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論　文　内　容　の　要　旨

氏　名　（　Yuming　Chen　）	
論文題名	Accuracy and influencing factors of dental models obtained by digital scanning and 3D printing (デジタルスキャニングと3Dプリンティングによって得られた歯科模型の精度と影響因子)

論文内容の要旨

Background

In the dental field, digitalization has emerged as the most significant trend. It refers to using digital technologies and devices to improve and streamline various aspects of dental practice. Dentists use intraoral scanners (IOSs)or desktop scanners to obtain data of patients' teeth structure, design it on software for specific treatment purposes, and then use milling or 3D printing technology to fabricate various dental products such as restorations, orthodontic devices, or implant guides. Such a digital workflow has gained widespread acceptance and is now commonly employed in dental practice.

Dental models are replicas of a patient's teeth and surrounding oral structures that play a crucial role in dental treatment and care. In the digital workflow, the dentist can scan the patient's mouth or plaster dental model to obtain a virtual dental model using an intraoral scanner or desktop scanner and produce a physical dental model based on scanned data using milling or 3D printing technology. It is noted that whether for virtual or 3D-printed dental models, sufficient accuracy is the most basic requirement. Recent studies have found that some factors will considerably affect the accuracy of the digital models created with an IOS, including the environment around the scanner, operators' experience, scanning sequence, et al. Factors that may affect the accuracy of 3D printed casts have also been evaluated with different characteristics of printers, printing materials, printing layer thicknesses et al. However, several factors may affect the dental models' accuracy within the scanning and manufacturing process that has yet to be fully investigated, including liquid, scan span, and internal design.

Digital workflow generates not only enthusiasm but also great uncertainty. It is still very challenging for dental technologists and dentists to differentiate between the various principles and capabilities of digital devices (intra-/extraoral scanners, 3D printers et al.) and to integrate them into the digital workflow for the appropriate clinical cases. Therefore, it is necessary to conduct experiments for the establishment of evidenced-based standards in the field of digital dentistry. Thus, this study aimed to further investigate the accuracy of dental models obtained by digital scanning and 3D printing by assessing specific factors, including liquid, scan spans, and internal design.

Materials and Methods

For experiment 1, a mandibular jaw model was scanned using an industrial computed tomography scanner to obtain a reference model. A scanning platform was designed to simulate three specific tooth surface states (dry, wet, and blow-dry). The test used two kinds of liquids (ultra-pure water and artificial saliva). Two intraoral scanners were used to scan the mandibular jaw model 10 times under each condition. All scanning data were processed and analyzed using dedicated software (Geomagic Control 2015). Trueness and precision comparisons were conducted within the 12 groups of 3D models divided based on different intraoral scanners and liquids used under each condition. The root mean square (RMS) value indicated the difference between the aligned virtual models. The color maps were used to evaluate and observe the deviation distribution patterns. The 3-way ANOVA (condition, intraoral scanner, liquid) followed by the Tukey test was used to assess precision and trueness.

For experiment 2, three plaster models representing different spans (full arch, half arch, and three teeth) were obtained from conventional silicone impressions of a maxillary typodont and used as the scanning objects.

An industrial scanner was used to scan the three plaster models to obtain reference digital models. The plaster models were then scanned using two intraoral scanners (Trios 3 and Primescan) and two desktop scanners (LS3 and D2000) to obtain test digital models. The reference and test models were imported into professional reverse engineering software for processing and analysis. The RMS value indicated differences between the reference and test models. Two-way ANOVA and Bonferroni multiple comparison tests were used for statistical analysis.

For experiment 3, a reference digital model was obtained by scanning a maxillary typodont using an intraoral scanner to create four types of internal designs. Digital models with different internal designs were printed by two 3D printers with different working principles (SLA and DLP). The printed models were scanned to obtain study models. All reference and study models were imported into Geomagic Control software for comparison and analysis of accuracy. The RMS value quantitatively indicated differences between the reference and study models. Kruskal-Wallis' one-way ANOVA and the Mann-Whitney U test were used to test significant differences between the internal design types and between the two 3D printers.

Results

1. The mean RMS values obtained from the wet condition were significantly higher than those of the dry and blow-dry conditions ($p < 0.001$, $F = 64.033$ for trueness and $F = 54.866$ for precision), which indicates less accurate trueness and precision for the wet condition. The deviations caused by liquid were positive and mainly distributed in the pits and fissures of the occlusal surface of posterior teeth, the interproximal area of the teeth, and the margin of the abutments.

2. There was no significant difference in the accuracy of the D2000 at three different scan spans. For the LS3 and the two intraoral scanners, the accuracy of the full arch scan was significantly lower than that of the half arch and three teeth scans.

3. The mean RMS values for trueness and precision were significantly higher for the type 2 design than for the other design types for models printed by both 3D printers. Regardless of the design type, the mean RMS values for trueness were significantly higher for models printed by DLP-based 3D printer than for models printed by SLA-based 3D printer. The mean RMS values for precision were significantly lower for models printed by DLP-based 3D printer than for models printed by SLA-based 3D printer.

Conclusions

1. According to the results of this study, dental models obtained through digital scanning and 3D printing can meet the accuracy requirements for clinical use, but their accuracy was significantly affected by liquids, scan spans and internal design.

2. Liquid on the tooth surface resulted in a positive deviation of more than 120 μm. Blow drying effectively avoided the liquid's effect on the tooth surface on the intraoral scanning results. A full arch span for intraoral scanning will lead to greater errors than a short scan span (three teeth, half arch). Choosing a suitable scan span for different clinical cases is crucial to improve the accuracy of the scanning results. The lack of a complete base significantly decreased the accuracy of the 3D-printed dental models. A proper internal design can help to save printing material while maintaining the accuracy of the 3D-printed dental models.

3. The in vitro experimental method established in this study can help dental clinicians to comprehensively understand and effectively assess the effect of liquid and scan span on the accuracy of intraoral scanning, as well as the effect of internal design on the accuracy of 3D printed dental models, thus providing evidence for clinical practice of the digital dentistry.

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論文審査の結果の要旨及び担当者

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論文審査の結果の要旨

デジタルスキャニングと 3D プリンティングによって得られた歯科模型の精度に影響を及ぼす要因の解明を目的として解析を行った．その結果，被測定面に残存する液体およびスキャンスパンが口腔内スキャナーによる測定精度に，内部構造が 3D プリント歯科模型の精度に影響を及ぼす要因であることが明らかとなった．

本研究は，デジタルデンティストリーにおける精度の確立において重要な知見を提供するものと考えられる．よって、博士（歯学）の学位論文として価値のあるものと認める．