Journal of Dental Sciences 17 (2022) 545—550

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.e-jds.com

Journal of Dental Sciences

Original Article

Analysis of the relationship between the surface topography of prepared tooth surfaces and data quality of digital impressions from an intraoral scanner

Neset Volkan Asar [a], Sarah Yun [b], Shelby Schwartz [b], Ilser Turkyilmaz [c*]

[a] *Department of Prosthodontics, School of Dentistry, Gazi University, Ankara, Turkey*
[b] *New York University College of Dentistry, New York, NY, USA*
[c] *New York University College of Dentistry, Department of Prosthodontics, New York, NY, USA*

Received 13 July 2021; Final revision received 16 July 2021
Available online 31 July 2021

KEYWORDS
CAD/CAM;
Digital dentistry;
Digital impression;
Intraoral scanner;
STL;
Surface topography

Abstract *Background/purpose:* With the rise of digitalization in dentistry, intraoral scanners and digital impressions have recently been adopted by many clinicians. The aim of this study was to investigate surface topography of prepared teeth and the accuracy of digital impressions.
Materials and methods: Twenty mandibular typodonts, containing left first premolar and left first molar abutment teeth manufactured by using CAD/CAM, were used in this study. An intraoral scanner was used to scan each typodont, and each STL file generated was exported in high resolution (Group H), moderate resolution (Group M), and low resolution (Group L). All 60 files were inspected in a 3-D mesh processing software. For each file, the number of triangulation points in the meshwork were obtained for both abutment teeth.
Results: The measurements obtained from the 3-D mesh processing software revealed that the mean number of triangulation points on the 3-D surface of the abutment teeth (20 premolars + 20 M) were 790,625 ± 98,890 dots in Group H, 592,283 ± 74,881 dots in Group M, and 198,067 ± 19,328 dots in Group L. Significant differences were found between Group H and M ($p < 0.05$), Group H and L ($p < 0.001$), and Group M and L ($p < 0.01$).
Conclusion: The outcomes of this study reveal that there are strong correlations between the data quality of digital impressions and surface topography of prepared teeth. Therefore, the utilization of STL files in high resolution format is the recommended choice for clinicians engaging in a digital workflow process.

* Corresponding author. New York University College of Dentistry, Department of Prosthodontics, 380 Second Avenue, Suite 302, New York, NY, 10010, USA.
E-mail address: ilserturkyilmaz@yahoo.com (I. Turkyilmaz).

https://doi.org/10.1016/j.jds.2021.07.013

Introduction

Although traditional dental impression materials have evolved into the highly accurate and dimensionally stable elastomeric materials used in prosthodontics today, the analog workflow remains cumbersome and inefficient.[1–3] With multiple steps involved in traditional impressions (from appropriate material and tray selection, proper impression technique and knowledge, disinfection, to pouring and shipping of models), this lengthy and involved process can lead to a myriad number of processing and human errors to accumulate, ultimately affecting treatment outcomes and the accuracy of final impressions.[3,4]

With the rise of digitalization in dentistry in recent years, intraoral scanners (IOS) and intraoral digital impressions (IDI) have been adopted by many clinicians[5–7] as an accurate and preferable alternative to conventional impressions, as it streamlines the entire workflow process by eliminating the handling of various dental materials. The accuracy of an IDI is defined by the extent to which a representation is both true and precise.[8–10] Trueness refers to how close the dimensions of the digital image are to the object being scanned, while precision refers to the reproducibility of the same dimensions in subsequent scans.[8–10] It is important to note that the accuracy of an impression can be affected during the data acquisition and digitization steps by the conversion of IDI to various types of file formats: the standard tessellation language (STL), object (OBJ) and polygon (PLY) file formats.[8] Therefore, clinicians should be well informed on the distinct advantages and disadvantages of each file format.

Due to the universal application and utilization of STL files by practically all computer-aided design/computer-aided manufacturing (CAD/CAM) and 3-D printing software systems, the STL file is the file format predominately used by clinicians.[11–13] As the name entails, this file format generates a representation of the surface geometry by forming an entire network of tessellating, or linking, variously sized triangles. Although its simplistic design allows for files with smaller storage units and time-efficient exporting, the STL file format only captures the surface geometry of the object without any detailed textures or colors, ultimately affecting the trueness of the IDI and the quality of the final restoration.[8] These shortcomings have been overcome with the introduction of OBJ and PLY file formats. PLY and OBJ formats use polygonal geometry (points, lines, and faces) and free-form geometry (curves and surfaces) that allow them to record even the most minute details of the surface of an object, including color, texture coordinates, and transparency.[8] Despite these advantages, these file formats are significantly larger than STL files and have yet to be incorporated in many CAD/CAM software systems.

With the already simplified design contained in STL files, clinicians should be cognizant of the detrimental effects compressing files can have on the overall accuracy and quality of a digital impression. Compressing files simplifies the triangular meshwork by reducing the number of triangular units, and thus, the number of triangular vertices fabricating the surface topography. Each vertex of a triangle represents a point of data encoding the details of the surface. Therefore, fewer triangular units result in a further generalized and vague representation of the surface.[14–16] A few 3-D inspection and mesh-processing software programs,[17–20] which offer tools and features for analyzing and optimizing digitized data before manufacturing, can be used to investigate the surface topography of digitized scans by displaying and measuring these triangular units and triangulation points.

Despite the importance of surface topography of a digital impression, there are only a few studies investigating the correlation between surface topography of teeth and accuracy of digital scans.[14,21] The purpose of this in vitro study was to analyze the relationship between the surface topography of prepared tooth surfaces and data quality of digital impressions from an intraoral scanner.

Materials and methods

Twenty mandibular typodonts with missing left second premolars were used in this study. The left first premolar and left first molar acrylic abutment teeth were fabricated by using CAD/CAM technology and placed into the typodont. These abutment teeth were manufactured with the exact same features in terms of margin design, taper, and reduction. An intraoral scanner (Cerec Omnicam, Dentsply Sirona, Charlotte, NC, USA) was used to obtain digital impressions of each typodont (Fig. 1). Then, STL files of each digital impression were exported from the software (Cerec software 5.1.3, Dentsply Sirona, Charlotte, NC, USA) by

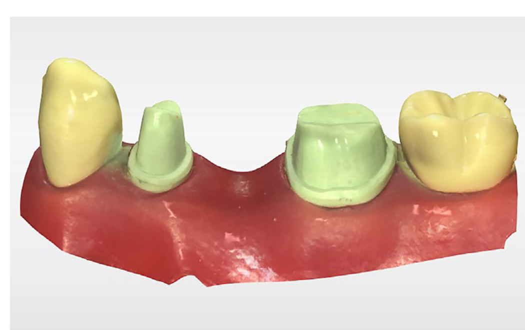

Figure 1 Digital impression of the prepared left mandibular first premolar and first molar abutment teeth.

using three different resolutions (Fig. 2): high resolution (Group H), moderate resolution (Group M), and low resolution (Group L). A total of 60 STL files were created: 20 high resolution STL files (Group H), 20 moderate resolution STL files (Group M), and 20 low resolution files (Group L).

Each STL file was then imported into an open-source 3D inspection and mesh-processing software (Meshlab, ISTI-CNR, Rome, Italy) to investigate the surface topography of the impressions (Figs. 3 and 4). This software program allows meticulous inspection of the surface triangulations of a meshwork so that clinicians can identify and address areas that require editing, healing, and retexturing for optimization.[22,23]

The surface topography of abutment teeth was first assessed by comparing and superimposing STL files of each digital impression in their differing resolutions (Fig. 5). Through superimposition of files, the clinician could visually see the discrepancy in surface topography indicated by the color differences throughout the superimposed image.

In addition, using the mesh view of the STL files in the software program allowed the clinician to inspect the density of triangular units and triangulation points throughout the digital impression. This surface triangulation method is often used to assess the surface topography on a microscale. A triangle is constructed on the surface geometry by linking three closest points of data on the scanned 3-D image. Increased number of smaller triangles and triangulation points in a given mesh indicate that there are more data points and the fine details of the surface are being encoded on the topography. Larger triangles and fewer triangulation points indicate less recorded data points and an inexact, approximate representation of the tooth surface.

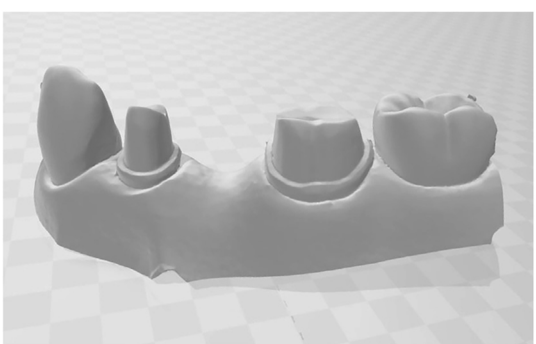

Figure 2 STL file of the digital impression of the prepared left mandibular first premolar and first molar abutment teeth.

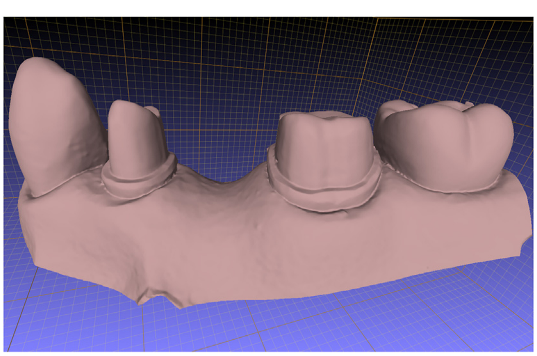

Figure 3 View of the high resolution STL file of the digital impression of the prepared left mandibular first premolar and first molar abutment teeth by using a 3D mesh processing software program.

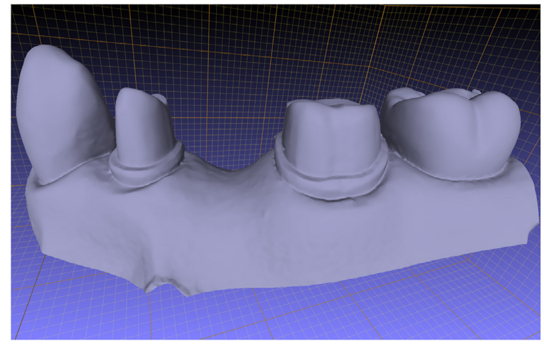

Figure 4 View of the low resolution STL file of the digital impression of the prepared left mandibular first premolar and first molar abutment teeth.

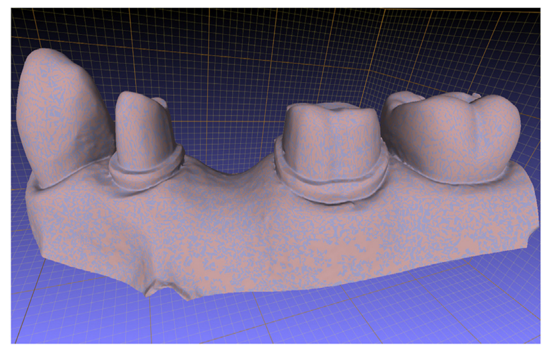

Figure 5 View of superimposed (high versus low resolution) STL files showing discrepancy in surface topography.

The surface topography of each prepared tooth was measured by counting the number of triangulation points on the 3-D surface of every abutment premolar and molar of each STL file (Figs. 6 and 7). For each separate STL file, the number of triangulation points of the premolar and molar were combined to give a total number of triangulation points. In total, 60 values were obtained (20 for each resolution category). The mean values of the triangulation points for each resolution (high, medium, and low) were computed to give a total of three mean values for comparing the data quality of each resolution type.

With the gathered data, statistical analysis was performed using a software program (SPSS for Windows, IBM Corp., Somers, NY, USA). To evaluate and compare the mesh quality of the three different STL file resolutions, the mean values of the number of triangulation points of each group were compared using a paired t-test. $P < 0.05$ was considered to be statistically significant. Pearson's correlation coefficient was used to analyze the correlation between the quality of surface topography and STL file resolutions.

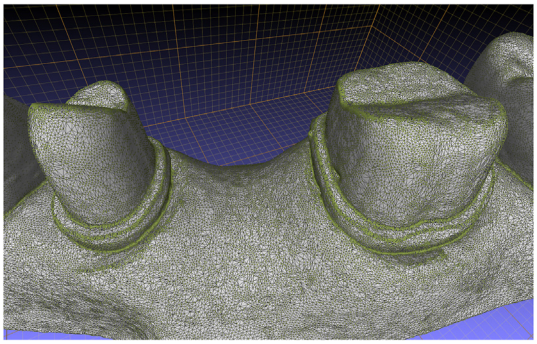

Figure 6 Triangulation points on 3D surface image of the high resolution STL file of the prepared left mandibular first premolar and first molar abutment teeth.

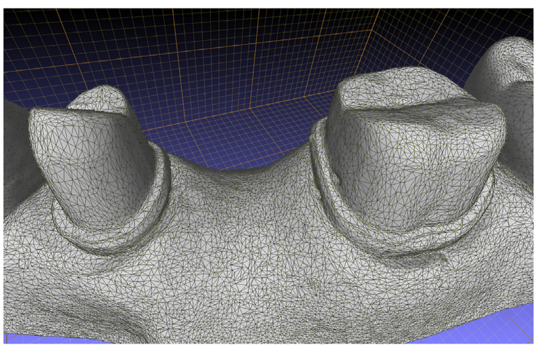

Figure 7 Triangulation points on 3D surface image of the low resolution STL file of the prepared left mandibular first premolar and first molar abutment teeth.

Additionally, the storage size of STL files were obtained for each STL file and the mean value of file size for each resolution category was computed. The paired t-test was performed to compare the difference in storage size mean values of each resolution category. And Pearson's correlation coefficient was used to analyze the correlation between the storage file size and STL file resolutions.

Results

A total of 60 STL files were analyzed in this study: 20 high resolution STL files (Group H), 20 moderate resolution STL files (Group M), and 20 low resolution files (Group L).

The mean ($\pm$SD = standard deviation) number of triangulation points on the prepared teeth surfaces (20 premolars + 20 M) were 790,625 $\pm$ 98,890 dots in Group H, 592,283 $\pm$ 74,881 dots in Group M, and 198,067 $\pm$ 19,328 dots in Group L. Statistically significant differences were found between Group H and M ($p < 0.05$), Group H and L ($p < 0.001$), and Group M and L ($p < 0.01$). Statistically significant positive correlations were also noted between Group H and M ($r = 0.67$), Group H and L ($r = 0.9$), and Group M and L ($r = 0.81$).

In addition, the mean ($\pm$SD = standard deviation) size of STL files were 11.5 $\pm$ 1.3 MB (megabytes) in Group H, 8.4 $\pm$ 1 MB in Group M, and 2.85 $\pm$ 0.4 MB in Group L. Statistically significant differences were found between Group H and M ($p < 0.05$), Group H and L ($p < 0.01$), and Group M and L ($p < 0.01$). Statistically significant positive correlations were also observed between Group H and M ($r = 0.69$), Group H and L ($r = 0.89$), and Group M and L ($r = 0.78$).

Discussion

Intraoral scanners are capable of accurately replicating patients' dental arches by using light or laser technology to generate a point cloud, or a set of data points in space.[24,25] Each point, encoding a particular characteristic of the scanned object, is located at a specific Cartesian coordinate (X, Y, Z) in a given plane. When the point cloud is converted into a network of triangles through the linking of data points, a 3-dimensional model is created.

Up until now, there have been very few published studies investigating the surface topography and accuracy of digital impressions.[16–18] There are many factors that can affect the accuracy of digital impressions, including various scanning techniques, environmental light conditions, the use of different IOS systems, and file formats, but few studies have investigated the effects of these different factors on a microscale. Through this in vitro study, the meshwork of triangles was closely inspected to determine the accuracy of digital impressions of 20 identical typodont models of various STL file resolutions.

The present study revealed that high resolution STL files have a significantly higher number of triangulation points than low resolution STL files. The high resolution STL file group had a mean number of 790,625 $\pm$ 98,890 triangulation points, whereas the low resolution STL file group had a mean number 198,067 $\pm$ 19,328 triangulation points. The gathered data revealed that there was a statistically significant positive correlation between the number of triangulation points and higher resolutions. This signifies that higher resolution files are closer in trueness to the actual object being scanned because they display more data points, or details. Similarly, significant positive correlations were noted between the resolution of STL files and file size.

Although previously published studies have also scrutinized surface topography to determine the quality of digital impressions, a direct comparison cannot be made with the present study due to the utilization of different software systems, scanners, measurement parameters and techniques. A study by Lee et al.,[14] aimed to evaluate the surface topography and the precision measurements of various intraoral and extraoral scanners by examining digital impressions of a maxillary arch with four implant analogs. The maxillary arch was scanned fifteen times using three different intraoral and two different extraoral scanners. A 3D inspection and mesh-processing software was then used to examine the surface topography and obtain same quadrant and cross-arch precision measurements. These precision measurements were determined by the number of triangulation points enclosed within a sphere of 0.5 mm radius on various tooth surfaces. In the present study, the number of triangulation points were obtained for entire tooth surfaces of prepared premolars and molars, which yielded greater numbers of triangulation points. It is evident that the number of triangulation points differs significantly based on various factors, including the surface area being considered, the resolution of digital files, and the settings of the 3D inspection and mesh-processing software (usage of smaller versus larger triangles). Therefore, in order to objectively compare the results of different studies and understand the relationship between surface topography and the number of triangulation points, all of these factors need to be considered, not simply the numbers of triangulation points.

In the present study, the effects of saving digital scans in various STL files sizes (full, moderate, and small) were investigated due to the impact sizing has on the accuracy of the digital impressions. Saving files in its full size retains the IOS's original digital scan, while compressing files to moderate and small sizes forces the software to decrease the number of data points and triangulations. Although, file compression allows for utilization of less storage space and quicker exporting times, fewer data points and less details of the scanned object yield less accurate impressions. This, in turn, leads to the fabrication of inaccurate final restorations.

In order to fully understand the impact of surface topography on final restorations, further research should be done by fabricating crowns or fixed dental prosthesis and obtaining internal fit measurements. One may claim that 3D software programs provide cement space in restoration designs, which allow leeway for inaccuracies in digital impressions; however, one should realize that 3D design software programs only allow cement space on the occlusal and axial walls, not on the finish line or margins. Therefore, any decrease in the accuracy of digital impressions will compromise the marginal fit of the final restoration, a major source of failed fixed restorations.

The results of this study demonstrated that data resolutions significantly influence the data quality of STL files, with the highest mean mesh quality value found in high resolution formats and the lowest mean mesh quality value found in low resolution formats. Therefore, clinicians should not compress files and opt to select high resolution formats to provide more accurate impressions of prepared teeth and, ultimately, improved treatment outcomes for patients.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

References

1. Wagner SA, Kreyer R. Digitally fabricated removable complete denture clinical workflows using additive manufacturing techniques. *J Prosthodont* 2021;30:133—8.
2. Joda T, Zarone F, Ferrari M. The complete digital workflow in fixed prosthodontics: a systematic review. *BMC Oral Health* 2017;17:124.
3. Ting-Shu S, Jian S. Intraoral digital impression technique: a review. *J Prosthodont* 2015;24:313—21.
4. Sivaramakrishnan G, Alsobaiei M, Sridharan K. Patient preference and operating time for digital versus conventional impressions: a network meta-analysis. *Aust Dent J* 2020;65: 58—69.
5. Zhivago P, Turkyilmaz I. A comprehensive digital approach to enhance smiles using an intraoral optical scanner and advanced 3-D sculpting software. *J Dent Sci* 2021;16:784—5.
6. Ahlholm P, Sipila K, Vallittu P, Jakonen M, Kotiranta UM. Digital versus conventional impressions in fixed prosthodontics: a review. *J Prosthodont* 2018;27:35—41.
7. Ballo AM, Nguyen CT, Lee VSK. Digital workflow of auricular rehabilitation: a technical report using an intraoral scanner. *J Prosthodont* 2019;28:596—600.
8. Turkyilmaz I, Lakhia S, Tarrida LG, Varvara G. The battle of file formats from intraoral optical scanners. *Int J Prosthodont (IJP)* 2020;33:369—71.
9. Nulty AB. A comparison of full arch trueness and precision of nine intra-oral digital scanners and four lab digital scanners. *Dent J* 2021;9:75.
10. Kim RJY, Benic GI, Park JM. Trueness of ten intraoral scanners in determining the positions of simulated implant scan bodies. *Sci Rep* 2021;11:2606.
11. Hayama H, Fueki K, Wadachi J, Wakabayashi N. Trueness and precision of digital impressions obtained using an intraoral scanner with different head size in the partially edentulous mandible. *J Prosthodont Res* 2018;62:347—52.
12. Turkyilmaz I, Wilkins GN. 3D printing in dentistry - exploring the new horizons. *J Dent Sci* 2021;16:1037—8.
13. Ammoun R, Bencharit S. Creating a digital duplicate denture file using a desktop scanner and an open-source software program: a dental technique. *J Prosthet Dent* 2021;125:402—6.
14. Lee SJ, Kim SW, Lee JJ, Cheong CW. Comparison of intraoral and extraoral digital scanners: evaluation of surface topography and precision. *Dent J* 2020;8:52.
15. Ivanova V, Chenchev I, Zlatev S, Iordanov G, Mijiritsky E. Comparative study between a novel in vivo method and CBCT for assessment of ridge alterations after socket preservation-pilot study. *Int J Environ Res Publ Health* 2019;16:127.
16. Revilla-Leon M, Subramanian SG, Ozcan M, Krishnamurthy VR. Clinical study of the influence of ambient lighting conditions on the mesh quality of an intraoral scanner. *J Prosthodont* 2020; 29:651—5.
17. Revilla-Leon M, Jiang P, Sadeghpour M, et al. Intraoral digital scans: Part 2-influence of ambient scanning light conditions on the mesh quality of different intraoral scanners. *J Prosthet Dent* 2020;124:575—80.
18. Revilla-Leon M, Jiang P, Sadeghpour M, et al. Intraoral digital scans-Part 1: influence of ambient scanning light conditions on the accuracy (trueness and precision) of different intraoral scanners. *J Prosthet Dent* 2020;124:372—8.
19. Favero R, Volpato A, Francesco M, Fiore AD, Guazzo R, Favero L. Accuracy of 3D digital modeling of dental arches. *Dental Press J Orthod* 2019;24:38e1—7.
20. Liczmanski K, Stamm T, Sauerland C, Blanck-Lubarsch M. Accuracy of intraoral scans in the mixed dentition: a prospective non-randomized comparative clinical trial. *Head Face Med* 2020;16:11.
21. Bas M, Waltenberger L, Kurzmann C, Heimel P, Rebay-Salisbury K, Kanz F. Quantification of dental macrowear using 3D occlusal surface topographic measurements in deciduous

and permanent molars of children. *Am J Phys Anthropol* 2021;175:701—11.
22. Keeling A, Wu J, Ferrari M. Confounding factors affecting the marginal quality of an intra-oral scan. *J Dent* 2017;59:33—40.
23. Fu X, Peng C, Li Z, Liu S, Tan M, Song J. The application of multi-baseline digital close-range photogrammetry in three-dimensional imaging and measurement of dental casts. *PloS One* 2017;12:e0178858.
24. Tomita Y, Uechi J, Konno M, Sasamoto S, Iijima M, Mizoguchi I. Accuracy of digital models generated by conventional impression/plaster-model methods and intraoral scanning. *Dent Mater J* 2018;37:628—33.
25. Pesce P, Pera F, Setti P, Menini M. Precision and accuracy of a digital impression scanner in full-arch implant rehabilitation. *Int J Prosthodont (IJP)* 2018;31:171—5.