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The Accuracy and Trueness of CAD of 3-Unit Fixed Dental Prosthesis by 3 CAD Systems

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ABSTRACT

Background: Computer-aided design (CAD) software programs offer the option to export 3D scans and designs across different CADCAM systems, commonly referred to as open CADCAM technology. However, there is insufficient evidence of whether this exporting procedure has an impact on the accuracy of digital designs. Aim: This study aimed to investigate the accuracy of 3 Intra oral scanners and the accuracy of 3 computer-aided design (CAD) softwares for a three-unit fixed dental prosthesis. Materials and Methods:Three CAD softwares (inLab 17™ , CeraMill Mind™ , Dental System 2017™) were used to generate designs of a three-unit fixed partial denture. The designs generated by each CAD software were exported as stl files to the other two CAD softwares. The exported designs were superimposed on the proprietary designs to evaluate the trueness of the exported designs. Results: The 3D analysis of the exported designs, revealed best trueness with Cerec inLab, followed by Dental System and then Ceramill Mind. The 2D analysis of the exported designs, revealed best trueness values with Dental System, Cerec inLab, then Ceramill Mind. There was however no statistically significant differences between the trueness of exported designs of the three CAD softwares. Conclusions: Exporting Computer aided designs of 3 unit FPD as stl files, designed using Cerec inLab, Dental System and Ceramill Mind did not effect its accuracy. There was no statistical significant difference between the host designs and the exported designs on the three investigated CAD softwares.

Clinical Significance: Exporting Computer aided designs of 3 unit fixed dental prosthesis as stl files is a reliable way of data transfer. The deviations due to exporting recorded are minute and statistically insignificant in the in vitro and virtual level of evaluating the accuracy of short span fixed dental prosthesis.

1. INTRODUCTION

Digital workflows for fabrication of fixed dental prostheses offer the advantage of speed and comfort [1] while providing predictably accurate restorations through Computer aided milling(CAM) [2]. Between the optical impressions and milling of restorations lies Computer aided designing (CAD), that today allows the virtual designing of fixed and removable prosthesis, implant restorations, wax-ups, as well as esthetic smile designing.

Based on their digital data sharing capacity; CADCAM systems can be classified as open and closed. In a closed system, a manufacturer tightly restricts the CAD and CAM components of the restorative process. In a closed system, an optical impression made with the system's scanner or designed on proprietary CAD software can only be exported to the CAM component of that same manufacturer's system. [3]

An open CAD software would freely allow the export and import of digital scans and designs from scanners and to milling centers or 3D printers that are of other manufacturers. The ability to freely exchange digital scans or designs between systems which is typically referred to as "open sourcing", provides dentists with the feasibility and flexibility of using scanners, CAD softwares and milling machines interchangeably and freely, without being obliged to use a single unique manufacturer's system.[4]

Considering the multiple intraoral and desktop scanners available today, fully integrated CADCAM systems, and milling centers, many dentists and digital laboratories may acquire a scanner and a milling machine that are not from the same manufacturer. The digital workflow in such cases will necessitate exporting scans of preparations or/and designs of restorations from CAD softwares to distant milling machines. Today dentists and dental laboratories can fabricate prostheses using various types of open CAD programs, that allow the export of 3D designs in the form of STL formats.

An STL format [5] is a digital file format (.stl) used to represent 3D model data. The stl file format has become the de facto standard representation [6] in addition to being a predominant file format representation when importing or exporting files in CAD systems. In addition to stl formats, obj[7] and ply[8] formats are available for exporting digital scans, however, almost all dental computer aided designs are exported to computer aided milling (CAM) phase as STL formats.

The accuracy of any digital workflow is dependent on the accuracy of each step, from the scanning , designing to the milling [9]. Although the accuracy of scanners, scanning techniques and conditions and accuracy of milling has been extensively studied, the accuracy of the CAD phase has not been sufficiently investigated.

The parameters set on the CAD softwares have shown to affect the accuracy of the milled prosthesis. [10] Shim et al [11] reported the effect of CAD software version and the parameter settings selected on the fit of the final prosthesis. Lee et al [12] investigated the validation of different CAD softwares and confirmed that errors might occur when using a CAD program to fabricate a three-unit FPD.

Investigating the possibility of CAD exporting errors that might effect the intended design of the prostheses is mandatory.[13] So far, the possibility of occurrence of errors in the CAD process while exporting designs in STL format has not been investigated. Therefore, the purpose of this in vitro study was to evaluate the effect of exporting STL files of 3-unit FPD digital designs between 3 CAD softwares on the trueness of the digital designs. The null hypothesis was that exporting Computer-aided designs of 3-unit fixed dental prosthesis as STL files would not effect their accuracy.

2. MATERIAL AND METHODS

In this study, the accuracy of CAD 3-unit FDP generated by three CAD softwares (Cerec inLab, Dental System and Ceramill Mind and exported across other CAD softwares was investigated, by comparing datasets obtained by each host CAD software to the exported design datasets on the other two CAD softwares.

A typodont (Sirona Dental System GmbH, Bensheim, Germany) with a missing upper right second premolar and prepared abutments; upper right first premolar and upper right first molar (for a 3 unit fixed dental prosthesis restoration) was used as the basic model. According to manufacturer's guide, the typodont had prepared teeth with the recommended criteria for all ceramic tooth preparations; occlusal reduction of 1.5 mm, an axial reduction of 1mm, a circular supragingival deep chamfer finish line that is 0.5mm above the cervical line and an axial wall reduction of 6°convergence angle.

The typodont was directly scanned using the 3 intraoral scanners: Cerec Omnicam ,Carestream CS3600 and 3Shape Trios 3. Scanning of the opposing cast and a buccal bite registration scan was performed to facilitate the creation of a well aligned CAD proposal.

The specifications of the CAD softwares used are listed in Table (1). The First proposal design from the generic library of each CAD software was chosen. Margin detection was automatically generated, and restoration parameters were set at a cement gap of 40 microns, a minimum occlusal thickness 1000 micron, and a minimum axial thickness of 800 microns.

Table 1:

Specifications of CAD softwares used in this study:

CAD Software	System
Ceramill Mind (version 3.9)	Completely open – proprietary files (CSZ) but also open formats (PLY,STL) are immediately available
Dental System (version 2017)	Closed – only proprietary files (.DCM) are available, but with the possibility to obtain open formats (STL) via Trios Inbox.
Cerec inLab (version SW 17.0).	Closed – proprietary files (CS3,SDT,CDT,IDT) are available, but with the possibility to obtain open formats (STL) with Cerec Connect®

According to the type of scanner used and its proprietary or host CAD software used for the designing the FDP, the datasets were classified into three main groups: Group O; Design made using Cerec inLab, Group C; design made using Ceramill Mind and Group T; design made using Dental System. One random scan was selected from each main group to produce ten full anatomical designs for a 3-unit FDP on each of the three host CAD softwares. The design datasets were named: OD: design done on Cerec inLab, TD: design done on Dental Designer and CD: design done on Ceramill Mind. Each design was exported to the other two systems, reopened and saved again as new datasets. The generated datasets were named accordingly: (Table 2)

Table 2:

Study design for the accuracy of the exported design

Host Design	Exported Design
Cerec inLab Design (OD)	O/T (Cerec inLab design exported to Dental System)
	O/C (Cerec inLab design exported to Ceramill Mind)
Dental System Design (TD)	T/O (Dental Designer design exported to Cerec inLab)
	T/C (Dental System design exported to Ceramill Mind)
Ceramill Mind Design (CD)	C/O (Ceramill Mind design exported to Cerec inLab)
	C/T (Ceramill Mind design exported to Dental System)

The exported, newly saved design datasets (Exported design) on each of the two systems were superimposed on the original design (Host design) to evaluate the deviations caused by exporting.

For Obtaining STL Files from Different Systems:

Cerec Omnicam: Since the Cerec Omnicam used in this study was a closed system, exporting digital impression data as proprietary files (.CS3,.SDT,.CDT,.IDT) that work only on Sirona's supporting CAD software and CAM devices. However, the system has been partially opened, and with Cerec Connect, there is the possibility to transform the proprietary files into STL files, usable by any CAD system. The software Cerec Connect 4.4.4 was used, and all proprietary files were converted into.STL using the Inlab software.

CS 3600 is an open scanner because its produces proprietary files (.CSZ) but also open files (PLY, .STL) that can be opened from any computer assisted design (CAD) software. Trios 3 is a closed system that produces proprietary files (.DCM) which can be opened only by the 3-Shape (CAD) software (3-Shape Dental System). To obtain .STL files, the .DCM files were sent via the proprietary cloud-based platform (Trios Inbox) that was later opened by CAD software Dental System 2017 and converted into .STL files.

Reference dataset together with all STL datasets obtained from the three groups were imported into powerful reverse-engineering software; Geomagic Design X software (Geomagic, Morrisville, NC, USA). To ensure a precise analysis, the datasets were reduced to the field of interest. Therefore, artefacts and irrelevant areas below the finish lines were eliminated to ensure precise superimposition and equal boundaries of all datasets. This was achieved by establishing a set plane based on the REF model, followed by rough alignment of all the other models on top of the REF model and finally trimming all models at exact the same location to avoid any operator induced differences (fig. 3). For comparisons, all datasets were separately aligned with the REF dataset by a bestfit algorithm. This function helps analyzing the agreement between two surface datasets by superimposition, and hence calculates deviations that are needed for further analysis of the 3D divergences, to determine the trueness parameter.

Deviation analysis

Analysis of 3D Divergences to Determine the Parameter Trueness and Precision:

By use of the inspection software; Geomagic Control X((Geomagic, Morrisville, NC, USA) the three-dimensional Euclidean distances (ED, which is the straight line distance between two points in Euclidean space), for each single measurement point were calculated, which could take positive or negative values in relation to the REF dataset. Divergences between test (exported stl) and the reference dataset (proprietary design) were given as the following parameters: positive deviation, negative deviation and absolute deviation. The absolute values of the ED values were calculated by summing up the magnitude of positive and negative deviations and dividing the result by the number of measured points.

To ensure a precise analysis, measurement surface points were also spread over the designs in four different aspects:

- Compare 1: measurement surface points along entire Mesio-Distal cross section of the designed bridge restoration (Figure 1).

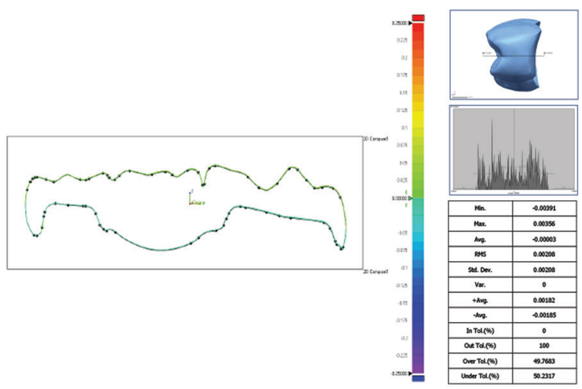

Figure (1) — Compare 1 of remote design (T/O) to host design (TD)

- Compare 2: measurement surface points along Bucco-lingual cross section of molar retainer (fig. 2).

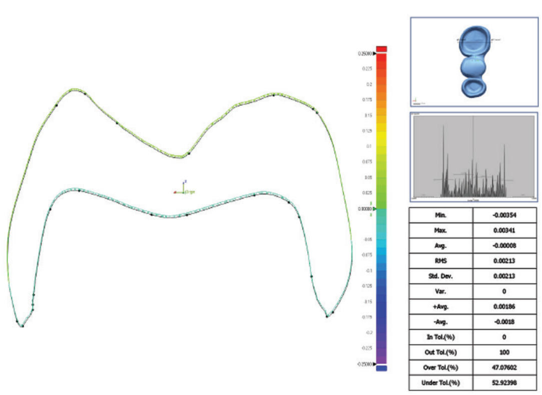

Figure (2) — Compare 2 of remote design (T/O) to host design (TD)

- Compare 3: measurement surface points along Bucco-lingual cross section of the pontic (fig. 3).
- Compare 4: measurement surface points along Bucco-lingual cross section of premolar retainer (fig. 4).

Geomagic Control X inspection software, was used to superimpose each exported design of each group, to their corresponding host design to calculate the Root Mean Square (RMS) of EDs of all the aligned surface points from the two tested design datasets for quantitative analysis and hence receive values for trueness. 3D comparisons were also conducted to export color coded difference images for the qualitative description of deviations distribution. The color maps indicate in-ward(blue) or out-ward(red) displacement between overlaid structures, whereas a minimum change was indicated by a green color.

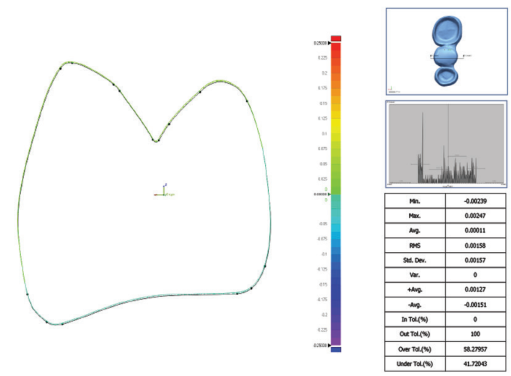

Figure (3): Compare 3 of remote design (T/O) to host design (TD)

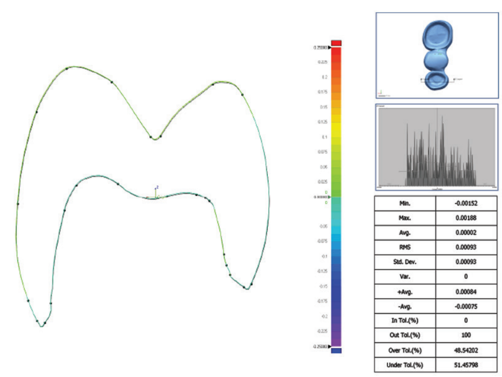

Figure (4): Compare 4 of remote design (T/O) to host design (TD)

Two Dimension Analysis(2D):

Linear measurements on the remote design datasets from all groups were also calculated and compared to their corresponding measurements on the host design datasets.

Linear measurements representing (fig. 5) inter-abutment dimensions, mesio-distal dimensions of both retainers.

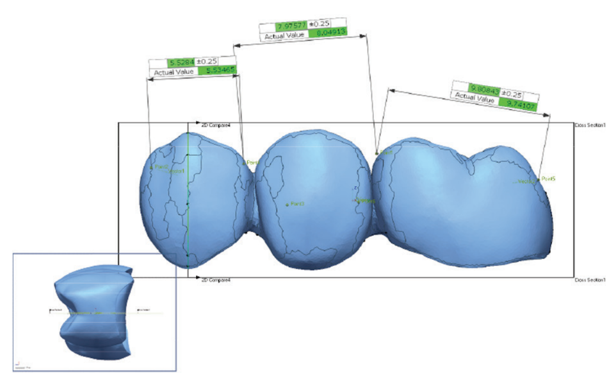

Figure (5): Linear Measurements of Remote Design (T/O) to Host Design (TD)

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). All data showed non-normal (non-parametric) distribution. Data were presented as median, range, mean and standard deviation (SD) values. Kruskal-Wallis test was used to compare between the groups. Dunn's test was used for pair-wise comparisons. The significance level was set at P ≤ 0.05. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.

3. RESULTS

Accuracy of exported designs (3D Analysis)

The best trueness was found with Cerec inLab /Dental System(O/T) and Cerec inLab /Ceramill Mind (O/C) with mean and standard deviation (SD) values deviation = -0.0031 (0.0553) mm for both groups. This was followed by Dental System/ Ceramill Mind (T/C) group [0.0033 (0.0649) mm], Dental System/ Cerec inLab (T/O) group [0.0041 (0.0704) mm] then Ceramill Mind/ Cerec inLab (C/O) [-0.0042 (0.0261) mm]. The least trueness was found with Ceramill Mind/ Dental System(C/T) [0.0216 (0.0206) mm]. However, there was no statistically significant difference between the groups (P-value = 0.888, Effect size = 0.206).

Table 5:

Descriptive statistics and results of Kruskal-Wallis test for comparison between trueness of the different designs in 3D (mm)

	Median (Range)	Mean (SD)	P-value	Effect size (Eta Squared)
Cerec inLab / Dental System (O/T)	-0.007 (-0.0663-0.068)	-0.0031 (0.0553)	0.888	0.206
Cerec inLab/ Ceramill Mind (O/C)	-0.007 (-0.0663-0.068)	-0.0031 (0.0553)		
Ceramill Mind/ Dental System (C/T)	0.0166 (0.0024-0.0507)	0.0216 (0.0206)		
Ceramill Mind/ Cerec inLab(C/O)	-0.0043 (-0.0318-0.0237)	-0.0042 (0.0261)		
Dental System/ Cerec inLab (T/O)	0.0063 (-0.0674-0.0734)	0.0041 (0.0704)		
Dental System/ Ceramill Mind (T/C)	0.006 (-0.063-0.0668)	0.0033 (0.0649)		

**: Significant at P ≤ 0.05*

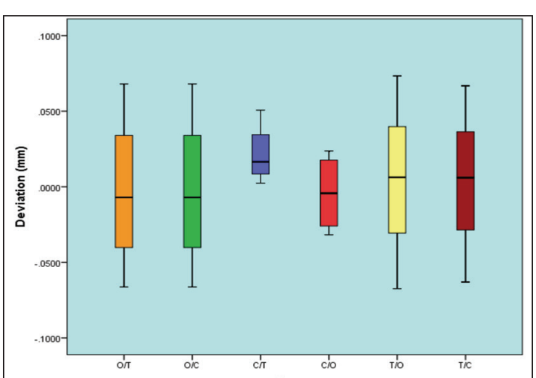

Figure (6): Box plot representing median and range values for trueness of the different designs in 3D

Accuracy of exported designs (2D analysis)

The best trueness values were found with Dental System/ Cerec inLab(T/O) with mean and standard deviation (SD) values of deviation = 0.0008 (0.0579) mm. This was followed by Dental System/ Ceramill Mind (T/C) [0.0015 (0.0531) mm] then Cerec inLab / Dental System(O/T) and Cerec inLab /Ceramill Mind (O/C) with mean and standard deviation (SD) values of deviation = -0.0041 (0.0677) mm for both groups. This was followed by Ceramill Mind/ Dental System(C/T) [-0.0118 (0.0084) mm]. The least trueness values were found with Ceramill Mind/ Cerec inLab (C/O) [-0.0134 (0.0225) mm]. There was no statistically significant difference between the groups (P-value = 0.896, Effect size = 0.240).

Table (9)

Descriptive statistics and results of Kruskal-Wallis test for comparison between trueness of the different designs in cross section 1 (mm)

	Median (Range)	Mean (SD)	P-value	Effect size (Eta Squared)
Cerec inLab / Dental System(O/T)	-0.014 (-0.0663-0.068)	-0.0041 (0.0677)	0.896	0.240
Cerec inLab /Ceramill Mind (O/C)	-0.014 (-0.0663-0.068)	-0.0041 (0.0677)		
Ceramill Mind/ Dental System (C/T)	0.0148 (0.0024-0.0183)	0.0118 (0.0084)		
Ceramill Mind/ Cerec inLab(C/O)	-0.0201 (-0.0318-0.0116)	-0.0134 (0.0225)		
Dental System/ Cerec inLab (T/O)	-0.0014 (-0.0674-0.0734)	0.0008 (0.0579)		
Dental System/ Ceramill Mind (T/C)	0.0011 (-0.063-0.0668)	0.0015 (0.0531)		

**: Significant at P ≤ 0.05*

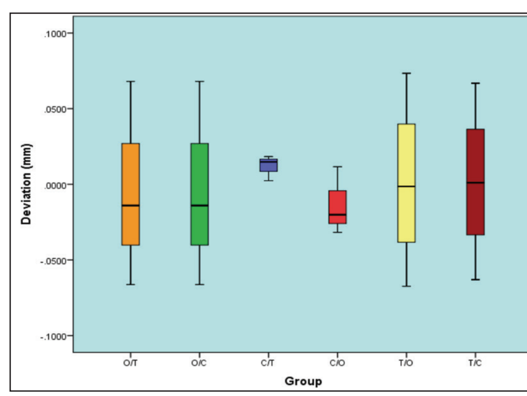

Figure (7): Box plot representing median and range values for trueness of the different designs in cross section 1

4. DISCUSSION

According to the findings of this study, the null hypothesis, which stated that exporting Computer-aided designs of 3-unit fixed dental prosthesis as stl files would not affect their accuracy was accepted.

Digital impressions collect information about the topography of teeth and the dental arch in a way to facilitate the construction of a three-dimensional model of that dental arch and is referred to as three- dimensional 3D scanning.

Digital 3D models of dental arches can be obtained using either intra oral or extra oral scanners. The information collected by these scanners is processed by powerful software that reconstructs the three-dimensional (3D) model of the desired dental structures. The output is usually stored as STL (StereoLithography or Standard Tessellation Language) file format. STL is a standardized computer exchange file, that is readable by dental and non-dental Computer Aided Design (CAD) softwares. This file format has become a world standard for exchanging 3D objects between programs and is now used as input for virtually all rapid prototyping processes as well as 3D machining.

A 3D design of a dental prosthesis may be exported as an STL file for milling or 3D printing. 3D File formats can be divided into exact and approximate types. Standard Tessellation Language (STL) formats are approximate formats. The STL format represents geometry via a simple approximation technique called tessellation, a process of covering a surface with one or more geometric shapes (e.g., triangles, polygons) which have no overlaps or gaps.[14]

Tessellations with only planar triangles in the STL formats can bring relatively large approximation error, which is a major issue of these formats. This approximation error would logically manifest as an inaccuracy during conversion and exporting. [15]

Therefore, transforming the proprietary files that work only on a particular supporting CAD software to .STL files may cause loss of some of the information carried by the .STL file and hence affect their accuracy. Selection of an appropriate tessellation accuracy are based on the capabilities of the CAD system. The minor differences between the investigated CAD programs in this study may be justified by their different settings. Unfortunately, the settings of dental CAD softwares are not known to users, although some CAD softwares allow the choice of two or more levels of resolution of the exported design. Exporting an STL with a low resolution, would create a faceted inaccurate model. An STL with too high of a resolution, would unfortunately be too large and harder to share or export.

In addition, an STL format, is incapable of representing colour, materials, and texture. Incorrect intersections, and facet degeneracy will arise in the conversion. [16] The accuracy of an STL file also varies with the geometry of the design.[17] In this study, exporting designs was of 3 unit fixed dental prosthesis may have not effected their accuracy due to the smaller extent of the geometry. It is expected however that with larger and more complex geometries, the error may be significant. [18] Limitations of this study include that although an effort was made to create similar CAD proposals, yet there were slight differences between the CAD auto-generated designs.

The results of this study would allow us to conclude that exporting STL files of short span dental prosthesis through CAD technology does not jeopardize the accuracy of the digital designs. The deviations recorded are minute and statistically insignificant in the in vitro and virtual level of evaluating the accuracy of short span fixed partial dentures. However it would not be safe to extrapolate these results to say that open source CAD/CAM technology does not affect the accuracy of fixed partial dentures, since no restorations had been actually milled. Further investigations should be done to evaluate the complete fabrication chain.

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