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·综述·

种植修复口内扫描印模精度的影响因素

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【摘要】 在种植修复领域中，随着数字化技术逐渐推广，口内扫描印模因其简捷高效、舒适度高、便于医患交流的优势，临床应用日益广泛。但是在实际应用中，口内扫描印模的精度会受到多种因素的影响，包括扫描技术、牙列和种植体的情况、辅助标记和材料以及环境等，进而导致精度的降低，限制其适用性；应用于牙齿缺失较多的患者时可能会精度不足，建议当种植体数量多、间距大时谨慎使用口内扫描，不要过度拧紧扫描杆，尽量维持合适的环境条件。本文回顾近期相关研究文献，对种植修复中口内扫描印模精度的影响因素进行综述。

【关键词】 牙列缺失；　口腔种植；　数字化；　印模；　口内扫描印模；　扫描成像技术；　扫描杆；　精度；　误差；　真实度
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Factors influencing the accuracy of intraoral impression in implant restoration

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【Abstract】 Due to advances in digital technology, intraoral impressions have been increasingly used to fabricate implant restorations because of its simplicity, high efficiency, comfortableness and convenience. In clinical practice, the accuracy of intraoral impressions depends on various factors, including scanner technique, status of dentition and implants, auxiliary devices, materials and environment, which might influence its accuracy and limit its application. When applied to patients missing more teeth, its accuracy may be insufficient. It is suggested that intraoral impressions be used cautiously when there are multiple and far apart implants and that the scan body not be tightened excessively and that maintain appropriate environmental conditions. In this article, we have reviewed recent relevant literature and the factors affecting the accuracy of intraoral impressions for implant restoration.

【Key words】 dentition defect; dental implantation; digitization; impression; intraoral scanning impression; scanning imaging technology; scan body; accuracy; errors; trueness
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随着数字化技术的推广，口内扫描印模因简捷高效、舒适度高、便于医患交流等优势而广泛应用于临床[1-3]。但其精度受到多种因素影响[4-6]，并不总是适用于所有临床情况，一般认为用于种植单冠的精度令人满意，但多颗种植体支持的局部或全口固定义齿的精度尚不足[4-5]，例如2018年ITI共识不推荐对种植体间跨度大的牙列缺损和牙列缺失患者常规使用口内扫描印模[7]。为了减少口内扫描印模的误差，增加其适用性，医生需要了解该技术的原理及其影响因素，以便在临床操作中控制相关因素，提高印模精度[8]。因此本文介绍常见的口内扫描原理，并较全面地分析影响精度的相关因素，以补充相关综述未涉及的内容，为临床应用提供参考。

1　口内扫描印模的原理

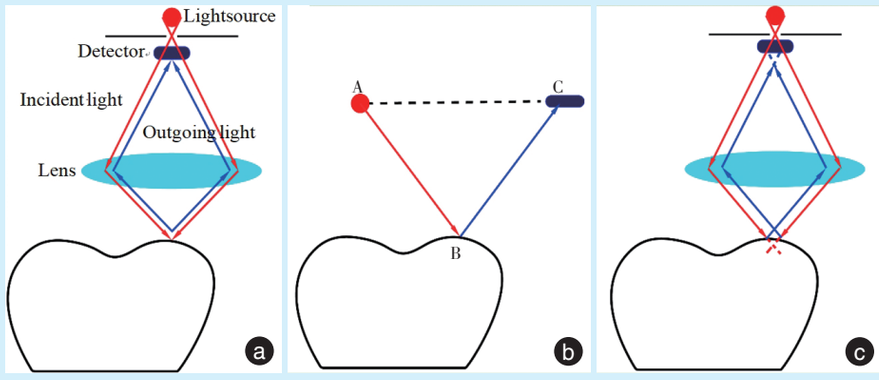
口内扫描系统使用光学扫描技术，利用光源对口内组织进行照明，传感器采集到图像，软件识别出兴趣点（point of interest，POI）并计算出各点的三维坐标，通过最佳匹配算法（best-fit algorithm）将各张图像合成为三维模型[9]。

常见的扫描原理包括[9-10]：①共聚焦显微成像技术（confocal microscopy technology），扫描仪发射光束经过特定焦距的透镜，来获取物体的对焦信息和距离（图1a）；②三角测量技术（triangulation technology），扫描仪发射光束投射于物体并反射至探测器，通过三角原理（BC=AC×sinA/sin（A+C））计算出物体的距离（图1b）；③主动波前采样技术（active wavefront sampling technology），扫描仪投射光束后通过透镜系统反射至探测器，若图像是对焦状态，则物体距离等于透镜焦距，若图像失焦，则根据图像大小计算出物体距离（图1c）（表1）。

2　口内扫描印模精度的影响因素

2.1　口内扫描技术

因各种口内扫描仪除了扫描技术以外还有很多差异，无法直接比较不同技术的优劣，只能大致分析不同技术的精度范围。Zhang等[4]发现，Trios（共聚焦显微成像）、CS 3600（主动三角测量）和CEREC Omnicam（主动三角测量）的平均误差在各项研究中都小于100 μm，而PlanScan（共聚焦显微成像）和3D Progress（共聚焦显微成像）的误差较



a: confocal microscopy. b: the scanner emits a beam which is projected on the object and reflected to the detector. The distance of the object is calculated by the trigonometric principle: (BC=AC×sinA/sin(A+C)). A: lightsource; B: object; C: detector. c: active wavefront sampling

Figure 1　Intraoral scanning techniques

图1　口内扫描技术

表1　常见设备及其相应扫描原理[11-14]

Table 1　Intraoral scanners and scanning technique[11-14]

Scanning technique	Common devices
Confocal microscopy technology	Trios 3 (3-Shape, Denmark), iTero (Align Technology, USA), PlanScan (Planmeca, Finland)
Triangulation technology	Cerec Omnicam (Dentsply-Sirona, USA), CS 3600 (Carestream Dental, USA), Aoralscan 3 (Shining3D, China)
Active wavefront sampling technology	True Definition (3M Espe, USA), Cerec Omnicam (Dentsply-Sirona, USA), Lava COS (3M Espe, USA)

Cerec Omnicam consists of two techniques

大，可超250 μm。Kachhara等[15]经分析发现，True Definition（主动波前采样）、iTero（共聚焦显微成像）和Lava Cos（主动波前采样）的误差较小，而误差最大的ZFX Intrascan和3D Progress均采用共聚焦显微成像。Rutkūnas等[16]统计了多项研究，发现大部分主动波前采样仪器的误差为0～100 μm，大部分三角测量技术的误差为50～150 μm，共聚焦显微成像技术的误差为0～100 μm，但也有约28%的误差大于100 μm。

三种技术都各有精度较高的口内扫描仪，但采用共聚焦显微成像技术的仪器间差异较大，采用主动波前采样技术的仪器精度较稳定。三角测量适合于高对比度的目标和清晰的边缘，对缺乏特征的表面，可能难以识别，且其精度会随着光源和探测器之间的距离增大而提高，但该距离受到扫描头尺寸的限制，另外增大的角度使得光线更易受到阻挡，因此仪器使用时需要对此做出取舍和平衡[11]。共聚焦显微成像每次只能获取一个聚焦平面的信息，为了确保精度，扫描速度较慢；主动波前采样可通过图像的对焦和离焦状态来捕获曲面的距离，进行拟合时图像间重叠的特征点更多，可能是其精度更稳定的原因[11, 17]。

2.2　牙列情况和修复类型

如前文所述，口内扫描印模需要识别标志点以重叠多张图像并合成三维模型。当扫描对象表面特征明显时，图像的重叠比较准确，但当对象表面平滑时就容易出现误差。在患者口内，结构明显的牙齿提供了重要的标志点。缺失牙越多，标志点越少，特别牙列缺失时光滑的口腔黏膜难以提供识别标志点，误差会明显增加。同时牙齿缺失越多，所需种植体的数量和间距往往也会增加，同样会降低精度，其影响将在下文叙述。

Nagata等[18]比较患者口内扫描印模制作三种修复体的精度，分别为单颗种植体支持的单冠、两颗种植体支持的双单位联冠以及两颗种植体支持的三单位桥，发现单冠的误差为（40.5 ± 18.9）μm，显著低于三单位义齿（80.3 ± 12.4）μm。Mangano等[12]的体外研究证明，分别在单冠、局部义齿、全口义齿三种情况下，多种口内扫描仪的精度都依次降低，在全口义齿中误差增加得最多（分别为15.2～43.1 μm，23.0～49.8 μm和44.9～92.1 μm）。Imburgia等[13]对植入三颗种植体的牙列缺损和六颗种植体的牙列缺失两种体外模型进行扫描，同样发现后者的真实度和精密度都显著降低。可见缺失牙越多，修复范围越大，口内扫描印模的精度越低。

2.3　种植体间距

因口内扫描印模需要将分次获取的图像拟合重叠，每次拟合不可避免地会产生一定误差，所以种植体间距越大，拟合次数越多，越有可能产生和积累误差。Fukazawa等[19]比较了扫描两种体外模型（35和36为种植体、45和47为种植体）的精度，发现后者的相对误差约为前者的两倍。Miyoshi等[20]和Ming等[21]在各自的体外研究中同样证实相距越远的种植体，误差越大。Kim等[14]对6颗种植体跨牙弓分布的体外模型进行研究，发现距离扫描起点越远的种植体，其误差越大。因此种植体间距越大，总体误差越大；在种植体水平上，距离扫描起点越远的种植体，误差也会增大。

2.4　种植体间角度

Papaspyridakos等[22]共对6篇文献进行荟萃分析，发现当种植体间角度小于20°时，口内扫描印模的误差比传统印模高69.29 μm；当种植体间角度大于或等于20°时，口内扫描印模的误差比传统印模高18.62 μm，但两个差异都没有统计学意义。Abduo等[23]以植入2颗种植体的模型为研究对象，发现15°的角度只导致非夹板式传统印模的误差显著增大，而对夹板式传统印模和口内扫描印模没有影响。Gimenez-Gonzalez等[24]未发现种植体间平行或30°的倾斜对于口内扫描仪的精度有显著性影响。

也有研究得出不同的结果：Ribeiro等[25]在有4颗种植体的模型上比较了平行或15°倾斜的种植体的精度，发现口内扫描印模对倾斜种植体的精度略低，但作者认为该差异很小，倾斜不是决定性因素。当种植体平行时，传统印模从口内取出时受到的阻碍较少；而当种植体倾斜的角度增大，脱模时转移杆的阻力增大，更可能对印模造成永久形变和误差；口内扫描印模则可以避免该问题[23, 26]。这能解释Papaspyridakos等[22]发现种植体倾斜使口内扫描的精度相对于传统印模有所提高和Abduo等[23]的研究中只有非夹板式传统印模受到种植体倾斜的影响。

目前研究未证实种植体间角度对口内扫描印模精度有影响。当种植体间角度较大时，更建议使用口内扫描印模。

2.5　种植体深度

口内扫描印模需要通过识别扫描杆来确定种

植体的位置，理论上种植体的深度越大，扫描杆暴露越少，扫描的精度将会下降[24]。但多个体外研究都发现植入深度对精度无显著性影响[24, 27-29]。这些研究中种植体最深为龈下4 mm，而扫描杆长度为8 mm，说明剩余的暴露长度（4 mm）已足以被准确识别，这可能是得出种植深度对口内扫描印模精度无影响的原因。临床上若植入较深、牙龈较厚时，建议使用更长的扫描杆。

2.6　连接方式

Marzieh等[29]在无牙颌模型上发现内连接和外连接对误差无影响。Chia等[30]在研究中发现，单纯手拧紧会产生-5 μm的偏移，而15 N·cm会产生-11 μm的偏移，提出固定扫描杆的扭矩会导致微小形变，主要导致Z轴上的误差，扫描所得的种植体位置会偏向根方，并且认为该问题在锥形连接中会更明显，因为该连接方式没有明显的平台止点。连接方式对精度的影响尚不明晰，但只需按照说明书固定扫描杆即可，无需额外加力，尤其对于锥形连接。

2.7　辅助标记

对于无牙颌患者，因为口内缺少解剖标志点而难以保证精度。因此有研究者希望通过增加辅助标记，来提高口内扫描的精度。Iturrate等[31-32]研究发现，装在种植体周围的辅助几何装置能明显改善精度，可以将最后一颗种植体的误差从85～189 μm减少至35～83 μm。Mizumoto等[33]探究了玻璃球、压力指示膏、牙线对精度的影响，结果显示牙线显著增加了误差，而其他标记对精度无影响；可能是牙线对扫描杆的牵拉所致。Pan等[34]发现单纯的树脂基托能改善第一象限（扫描起点）的精度，而基托加人工牙能在全牙弓范围改善精度。但该方面缺少临床研究，以上的辅助标记能否简便有效地增加口内扫描印模的精度是值得研究的方向。

2.8　辅助材料

被扫描物体需要有合适的光学特性来反射光线让扫描仪识别，研究显示被扫描物体越透明，口内扫描的精度越低[35]。为了避免唾液、金属冠的反光影响口内扫描仪，有研究者提出使用辅助扫描材料，例如二氧化钛粉末、涂剂等[36-37]。Oh等[36-37]发现粉末和涂剂的使用提高了口内扫描印模的精度并减少了扫描时间。但实际应用中有诸多不便，首先是需要涂布均匀，否则反而可能降低精度[38-39]；空气中扩散的粉末可能会刺激呼吸道，影响患者和医生的健康[40]；材料的使用、维持和清洁并不容易，可能耗费更多的时间和精力[9]。为了避免以上缺点，且随着设备和算法的改进，现在的主流口内扫描仪大多不使用辅助材料，也能达到良好的精度。

2.9　环境

Carneiro等[6]提出使用口内扫描仪的适宜环境条件为温度20 ℃～21 ℃，大气压750～760 mmHg，空气湿度45%。Arakida等[41]发现色温为3 900 K和亮度为500 lux时口内扫描仪的精度最高。临床上应该尽量维持适宜的环境以提高扫描精度。

3　总结和展望

本文聚焦于种植修复中的口内扫描印模技术，介绍了其原理并分析了影响印模精度的相关因素。经过本文的分析，共聚焦显微成像的仪器间差异较大而主动波前采样的仪器较稳定；缺失牙越多、种植体越多、种植体间距越大，精度越低，此时谨慎使用口内扫描印模；当种植体间倾斜明显时，口内扫描印模更能避免误差；未发现种植深度会影响印模精度；固定扫描杆时过大的扭矩会增加误差，仅需按照制造商的建议（一般为手拧紧）固定扫描杆即可；需研发更便捷易用的辅助标记或材料，并在临床进行验证；尽量维持合适的环境条件。在临床上使用口内扫描印模时，要考虑到上述因素并进行相应调节，以确保精度能满足临床需求。

由于体内研究中患者的情况多样化，难以精确地调控所研究的变量，而体外研究可以准确地控制混杂因素，避免研究结果受到干扰，现今相关研究大多为体外的模型实验，体内研究较少，今后需要更多的临床数据来验证这些因素的影响，并发掘新的影响因素，以更好地指导临床实践，扩大口内扫描印模的适应证。

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