)和去龋后健康牙体体积(图1c体积减图1d体积)。



2.3 龋损组织清除效果

3组龋损组织清除效果分别为传统球钻组 0.087 ± 0.04 ,去腐凝胶组 0.51 ± 0.10 ,龋显像笔组 0.36 ± 0.10 ,差异均有统计学意义($P < 0.01$),说明传统球钻组龋损组织清除效果最佳,其次是龋显像笔组,去腐凝胶组效果最差(图2,表1)。

传统球钻组的微创潜能值低于去腐凝胶组和龋显像笔组,差异具有统计学意义($P < 0.01$);去腐凝胶组和龋显像笔组的微创潜能差异无统计学意义($P > 0.05$)。说明去腐凝胶法和龋显像笔法均比传统球钻法能保留更多的健康牙体组织(图2,表1)。

2.4 微创潜能

3组微创潜能分别为传统球钻组 0.87 ± 0.05 ,去腐凝胶组 0.99 ± 0.01 ,龋显像笔组 0.98 ± 0.01 。

3 讨论

近年来,随着微创牙科理念的普及,对于深龋的治疗,更多的医生倾向于微创选择性去龋,旨在

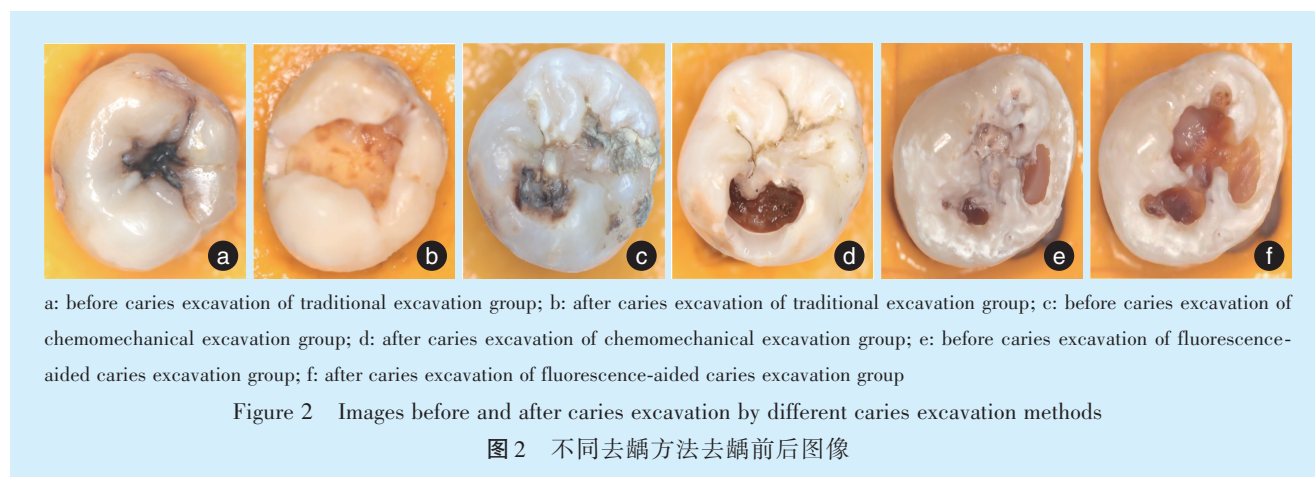


表1 各组龋损组织清除效果、微创潜能及操作时间的比较

Table 1 Comparison of caries excavation efficacy, minimally invasive potential, and operation time in each group

Groups	Time/s	Caries excavation efficacy	Minimally invasive potential
Traditional excavation	263.9 ± 121.2	0.087 ± 0.04	0.87 ± 0.05
Chemomechanical excavation	501.7 ± 143.6 ¹⁾	0.51 ± 0.10 ¹⁾	0.99 ± 0.01 ¹⁾
Fluorescence-aided caries excavation	284.2 ± 135.6 ²⁾	0.36 ± 0.10 ¹⁾²⁾	0.98 ± 0.01 ¹⁾
<i>F</i>	9.71	63.10	44.60
<i>P</i>	< 0.01	< 0.01	< 0.01

1): compared with traditional excavation, $P < 0.01$; 2): compared with chemomechanical excavation, $P < 0.01$

选择性去除龋损牙本质,并尽可能保留脱矿及健康牙体组织,从而防止对牙髓-牙本质复合体的损伤^[11-12]。选择性去龋一方面可以提高牙体组织的抗力,另一方面可以防止去龋过程中造成的意外穿髓。尤其是对年轻恒牙的治疗,需要最大限度保留健康牙髓和牙体组织。另有研究发现,选择性去除软化牙本质并不会影响修复体的5年存活率^[13]。由于微生物及其代谢产物在感染的牙本质中大量存在,使得深层牙本质的再矿化变得困难,一些体外研究添加了抗菌剂和不同的仿生剂,以评估其对微生物的作用,如研究显示在充填材料严密封闭的条件下,下方牙本质龋中未完全清除的乳酸杆菌也会随着时间的延长逐渐减少^[14];同时,多种新型生物材料可对脱矿牙本质进行有效再矿化,使得矿化后的牙本质弹性模量接近天然牙本质,例如已进行体内研究的MTA及水凝胶系统等^[15]。

当前用于评估龋清除效果和微创潜能的方法主要有微型计算机断层扫描^[16]、显微硬度测量^[17]和三维形貌测量激光显微系统^[18]。显微硬度仪只能测定洞底选定点的硬度值,存在一定选择偏差。三维形貌测量激光系统能够区分牙本质龋的不同层,但是只能测定表面积,不能测量体积。micro-CT近年来被广泛应用于口腔牙体组织的研究,它是一种非破坏性的技术,不仅可以测量不同矿化程度的牙本质体积,还可以测量洞底平均矿物密度^[19]。Neves等^[10]通过一系列计算确定密度值1.11 g/cm³ HAp为龋坏牙本质和正常牙本质的界限并提出了micro-CT可以评估不同去龋方法的去龋效果和微创潜力,后续又有多篇文献使用该方法评估不同去龋方法的去龋效果和微创潜力^[16, 20-21]。因此本实验采用了micro-CT扫描重建并使用mimics软件分析各部分牙体体积。

目前有多种去除龋损组织的方法和技术,最普遍使用的方法依然是传统球钻去龋法,近年来也出现了一些新型的去龋钻针,但是结果显示,其去龋效果与传统车针一致,但所需去龋时间会延

长^[22]。这些传统去龋法是由医生根据牙本质硬度和颜色来判断去龋深度,而此法对于牙体组织的磨除量缺乏精确的界限,仅由医生的经验判断,在操作过程中会过多去除健康牙体组织以及一些脱矿牙本质^[23]。根据本研究的微创潜能结果证实,传统去龋法会去除过量的脱矿牙本质及健康牙本质。牙体组织磨除量越大,牙齿的抗折性越差,后期发生牙体折裂的风险越高。尤其是在龋坏年轻恒牙中,过多的去除牙本质,不利于保存年轻恒牙的牙髓组织^[24]。研究者用扫描电镜观察不同去龋方法去龋后牙本质界面,除传统去龋法,其余的去龋方法均能保留更多健康牙体组织^[25]。

化学机械去龋法是使用龋蚀检知液^[26]或去腐凝胶^[27]等化学物质指示龋坏范围,再用机械工具去除。这种方法相比较传统方法有明显的去龋界限,可以避免去除健康牙本质。Neves等^[20]通过比较9种去龋方法也得出结论,使用化学机械法去龋在保存健康牙体组织方面优于其他方法,但同时也提出了化学机械法可能会留存部分龋坏牙本质。近期也有研究显示凝胶法比龋染色剂法和传统法所残留的细菌更多^[28]。本研究结果也显示,去腐凝胶法的健康牙体留存率最高,但龋损组织清除效果较差,考虑可能原因有以下两个,首先以往文献多用于乳牙去腐的研究^[27],乳牙多为湿性龋,而恒牙多为干性龋,可能凝胶去腐有差异,还需进一步的研究证明。其次可能与所使用的凝胶成分有关,最新的研究显示,一些新的酶基类的去腐凝胶在研发中,可以有效去除龋坏牙本质并增加消毒能力^[29]。此外,以往文献指出化学机械法所需的操作时间比传统球钻法长^[30],本研究结果也得到了与其一致的结论。化学机械法需要的去龋操作时间较长,约为其他两种方法的两倍,可能跟该方法第一次放置凝胶需要等待30 s后再进行龋挖除操作有关,并且此方法需要反复涂布凝胶与挖除龋坏,以上因素均延长了操作时间。最近的研究也显示,凝胶去腐法比传统球钻去龋法和

龋染色法所需时间长,而且龋去除量最低^[31]。但是该方法有效的减少了涡轮机的使用,有文献提出大多儿童对于涡轮机操作时的声音及磨牙时的酸痛感有恐惧心理^[32],化学机械法避免了高速及慢速涡轮机的使用,因此在儿童口腔治疗时可优先考虑。

近年来出现的荧光辅助去龋法,因需要特殊的龋显像设备,在国内普及的速度比较慢。该方法是用带宽在370~420 nm的蓝紫色光照射窝洞,然后通过滤光片进行观察,被细菌感染的牙本质会发出橙红色光。细菌代谢产生的卟啉化合物是感染牙本质及牙菌斑发出这种红色荧光的原因^[33]。光谱研究显示,红色荧光的强度可以代表牙齿龋坏的程度^[34]。本实验结果也显示龋显像笔辅助去龋法比传统球钻去龋法能保留部分脱矿牙本质,进行再矿化治疗,最大限度保留年轻恒牙的牙髓组织。这在年轻恒牙的深龋治疗中尤其重要^[24],有研究表明,选择性去除软化牙本质并不影响树脂修复体的寿命^[13]。一项最近的研究结果也显示经过荧光辅助去龋保留部分脱矿牙本质后,并不影响粘接的强度^[35]。

综上所述,传统球钻去龋方法去龋效果最佳,但无法保留脱矿牙本质,甚至可能会去除脱矿牙本质和健康牙本质,适用于浅龋和中龋,在处理深龋患牙时,临床操作中要注意对髓壁脱矿牙本质的保留。去腐凝胶辅助去龋法临床操作时间较长,可能会留存部分龋损牙本质,但能完全保留健康牙本质和脱矿牙本质,且能减少治疗过程中声音和震动的产生,可用于有牙科恐惧患儿的龋齿治疗。龋显像笔辅助去龋法龋清除能力适中,能选择性保留脱矿牙本质和健康牙本质,可以用于深龋或年轻恒牙的龋病治疗。

【Author contributions】 Wang RY collected, processed, and analyzed the data, and wrote the article. Zhang L designed the study and reviewed the article. Liu MM collected, processed and analyzed the data and revised the article. All the authors read and approved the final manuscript as submitted.

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