

数字化全口义齿研究进展

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摘要:数字化技术在口腔领域已广泛普及, 面对体量巨大的老年人群体, 数字化全口义齿修复的热度一直居高不下。相比传统全口义齿修复, 数字化全口义齿为患者带来了更短的就诊周期和更舒适的就诊体验。本文从数字化印模、CAM技术、材料性能以及临床效果评价等方面介绍数字化全口义齿的最新研究进展, 旨在为临床医师提供参考。

关键词:计算机辅助设计; 全口义齿; 数字化印模技术; 三维打印; 无牙颌

中图分类号: R783

文献标志码: A

文章编号: 2095-5227(2025)03-0309-06

DOI: 10.12435/j.issn.2095-5227.24043002

引用本文: 张敏, 丁祝雯, 刘翠, 等. 数字化全口义齿研究进展 [J]. 解放军医学院学报, 2025, 46 (3): 309-314.

Research advances in digital complete dentures

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Abstract: Digital technologies have become widely adopted in dentistry, and in the context of a rapidly growing elderly population, digital complete denture fabrication remains a highly sought-after solution for addressing age-related tooth loss with enhanced precision and efficiency. Compared with the traditional complete denture restoration, the digital complete denture brings patients a more comfortable treatment experience and a shorter treatment period. This article briefly describes the latest research progress of digital complete dentures from the aspects of digital impression, CAM technology, material properties and clinical effect evaluation, in order to provide reference for clinicians and improve the efficiency and effectiveness of diagnosis and treatment.

Keywords: computer-aided design; complete denture; digital impression technique; 3D printing; edentulous jaw

Cited as: Zhang M, Ding ZHW, Liu C, et al. Research advances in digital complete dentures [J]. Acad J Chin PLA Med Sch, 2025, 46(3): 309-314.

自1994年数字化技术应用于全口义齿至今, 出现了大量商业化的数字化全口义齿系统^[1]。目前应用较多的数字化系统除国外主流品牌3Shape、AvaDent、Baltic、Vita Vionic外, 我国功能易适数字化全口义齿也逐渐推广开来^[2]。全口义齿的数字化修复主要应用涵盖三维数字扫描、计算机辅助设计(computer aided design, CAD)、计算机辅助制造(computer aided manufacturing, CAM)、3D打印以及用于数字加工的材料等, 简化传统方法复杂步骤的同时, 提高了全口义齿修复的精度和疗效。

本文将从数字化印模、CAM技术、3D打印技术、用于数字化加工的材料性能及临床效果评价等方面对全口义齿数字化修复进行介绍, 旨在系统梳理当前数字化全口义齿领域的关键技术与应用进展, 分析其优势与现存问题, 为未来技术优化与临床应用提供参考。

1 无牙颌数字化印模

数字化印模技术是在数字化扫描后采集标准曲面细分语言(standard tessellation language, STL)格式的数据, 并导入到CAD进行虚拟设计。既可以直接扫描口腔软硬组织(即口内扫描), 也可以间接扫描口腔印模或者石膏模型(即口外扫描)。在全口义齿修复过程中, 获取精细的功能性印模极为

收稿日期: 2024-04-30

基金项目: 国家重点研发计划资助(2020YFC2008900)

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关键。扫描环节的准确性与精度,会直接影响数字化印模的精准度,进而影响最终修复体的稳定、固位及功能。虽然数字化扫描在口腔固定义齿修复中已被广泛应用,但无牙颌数字化扫描起步较晚。现阶段较为明确的是,口外扫描相较于口内扫描,能获得比传统取模更高的准确度和精度^[3-5]。

在无牙颌数字化扫描中,获取高质量的直接口内扫描数据是目前临床操作的一大难点。口内扫描受口内复杂情况的影响,在上颌腭部、腭中缝和后堤区以及下颌舌侧均容易出现较大的误差^[6]。另外,数字化扫描头难以获取口腔功能状态下的黏膜形态,无法像传统闭口式印模一样进行肌功能整塑,因而黏膜边缘封闭的范围界定是一个关键点。鉴于此,Fang等^[7]开发了一种专门用于口内扫描的黏膜牵开器,以便充分暴露前庭沟,进而可对数字印模进行清晰的范围界定。此法虽可清晰扫描视野,对义齿边缘伸展范围也有一定的优化作用,但获取的仍是口腔黏膜的静态数据。Lee等^[8]报道了一种新方法,在获取功能性印模的数字模型的同时,利用CAD软件设计出虚拟全口义齿。分别保留功能性印模的组织面和边缘整塑部分以及虚拟全口义齿的义齿主体(牙列和部分基托),从而将截选后的两部分在网格建模软件中进行互补整合;以此来最大限度保留组织面的形态,减少对石膏模型的灌注和扫描,并减少人为和系统误差,进而最大限度保证全口义齿的固位和稳定。也有研究通过改进扫描策略提升口内直接扫描获取的上颌初印模的正确度,取得的终印模与间接数字化个别托盘获取的终印模无明显差异^[9]。值得注意的是,操作者经验可能影响无牙颌模型数字化印模获取的准确性,但其对无牙颌模型正确度的影响尚无定论,这或许与扫描设备自身的精度有关。同样,扫描仪探头大小以及扫描时有无标记物,对数字化印模精确性的影响,在不同研究中结论截然相反^[3,10-11]。即使如此,这些研究足以表明上述因素是影响数字化印模准确性的重要因素。后续研究应围绕新一代扫描设备开展相关测试与探索,以进一步明确其影响机制。

因操作者、扫描设备、参照对象存在差异,各研究难以直接比较,结论适用性较为局限。因此,基于现有研究成果与扫描设备的性能,通过口内直接扫描所获取的数字化印模可用于制作个别托盘或诊断义齿,在一定程度上减少患者的不适感,但不建议用其获取终印模。为确保全口义

齿良好的固位与稳定,制取功能性印模是十分必要的。因此,多数临床医师会选择间接扫描硅胶功能性印模或石膏模型,以此能够确保获得出色固位力的数字化全口义齿。

2 全口义齿CAM技术

2.1 数控切削技术

计算机辅助制作主要可以分为数控切削(即减法制作工艺)和3D打印(即加法制作工艺)两大主要制作工艺。数控切削最先应用于全冠、嵌体等固定修复中,技术较为成熟,也是目前数字化全口义齿常用的加工方式。以聚甲基丙烯酸甲酯(polymethyl methacrylate, PMMA)基托色树脂盘为材料,数控切削出带有人工牙定位孔的义齿基托,将切削的人工牙或成品人工牙粘接至基托定位孔中完成全口义齿的制作。这种减法制作工艺解决了聚合收缩的问题,切削精度高,制作效率高^[12]。然而,基托和人工牙的分步加工可能会在牙齿粘接就位的过程中产生较大的误差。闫越琪等^[13]制备了一种新型数控切削全口义齿基托树脂材料,其部分物理性能得以提升,如挠曲强度、挠曲弹性模量、吸水性能和溶解性能。多个体外模型研究均表明CAD-CAM铣削全口义齿组织面准确度优于3D打印^[14-16]。Russo等^[17]的体内实验也表明,在全数字化制造流程下,数控切削仍可以获得略优于3D打印的组织面准确度。

2.2 3D打印技术

与数控切削比较,3D打印能够降低成本、减少材料浪费,可同时打印多个义齿基托,实现无法切削的复杂设计^[18]。当前,在3D打印机的研究范畴内,数字光处理型和立体光刻型3D打印机为主要研究对象^[19]。近期一项体外研究对2台铣削设备(350i和Programill 7)与5台3D打印机(Asiga max UV、Nextdent 5100、Form 3B、Cara print 4.0和D30i)制作的上颌全口义齿基托组织面精度进行了横向比较,结果显示,2台数控铣削设备的切削精度一致,且均优于增材制造技术。此外,不同的增材制造设备在制作上颌全口义齿基托组织面时,正确度存在差异^[20]。因此,3D打印制作的准确性尚无定论,许多研究结果存在差异。

打印方向会影响3D打印的精度、强度、表面粗糙度,因此大量学者探究了3D打印最佳构建方向或构筑角度^[18]。Gao等^[21]研究显示,使用MultiJet 3D打印机打印下颌全口义齿时,45°构建

方向的精度最高。Chaiamornsap 等^[22]采用数字光处理技术时,则建议为 270°的构建方向。此外, Song 等^[23]研究发现,优化构建方向,既能提高数字光处理型打印精度,又能减少材料消耗和打印时间。该研究推荐,采用数字光处理型打印上颌全口义齿模型时,若时间充裕,可选择 L90°构建方向以降低材料消耗;若时间有限,可选择 L45°。多数研究进一步证实,打印方向对数字光处理型打印树脂修复体的表面粗糙度影响显著,且均表明 0°打印时修复体表面粗糙度最低^[24-26]。Yan 等^[26]研究指出,0°构筑角度能使修复体获得更强的亲水性与更高精度,这与此前研究结果有所不同。此外,3D 打印时有无支撑杆也是影响修复体凹面(即组织面)精度的因素之一^[22,27]。在 3D 打印的义齿中,腭中缝区、腭穹窿部、上颌后堤区、上颌结节、下颌基部舌侧等部位的基托边缘,精度表现欠佳,与口内扫描相似^[23-26]。除数字光处理型打印机外, Cameron 等^[27]对 NextDent 5100 打印机展开研究,结果显示,打印上颌全口义齿基托时,45°、60°、90°的构建方向结合义齿面的支撑柱,可获得比其他方案更高的义齿精度。Russo 等^[28]采用熔融沉积成型 3D 打印机(fused deposition modeling, FDM),以聚乳酸为原料制作诊断义齿,其精度也得到了证实。

在数字光处理型打印中,确保义齿尺寸稳定和防止变形对义齿在长期使用过程中维持良好性能、确保佩戴舒适度与功能正常发挥至关重要。研究表明数字光处理型打印基托在 1 d 内就会发生尺寸变化^[29-30]。李恺等^[30]量化分析 14 d 内打印义齿的变形状况,发现基托组织面在双侧上颌结节区域与后堤区形变最为显著,且二者变形方向相反。此外,打印后的固化时长也会影响打印基托的尺寸稳定性^[29]。有研究指出,当构建角度为 0°、45°、90°时,上下颌义齿尺寸偏差均在临床可接受范围(100 μm)之内,但 90°时尺寸稳定性最差且随时间推移尺寸偏差逐渐增大^[26]。值得注意的是,由于打印机类型和参数各不相同,构建方向或角度对义齿精确度和稳定性的影响也存在细微差异。

上述各研究所选用的扫描仪、打印设备以及设定的软件参数各不相同,导致成果无法直接进行比较分析,同时难以在临床应用中广泛复刻。只有深入了解所使用设备的性能和影响增材制造精确度的各类因素,3D 打印技术才能够有针对性

地改进制作工艺,提升性能,从而在口腔临床工作中得以逐步推广应用。

3 用于数字化加工的材料性能

3.1 切削材料性能

材料性能对于全口义齿的功能发挥以及数字化加工技术的推进至关重要。而切削材料在数字化全口义齿制造中具有显著优势,其在物理性能(包括弯曲强度、硬度、冲击强度、断裂韧性等)、颜色稳定性、表面粗糙度等方面均优于 3D 打印材料^[31-36]。切削 PMMA(如 Ivotion Base 和 Ivoclar Vivadent)的抗压强度优于 3D 打印树脂(Asiga 和 DentaBASE)和 SR Ivocap 等材料^[37]。而新一代切削石墨烯增强 PMMA 在弯曲强度和维氏显微硬度方面又进一步提高,优于切削预聚合 PMMA(Ivotion base)和 3D 打印树脂(Denturetec)^[38]。热循环是体外检验义齿长期性能的重要手段。研究表明,切削和 3D 打印义齿基托材料经热循环后弯曲强度均会降低^[38-40],但切削义齿基托材料硬度和断裂韧性仍高于 3D 打印义齿^[41],且 CAD-CAM 切削树脂经冷热循环老化后的尺寸精度最高^[42],颜色稳定性更佳^[36]。切削材料优异的性能为义齿长期稳定性和耐用性提供了有力支撑。

3.2 打印材料性能

与传统热聚合 PMMA 相比,3D 打印树脂(NextDent、Dentona、Asiga)表面粗糙度、维氏硬度和弯曲强度普遍较低,且存在显著差异。其中,Asiga 表面粗糙度最小;Dentona 的平均冲击强度最高;NextDent 的维氏硬度值、弯曲强度、冲击强度最低,弯曲模量最高^[43]。近年来,通过添加硅化氧化铝、二氧化钛、纳米氧化锌及纳米银、硅等纳米颗粒显著提升了 3D 打印树脂的物理机械性能^[44]。如在 Asiga 中添加 TiO₂ 纳米颗粒,并延长固化时间,可有效增加其抗弯强度;而延长固化时间对于提升其弹性模量和硬度有积极作用^[45]。在数字光处理型打印树脂中添加 ZnO 和 CeZr 纳米填料可改善 3D 打印材料的颜色稳定性^[46]。因此,虽然 3D 打印材料存在一定不足,但通过对材料的改性和优化,其性能有很大的提升空间。

3.3 两类材料其他特性

此外,切削义齿基托材料在润湿性、抗腐蚀性及抗菌性上均表现更为出色^[31,47-48]。有研究建议采用醋和过氧化氢 1:1 混合液消毒 3D 打印义齿以降低其腐蚀风险^[49]。与热聚合树脂(Lucitone 550)

比较, 3D 打印义齿树脂(NextDent Denture 3D+, Cosmos Denture)更易被白色念珠菌定植, 这种差异可能与材料表面自由能有关^[50]。但3D打印义齿可通过加入抗真菌剂或调整打印参数以改善其抗黏附性能^[51]。多项体外试验表明, 使用传统义齿重衬材料修复后, 3D打印树脂的剪切粘接强度最低^[52-54]。通过机械处理(如使用碳化硅砂纸研磨和50 μm氧化铝喷砂等)或表面涂布单体均可有效提高这3种材料粘接强度, 以氧化铝喷砂效果最佳^[55-57]。然而, 即使经过不同的表面处理, 3D打印树脂的粘接强度仍低于热聚合树脂(Major base20)和研磨树脂(IvoCad, AvaDent)。

在数字化加工领域, 所涉及的材料丰富多样。上述研究成果有助于临床医师根据不同品牌材料的特性制定有效的治疗方案。然而, 综合考量现有材料在机械性能、成本效益及加工难易程度等方面的表现后, 切削PMMA仍是首选材料。相比之下, 3D打印材料在实际应用中仍面临诸多难题, 其优化与完善仍需长期探索与实践。

4 数字化全口义齿修复效果

数字化与传统全口义齿在患者主观体验、功能表现及长期稳定性方面的差异仍存在争议。其中, 患者满意度是评价义齿修复成功与否的关键指标, 涉及功能适应、舒适度及心理接受度等方面。多项研究数据显示, 数字化全口义齿与传统义齿在口腔健康相关生活质量评分以及患者满意度上并无显著差异^[58-62]。这些结果说明, 数字化流程虽改变了制作方式, 但患者对修复体功能与美观的最终评价与传统工艺接近。此外, 固位性能、基托适应性和咀嚼效率, 是衡量数字化全口义齿功能恢复和临床效果的重要指标。我国自主研发的功能易适数字化全口义齿, 在义齿制作精度、效率和临床应用效果方面获得了广泛认可。经临床初步验证, 该义齿在咬合稳定性上优于传统义齿^[63]。通过Meta分析可知, 切削数字化义齿与传统义齿在基托固位方面无显著差异, 而3D打印义齿可能因材料收缩率和工艺限制, 其固位力显著低于传统义齿^[58]。Zandinejad等^[59]进一步指出, 数字化义齿(切削/3D打印)的固位性能优于传统工艺, 但研究间存在较高异质性, 对于研究结果还需谨慎解读。另外, Casucci等^[64]开展的回顾性研究表明, 数字化组(切削/3D打印)在咬合力、咀嚼功能上与传统组无显著差异, 证实其临床适应性可满

足患者基本需求。

尽管数字化全口义齿具有一定优势, 但也存在一些问题。有学者对近20年来数字化全口义齿的相关研究进行系统回顾后发现, 数字化全口义齿修复虽然能够有效缩短临床操作时间(205~233 min), 但仍有高达37.5%的患者出现过义齿固位丧失的情况, 31.3%的患者需要重新制作义齿^[65]。同时, 部分研究也揭示了数字化义齿在初期适应阶段面临的潜在挑战。Peroz等^[66]的随机交叉试验表明, Baltic数字化义齿仅需2次就诊即可完成修复, 但在初戴(2周内)时, 因边缘过度延伸导致固位力下降, 可能会引发短期不适, 且佩戴初期出现疼痛的情况相比传统组更多^[61]。Kang等^[67]的研究也指出, 采用数字化流程的增材制造义齿在咀嚼效率和发音功能上均低于传统工艺, 不过基托适应性与传统工艺相当。这些差异表明, 数字化技术在临床初期的调改需求较高, 需通过优化扫描精度和咬合设计, 减少患者适应期的不适。

现有研究在样本选取、实验方法、评估标准等方面存在较大异质性, 难以得出统一、明确的结论。有研究建议, 可借助标准化工具对患者满意度进行评估, 以便在数字化工作流程和传统工作流程之间开展更具价值的比较分析^[62]。此外, 数字化全口义齿在初期固位精度和长期咀嚼功能方面仍有待进一步优化, 并且缺乏长期临床效果的观察数据, 未来应开展大样本长期随访研究以验证其临床疗效。

5 结语

在老龄化社会背景下, 数字化全口义齿修复在口腔修复领域展现出显著优势与广阔前景, 无疑是一个亟待深入研究的重要方向。而现阶段, 在实际操作中, 每个数字化制作环节中都存在未完全攻克的技术难点, 这成为阻碍全流程数字化全口义齿修复在临床广泛应用的关键因素之一。数字化诊疗技术的发展和突破, 在很大程度上依赖于整体科技水平的提升以及主流公司仪器设备的更新换代。在现有条件下, 临床医师应深入钻研并熟练掌握现有设备的使用技巧, 持续优化技术操作细节, 积极探索更贴合临床实际需求的解决方案。只有如此, 数字化全口义齿修复技术才能在临床上逐步推广普及, 更好地融入口腔诊疗工作, 最终为患者带来更多福祉。

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利益冲突 所有作者声明无利益冲突。

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