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·基础研究·

复制总义齿印模4种扫描策略的精度研究

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【摘要】 **目的** 探讨复制总义齿制作过程中口内扫描仪扫描不同总义齿弹性印模的扫描策略及其对总义齿表面三维尺寸准确性的影响，以期利用数字化技术改进复制总义齿的传统制作方法。**方法** 选取临床患者无牙颌翻制模型8套，常规制作上、下颌胶连总义齿。在石膏模型上模拟患者牙槽骨萎缩情况，利用总义齿作为个别托盘使用聚醚硅橡胶材料制取弹性印模。使用TRIOS 3口内扫描仪分别按照4种扫描策略(A：义齿组织面-人工牙-义齿磨光面；B：人工牙-义齿磨光面-义齿组织面；C：喷粉状态下扫描义齿组织面-人工牙-义齿磨光面；D：喷粉状态下扫描人工牙-扫描义齿磨光面-义齿组织面)对弹性印模进行整体扫描，以台式扫描仪所得3D数据作为参照，使用Geomagic Control X软件比较不同扫描策略所获取的3D印模数据与参照数据的最大偏差、平均偏差以及标准偏差，并将最大偏差与总义齿允许最大误差(0.3 mm)进行比较，结果用PASW Statistis 18统计软件进行分析。**结果** 口内扫描弹性印模数字化3D数据与台式扫描数据相比，上颌最大偏差值为(0.188 ± 0.109)mm、下颌最大偏差值为(0.200 ± 0.099)mm，两者差异无统计学意义(t = 0.139，P = 0.624)，但上、下颌最大偏差值均小于总义齿临床要求的最大误差(0.3 mm)，且差异具有统计学意义(均P<0.001)；上、下颌的平均偏差分别为(0.024 ± 0.212)mm和(0.014 ± 0.014)mm，二者差异具有统计学意义(t = 4.228，P = 0.021)；上、下颌的标准偏差分别为(0.074 ± 0.032)mm和(0.074 ± 0.034)mm，二者差异无统计学意义(t = 0.813，P = 0.371)。上、下颌不同扫描策略的平均偏差和标准偏差在各扫描策略组内和同颌各策略组间差异均无统计学意义；口内扫描仪和台式扫描仪扫描上、下颌3D数据组织面和磨光面偏差比较图显示上颌偏差比较大的地方多集中在上颌结节及腭穹隆区域，下颌偏差较大的地方多集中在磨牙后垫区域。**结论** 上颌和下颌弹性印模经口内扫描仪形成的数字模型的准确度可以满足临床复制总义齿制作的要求，但在临床实际应用中医师应注意检查和调改总义齿上颌结节及腭穹隆处以及下颌磨牙后垫区域的密合程度。

【关键词】 总义齿；　复制义齿；　计算机辅助设计/计算机辅助制造；　数字化；　口内扫描仪；　扫描策略；　上颌结节

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The accuracy of four scanning strategies for duplicate complete denture impressions

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【Abstract】 **Objective** To explore intraoral scanning strategies for elastic impressions during the fabrication process of duplicate complete dentures and to investigate the accuracy of 3D scanning strategies on the surface of complete dentures. The goal is to utilize digital technology to improve the traditional fabrication methods of duplicate complete dentures. **Methods** Eight sets of replicated denture model for edentulous patients were selected. Conventional complete

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dentures were created based on these models. The condition of the patient's alveolar bone atrophy was simulated on these models, and elastic impressions were built using complete dentures as individual trays with polyether silicone rubber materials. TRIOS 3 intraoral scanners were used to scan the elastic impressions according to four scanning strategies (A: tissue surface - artificial teeth - polished surface of denture; B: artificial teeth - polished surface of denture - tissue surface; C: tissue surface - artificial teeth - polished surface of denture in powder spraying state; D: artificial teeth - polished surface - tissue surface in powder spraying state). The 3D data obtained by the desktop scanner were used as the reference. The maximum deviation, average deviation, and standard deviation of the 3D data models obtained by different scanning strategies were compared using the Geomagic Control X software. For the complete denture, the maximum deviation was 0.3 mm. The obtained results were analyzed by PASW Statistics 18 software. **Results** The maximum deviation value of the maxillary scans in the 3D data compared with the desktop scanning data was (0.188 ± 0.109) mm, and that of the mandibular scans was (0.200 ± 0.099) mm. There was no statistically significant difference between them (t = 0.139, P = 0.624). However, the maximum deviation values of both the maxillary and mandibular scans were lower than the required maximum error (0.3 mm) for complete dentures in clinical practice, and the difference was statistically significant (P<0.001). The average deviations of the maxillary and mandibular models were (0.024 ± 0.212) mm and (0.014 ± 0.014) mm, respectively, and the differences were statistically significant (t = 4.228, P = 0.021). The standard deviations of the maxillary and mandibular models were (0.074 ± 0.032) mm and (0.074 ± 0.034) mm, respectively. There was no statistically significant difference between them (t = 0.813, P = 0.371). There were no statistically significant differences in the average deviations and standard deviations of each scanning strategy between the maxillary and mandibular impressions within and between groups. Comparing the deviation between the tissue surface and the polished surface of the 3D data of the upper and lower jaws on the oral scanner and the desktop scanner shows that the areas with larger deviations in the maxillary impressions were mainly concentrated in the maxillary tuberosity and palatal vault regions, and those in the mandibular impressions were mainly concentrated in the molar posterior pad region. **Conclusion** The digital impressions formed by intraoral scanning the maxillary and mandibular elastic impressions can meet the requirements for clinical fabrication of complete dentures. However, in clinical practice, special attention should be paid to checking and adjusting the fit of the maxillary tuberosity and palatal vault and the mandibular molar posterior pad areas of the complete dentures.

【**Key words**】 complete denture; duplicate denture; computer aided design/computer aided manufacturing; digital; intraoral scanner; scan strategy; maxillary tuberosity

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我国已加速进入老龄化时代，2018 年第四次全国口腔健康流行病学调查报告中指出，无牙颌的发病率仅在 65 ~ 74 岁组老年人群中就高达 4.5%，各类无牙颌患者总数超过 2 100 万人[1]。种植义齿虽能较好地恢复和重建无牙颌患者的口腔功能，但受限于患者全身情况、骨质条件和经济等因素，传统总义齿仍是无牙颌患者口腔修复的主流方案。

总义齿修复总疗程长、步骤繁琐、对医师个人经验、技工加工能力以及患者配合与适应的要求非常高。成功的总义齿修复，使用数年后，由于牙槽嵴的进行性萎缩、人工牙磨耗、树脂材料老化等原因，导致总义齿出现咀嚼效率、固位和稳定力下降、垂直距离减低、覆殆覆盖异常、美观不良等问题，需要更换新义齿。而此时老年患者随着年龄的增长，身体各项机能下降，适应能力降低，却面临戴用新义齿的神经肌肉模式整体调整适应过程。由于边缘伸展范围、义齿磨光面形态和牙齿排列位置等较大变化而需要很长的适应期和反复就诊调改，甚至因适应困难而弃戴新义齿。佩戴总义齿的患者年龄通常较大，这些患者通常会伴随着自身体力、行动能力、适应和耐受力以及听力的下降，来就医的过程充满困难，而且跟医生的交流和配合也面临挑战，对传统总义齿过程中制取印模、确定正中关系、边缘整塑等复杂操作感到明显不适并很难良好配合。老年无牙颌患者制作新

义齿将极为困难，甚至可能超过首次制作总义齿。

复制义齿的核心理念是复制已被患者耐受和适应的设计，参照和利用了旧义齿的软硬组织信息，既可以精确复制旧义齿牙弓形态、基托边缘位置、义齿磨光面形态等重要信息，同时改正其存在的问题，不但大大缩短了临床时间、降低了对患者本身配合的要求，也利于提高患者对新制作义齿的适应[2-3]，改进后的义齿咀嚼效率大幅提高[4]。很多学者都关注到了复制总义齿对于老年人的多种便利，并进行了报道[5-7]。

数字化技术的应用，使减少患者就诊次数、提高复制总义齿的准确性成为可能[8]。但对于如何利用口内扫描仪直接获取总义齿数字化模型，以及相关扫描策略与扫描精度国内外仅有少量报道[9]。本研究旨在探讨用口内扫描仪直接扫描不同总义齿弹性印模的扫描策略及其对总义齿表面三维数据准确性的影响，为全流程数字化复制总义齿在老年患者牙列缺失修复中的临床应用提供参考。

1　材料和方法

1.1　主要材料与仪器

无牙颌模型（临床患者模型翻制），常规胶连总义齿（QC-20义齿基托树脂，登士柏公司，美国；凯丰树脂牙，沪鸽公司，中国），聚醚硅橡胶（3M公司，美国），托盘粘接剂（3M公司，美国），口内扫描仪（TRIOS 3，3Shape公司，丹麦），Geomagic Control X软件（2022 1.0版，3D Systems，美国），扫描喷粉（蓝齿，OSTEO BIONICS公司，韩国），台式扫描仪（T8，美迪特公司，中国）。

1.2　总义齿制作

选取临床患者无牙颌模型翻制模型8套（上颌8个、下颌8个），按牙嵴形态、固定垂直距离上殆架，常规制作上、下颌胶连总义齿。

1.3　弹性印模的制取

总义齿制作完成后，将石膏模型组织面均匀磨除1 mm，模拟患者牙槽骨萎缩情况，涂布凡士林作为分离剂。将总义齿组织面及边缘反折处涂布托盘粘接剂，待粘接剂初步干燥后将适量聚醚硅橡胶印膜材料涂布于总义齿组织面并就位于无牙颌模型上，硬固后取下，用尖刀小心修整边缘多余聚醚材料，避免后续扫描过程中撕扯变形，印模表面清洗脱脂，干燥后备用。

1.4　扫描过程

使用TRIOS 3口内扫描仪分别按照以下4种扫描策略进行扫描。

策略A：扫描义齿组织面-扫描人工牙-扫描义齿磨光面。

策略B：扫描人工牙-扫描义齿磨光面-扫描义齿组织面。

策略C：喷粉状态下扫描义齿组织面-扫描人工牙-扫描义齿磨光面。

策略D：喷粉状态下扫描人工牙-扫描义齿磨光面-扫描义齿组织面。

扫描路径示意图见图1。扫描过程中注意随时检查扫描件质量，如出现明显数字印模不对齐、难以拼接的情况，删除数据重新扫描。将合格的数字模型保存为stl格式。

将总义齿弹性印模固定于台式扫描仪配套模型夹具上，确保各部分充分暴露，避免遮挡。使用Medit Scan for Labs软件，选择“模型扫描”模式，调整扫描分辨率为高精度模式，将扫描头垂直对准义齿基托组织面中心进行初始定位，距离约10～15 cm，确保光线均匀覆盖。进行弹性印模各部分扫描，在软件中自动拼接扫描数据，检查各部分是否完整连续，重点观察边缘线是否清晰、无缺失，必要时对局部进行重复扫描，确保数据完整性。所得数据保存为stl格式，作为参照数据。

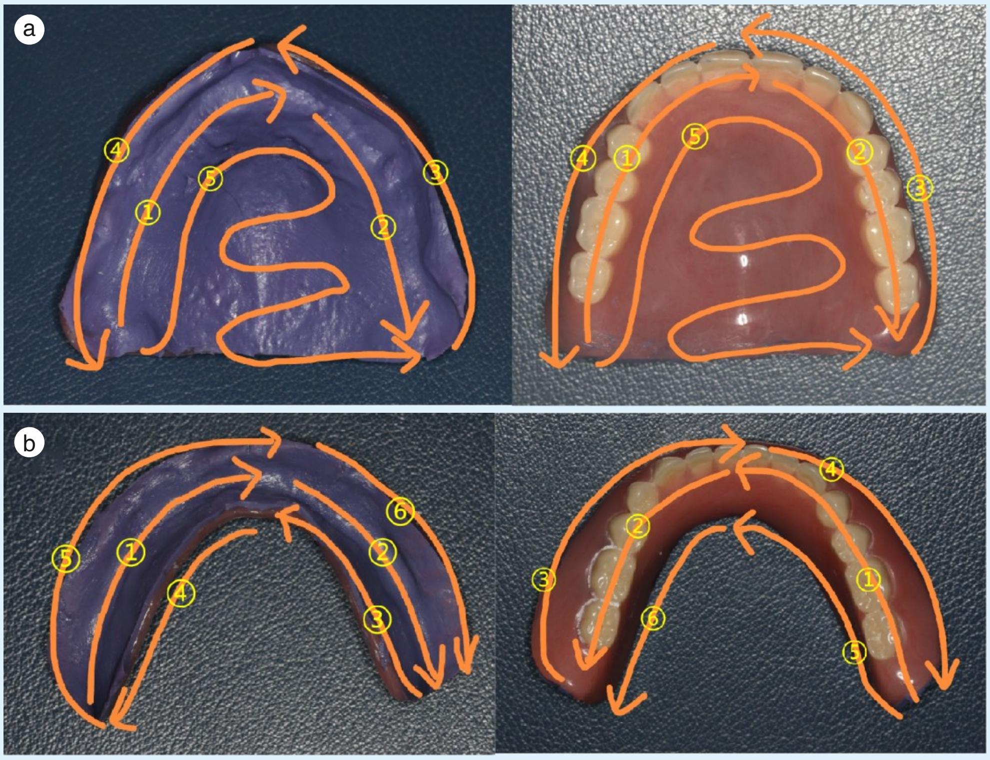
1.5　软件处理

将stl文件导入Geomagic Control X软件，以台式扫描仪数据作为参照，各扫描策略数据为测试数据，通过快速初始对齐预对齐，再通过最佳拟合对齐，比较各种扫描策略与参照数据的最大偏差和平均偏差、标准偏差（以mm为单位）。

1.6　统计学分析

扫描精密度的比较采用各扫描策略组内各模型的平均偏差均值，扫描准确度的比较采用各扫描策略组的标准偏差均值。

使用PASW Statistis 18统计软件对数据进行分析。上、下颌的最大偏差与总义齿允许的最大偏差（0.300 mm）[10]用单样本t检验进行比较。上颌与下颌最大偏差、平均偏差和标准偏差之间的比较用独立样本t检验。各策略组上、下颌间比较使用单因素方差分析，同颌不同扫描策略组间比较采用Tukey法（方差齐）。检验水准取双侧$\alpha = 0.05$。



a: scan path diagram of the tissue surface and occlusion surface of maxillary elastic impression; b: scan path diagram of the tissue surface and occlusion surface of mandibular elastic impression. Scans were conducted in ascending order

Figure 1 Schematic diagram of the scanning path

图1 口内扫描仪扫描路径示意图

2 结 果

2.1 上、下颌最大偏差、平均偏差与标准偏差比较

上、下颌最大偏差值分别为(0.188 ± 0.109)mm和(0.200 ± 0.099)mm，独立样本t检验显示差异无统计学意义(t = 0.139，P = 0.624)，单样本t检验显示上、下颌最大偏差均小于总义齿允许的最大0.300 mm的偏差值，且差异均有统计学意义(P< 0.001)。上、下颌的平均偏差分别为(0.024 ± 0.212)mm和(0.014 ± 0.014)mm，独立样本t检验显示差异具有统计学意义(t = 4.228，P = 0.021)；上下颌的标准偏差分别为(0.074 ± 0.032)mm和(0.074 ± 0.034)mm，差异无统计学意义(t = 0.813，P = 0.371)(表1)。

表1 上、下颌最大偏差、平均偏差与标准偏差比较

Table 1 Comparison of the maximum deviation, average deviation and standard deviation in maxilla and mandible $\bar{x}\pm s$

	Maximum deviation/mm	Average deviation/mm	Standard deviation/mm
Maxilla	0.188 ± 0.109#	0.024 ± 0.212	0.074 ± 0.032
Mandible	0.200 ± 0.099#	0.014 ± 0.014	0.074 ± 0.034
t	0.139	4.228	0.813
P	0.624	0.021	0.371

#The difference from the required maximum error (0.300 mm) was statistically significant after conducting a single-sample t-test (P values of maxillary and mandibular were both <0.001)

2.2 上、下颌不同扫描策略组平均偏差

单因素方差分析显示，同一扫描策略上颌和下颌的平均偏差差异以及同颌不同扫描策略之间平均偏差的差异均无统计学意义(P > 0.05)(表2)。

2.3 上、下颌不同扫描策略组标准偏差

单因素方差分析显示，同一扫描策略上颌和下颌的标准偏差差异以及同颌不同扫描策略之间标准偏差的差异均无统计学意义(P > 0.05)(表3)。

2.4 口内扫描仪和台式扫描仪扫描印模模型间的3D比较

上颌和下颌口内扫描仪和台式扫描仪所得的数字化印模之间的3D比较图可以看出，无论是磨光面还是组织面，上颌偏差比较大的地方多集中在上颌结节区域及腭穹隆处，下颌偏差较大的地方多集中在磨牙后垫区域(图2)。

表2　上、下颌不同扫描策略组平均偏差比较

Table 2　Comparison of the average deviation of different scanning strategies in maxilla and mandible　$\bar{x}\pm s$

Scanning strategy	Average deviation of maxilla/mm	Average deviation of mandible/mm
Strategy A	0.026 ± 0.030*	0.011 ± 0.006*
Strategy B	0.034 ± 0.024*	0.012 ± 0.008*
Strategy C	0.016 ± 0.011*	0.012 ± 0.010*
Strategy D	0.021 ± 0.014*	0.024 ± 0.021*
F	1.097	2.095
P	0.367	0.459

*One-way analysis of variance showed there was no statistically significant difference between the two groups of data in the same row, and there was also no statistically significant difference among the groups in the same column. n = 8. Strategy A: tissue surface - artificial teeth - polished surface of denture; Strategy B: artificial teeth - polished surface of denture - tissue surface; Strategy C: tissue surface - artificial teeth - polished surface of denture in powder spraying state; Strategy D: artificial teeth - polished surface - tissue surface in powder spraying state

表3　上、下颌不同扫描策略组标准偏差比较

Table 3　Comparison of standard deviation of different scanning strategies in maxilla and mandible　$\bar{x}\pm s$

Scanning strategy	Standard deviation of maxilla/mm	Standard deviation of mandible/mm
Strategy A	0.079 ± 0.033*	0.082 ± 0.033*
Strategy B	0.074 ± 0.050*	0.074 ± 0.035*
Strategy C	0.071 ± 0.021*	0.061 ± 0.021*
Strategy D	0.071 ± 0.022*	0.078 ± 0.048*
F	1.087	1.054
P	0.967	0.959

*One-way analysis of variance showed there was no statistically significant difference between the two groups of data in the same row, and there was also no statistically significant difference among the groups in the same column. n = 8. Strategy A: tissue surface - artificial teeth - polished surface of denture; Strategy B: artificial teeth - polished surface of denture - tissue surface; Strategy C: tissue surface - artificial teeth - polished surface of denture in powder spraying state; Strategy D: artificial teeth - polished surface - tissue surface in powder spraying state

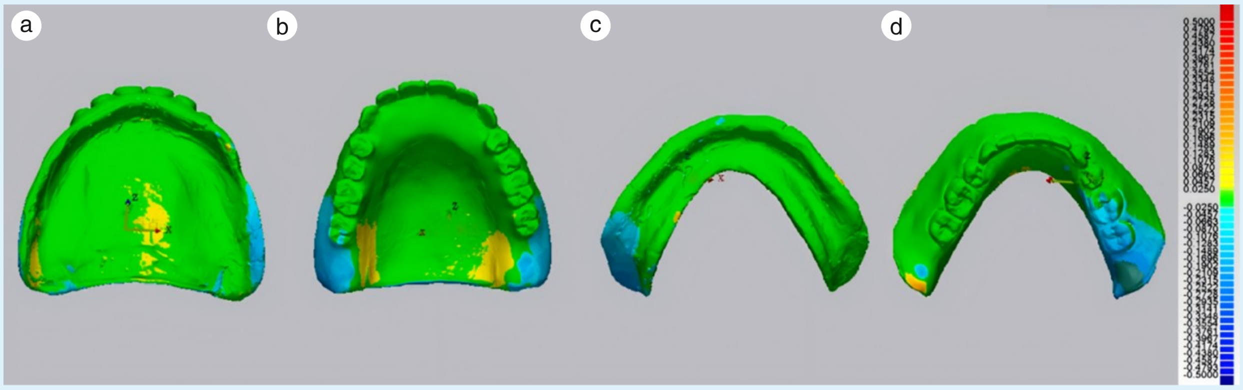
3 讨　论

复制总义齿可保留已被患者耐受和适应的义齿设计，同时改正不合适的设计，使高龄老年患者能不改变旧有神经肌肉模式的前提下快速过渡到新的义齿[11]，在患者主观满意度和客观口腔功能评价中，复制义齿都优于传统义齿[3]，复制义齿在老年患者，尤其是行动不便患者中有不可替代的优势[12]。

传统复制义齿技术由于采用弹性印模材料翻制旧义齿石膏阴模、人工制作蜡型与装盒填胶等容易引入尺寸误差，复制精度不高，影响了其临床应用[13]。数字化技术如数字印模、计算机辅助设计/计算机辅助制造（computer aided design/computer aided manufacturing，CAD/CAM）技术的引入，为简化复制义齿制作、提高复制精度、减少患者就诊次数提供了可能[14]。研究证明数字化技术制作的义齿基托的密合程度、表面磨光度以及人工牙的性能均优于传统义齿[15]，其中CAD/CAM制作的总义齿比3D打印及注塑技术制作的义齿精密程度更高[16]。

目前，国内外多家公司推出了不同的商用全口义齿CAD/CAM系统，各有亮点和不足，其临床适用性仍有待进一步的临床研究和改进[17-19]。随着研究的深入，全数字化流程制造总义齿在数字化印模、虚拟殆架调殆、创建国内数据库、开发适合全口义齿的数字化材料方面均已经取得了不小的进步[20-21]。但对于如何精确制取口腔黏膜的数字化压力印模、边缘修整状态下的三维表面数字模型，仍缺乏有效技术，需要与传统制作方法相结合[22]。这些数字化总义齿制作技术均离不开口内初印模、个别托盘等中间环节，中间步骤多，累积误差较大[23-24]。学者们对于口内扫描仪直接扫描无牙颌所得的数据用于总义齿制作的精确性结论不一，有学者研究认为口内扫描仪直接扫描黏膜，其精度与传统印模没有明显差异[25]，更多学者则认为由于黏膜动度等问题，直接口内扫描无牙颌黏膜，得出的数据无法直接用于总义齿的制作[23]。有学者想出了一些方案，例如用口内扫描黏膜与锥形束CT（cone beam CT，CBCT）数据二次校准匹配，可以提高数据准确度[26]。还有学者分别口内扫描总义齿组织面和磨光面后配准复制旧义齿，达到较好效果[5, 27]，但此方法用时较长、需要台式扫描仪（仓扫）扫描旧义齿，影响原有义齿在患者新旧义齿过渡期间的使用。

近年来越来越多学者认识到，对于总义齿这样的复杂功能性印模来说，对传统弹性印模的直接数字化可能是总义齿数字工作流程最合理的访问点[28-29]。基于现有的技术和研究结果，复制总义齿在解决了总义齿弹性印模的数字化扫描与精度后，可以实现全程数字化制作。台式扫描仪取得的数据准确度高，扫描精度可达5 μm，是精度和正确度最高的口腔三维数据采集技术[30]，常被作为口腔领域石膏模型或印模的三维数字化的参照标



The 3D comparison diagram shows that most areas are green, indicating small deviations (< 0.025 mm). Parts of the maxillary tuberosity area, the palatal vault area, and the mandibular molar posterior pad area are yellow and blue, indicating larger deviations (yellow area, ~ 0.125 mm; blue area, ~ 0.295 mm). a: the areas with relatively large deviations in the tissue surface of the maxillary elastic impression are mainly concentrated in the maxillary tuberosity region and the palatal vault area. b: the areas with relatively large deviations in the polished surface of the maxillary elastic impression are mainly concentrated in the maxillary tuberosity region. c: the areas with relatively large deviations in the tissue surface of the mandibular elastic impression are mainly concentrated in the area of the mandibular molar posterior pad. d: the areas with relatively large deviations in the polished surface of the mandibular elastic impression are mainly concentrated in the area of the mandibular molar posterior pad

Figure 2　Comparison of 3D deviation between different parts of the maxilla and mandible

图 2　口内扫描仪和台式扫描仪上、下颌 3D 数据组织面和磨光面偏差示例

准[31]。但其扫描自由度不及口内扫描仪，对于存在倒凹的旧义齿，难以获得完整的数字模型。口内扫描仪扫描自由度高、临床易获得，整体扫描所需时间较短，且可以椅旁直接扫描，不影响患者临床使用并避免转运过程中印模产生变形。借助口内扫描仪直接扫描旧义齿或者印模是临床上最便捷的方式[32]。对于如何利用口内扫描仪体外获取总义齿数字化模型、数字扫描策略与扫描精度并无统一结论[31，33]。TRIOS 3 扫描仪采用共聚焦激光扫描显微成像技术，准确性、易用性高，对操作人员的要求较低[34]，非常适合用于弹性印模的扫描[35]。本研究用 TRIOS 3 扫描仪体外扫描弹性印模，仓扫结果作为参考，最大程度地减小误差并还原临床实际情况。

数字印模的准确度评价有两个指标分别为精密度和正确度[36]。上、下颌扫描最大偏差均远远小于总义齿最大允许误差 0.300 mm[10]，证明了口内扫描仪直接扫描总义齿弹性印模的精密度可以满足临床应用要求。上、下颌标准偏差和各扫描策略间标准偏差均无统计学差异，说明口腔扫描仪直接扫描弹性印模的正确度可以满足临床对于手持式扫描仪扫描结果的要求。从本研究的结果来看，上颌弹性印模整体扫描平均偏差略大于下颌，差异均有统计学意义，但最大偏差上颌略小于下颌。可见下颌印模口内扫描结果与上颌比较虽整体偏差较小，但容易出现极值，可能是由于上颌印模范围连续但面积大、横向和纵向均跨度较大，所以平均偏差较大，但由于上颌有腭部这样范围大、连续性好的结构可供识别和校准，偏差不易累积[37]。下颌印模虽然跨度较小，但用于扫描识别的范围连续性较差，容易累积偏差，出现极值[38]。这也与本研究大部分 3D 比较图的结果以及其他学者的研究结果一致[39-40]，提示医师用口内扫描弹性印模方式直接制作的复制总义齿在临床应用中，更应注意检查上颌结节及腭穹隆处及下颌磨牙后垫区域的密合性，必要时可调磨或重衬。

本研究中，不同扫描策略或喷粉与否得到的数字化印模偏差均无统计学意义。提示医师无论先扫描义齿哪个部分，只要按照口内扫描的操作要领，扫描路径均匀连续，避免颊腭侧交替扫描造成的齿状扫描及垂直方向上的旋转[41]，并按口内扫描仪要求定期校准，均能保证扫描精度。弹性印模组织面接近哑光，反光较少，总义齿磨光面的反光和透射也十分有限，因此无需喷粉即能达到扫描要求，这也与其他专家的结论相似[42-43]。值得注意的是，本研究所采用的模型均来自牙列缺失多年需重新制作总义齿的老年患者，这类患者牙槽骨较为低平，相应弹性印模牙槽嵴处深度不超过口内扫描仪的限制深度 2.5 cm[44]，在牙槽嵴很高及倒凹极大的患者中，口内扫描仪直接扫描弹

性印模的策略仍需进一步探讨。

复制义齿可以大大减少老年总义齿患者更换义齿的步骤以及不适感，用口内扫描仪直接椅旁扫描总义齿弹性印模简单、快速、方便，可以把整个总义齿修复流程控制在2次以内，且不影响过渡期间旧义齿的使用。对于个别行动受限的高龄患者，甚至可以居家完成，这将为老年人总义齿的更换提供极大便利。未来将配合面部扫描、实时运动轨迹技术、3D打印技术，使总义齿制作路径更加成熟，以期帮助老年总义齿患者从无到有、从旧到新义齿的快速、平稳过渡，并可实现个性化数据的电子存档，不但可以使患者旧义齿损坏或丢失后能够直接调用存档数据快速制造新的义齿，而且居家老年患者甚至可以足不出户就完成新义齿的制作。这项技术的不断研究改进，必将为总义齿数字化流程带来极大便利。

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