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Innovative Digital Protocol for Standardized Endocrown Preparation of Natural Bicuspids

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ABSTRACT

Purpose: To establish and verify new digital technique to standardize endocrown preparations using CAD/CAM.

Material and Methods: Ten recently extracted intact maxillary premolars were selected in this study. All teeth received standardized endodontic treatment. A standard 3D virtual designed cavity preparation was selected with specific dimensions. This preparation was sent to CAD software as STL file. All teeth samples were held within milling machine using special design attachment. All teeth were then scanned using trios 3. The scanned teeth were checked for trueness using 3D comparing engineering software by superimposition of the virtual model STL file as a control model to each STL file of the ten scanned teeth.

Results: The total similarities and differences between 3D designed cavity preparations from Rhinoceros software were compared with the STL files of scanned specimens. The mean difference between the samples and the reference was 0.093 millimeters.

Conclusion: 1) The mean trueness of all teeth samples was quantitively within the acceptable range (+100 ___ -100 micron), considering clinically relevant threshold in literature, 2) Qualitatively, the pulpal floor showed the most uneven deviation pattern.

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Introduction

Regaining functional and esthetical properties of severely damaged coronal hard tissue of non-vital teeth is always a challenge in modern dentistry. Clinical theories regarding the restoration of devitalized teeth are debatable. The primary reason for weakness of endodontically treated teeth structure is loss of structural integrity due to caries, severe cavity preparation, in addition to physical changes in the dentin [1].

Clinical studies reported no significant difference in survival rates between molars restored with endocrowns and those restored with traditional techniques. However, the clinical performance of endocrown restored premolars is still questionable. Cohesive failure is the main reason for failure in premolars restored with endocrowns [2].

One of the main characteristics that should be obtained in In vitro research in the field of dentistry is consistency in similarity which is considered one of the main obstacles. This limitation restricts the application of these conclusions as evidence-based results in dentistry. It also prevents comparing between different In vitro researches, even when the same materials and techniques are used and limits the linking process of the results obtained due to lack of consistency [3].

Many in vitro studies of recent materials revolve around the milled samples or restorations but neglect the characteristics of the tooth preparation to which the restorations are to be cemented. There are innumerable techniques for producing samples manually for in vitro studies [4, 5].

Manual preparation of the cavities was applied with high-speed hand pieces, but in some occasions, it is not mentioned how the cavity dimensions were standardized. Standardization of preparation is very crucial during in-vitro studies to have results, which are representative to the clinical treatments.

Computer aided design and computer aided manufacturing (CAD/CAM) technology permits designing and fabrication of dental restoration. CAD/CAM software can be used to standardize the design and milling of any dental materials, whether discs, bars, cylinders, or restorations for the purpose of in vitro studies [6]. In addition to the standardization of dental materials, there is a huge demand to standardize the preparation of tooth models

as well. Using teeth that have been prepared by digitally standardized technique would greatly enhance comparison of the data maintained between studies and increase the credibility of these in vitro studies results
[7].

Although there is a great demand to standardize the dental specimen preparation through using CAD\CAM technology, there are limited studies that have been concerned with using this technology. Fernandez-Estevan et al., used CAD/CAM technology to standardize the preparation of extracted teeth through scanning a metal model for the standard preparation, then transferring the scan to CAD unit in order to prepare the extracted teeth by the same preparation diameters [8].

Regarding ISO 12836, the difference of measurements between the virtual model (control model) and the intraoral scan model is termed the 'trueness' of standardization technique. The trueness is obtained through the deviation of the tested method from the original geometry [9].

The only way to calculate the trueness is to over-impose tested scans to reference scan. After the superimposition of these images/models, powerful engineering software can be used to create colorimetric maps determining the differences between these scans and the reference model at micrometric level [10].

The objective of this study is to design a simple and accurate method for standardization of teeth preparation using CAD/CAM technology through a modification in the milling software.

Statement of the Problem
Restoration of endodontic treated premolars using endocrowns is considered a conservative biomimetic alternative to conventional restoration despite the debate in literature regarding its prognosis. However, standardization of preparation among samples is a crucial yet technique-sensitive step for study reliability. Few data are available in literature in relation to standardization methods.

Material and methods
Ten recently extracted intact maxillary premolars have been selected in this study. Teeth have been stored in a 0.9% sodium chloride solution (Normal saline; El-Nile company, Egypt) (pH 7) at 25C.

All teeth received standardized endodontic treatment. Preparation of the access cavity was accomplished with a diamond rotary cutting instrument (836KR, 17; Oekodent, Lindenweg, Germany). Standardized canal enlargement was performed with an engine-driven rotary NiTi system (Soco pro; Socodent, Foshansoco, Guandong, China) up to 2 degrees of taper and 0.4 mm of diameter 25 for the apical preparation, using a crown-down technique. Rotary instruments were used with endomotor device (saeyang endomotor; saeyang microtech Co., Daegu, Korea). Root canals were rinsed for 30 seconds with 1% NaOCl before switching to the next instrument. Root canals were obturated with lateral condensation technique using gutta purcha normal and special taperes (25 taper 4) (gutta purcha; Metabiomed, Korea) and resin sealer (Syntex, Cerkamed, Polska), according to manufacturer's instructions, providing a standardized filling procedure. The superior aspect of the gutta-percha material was extended 1mm below the CEJ, forming the apical foundation for indirect restoration.

All teeth were centrally submerged in auto polymerizing resin (Palavit G; Heraeus Kulzer, Hanau, Germany) inside a plastic cylindrical holder. The teeth were positioned 2 mm below the cemento-enamel junction (CEJ) guided by a dental surveyor (Figures 1, 2).

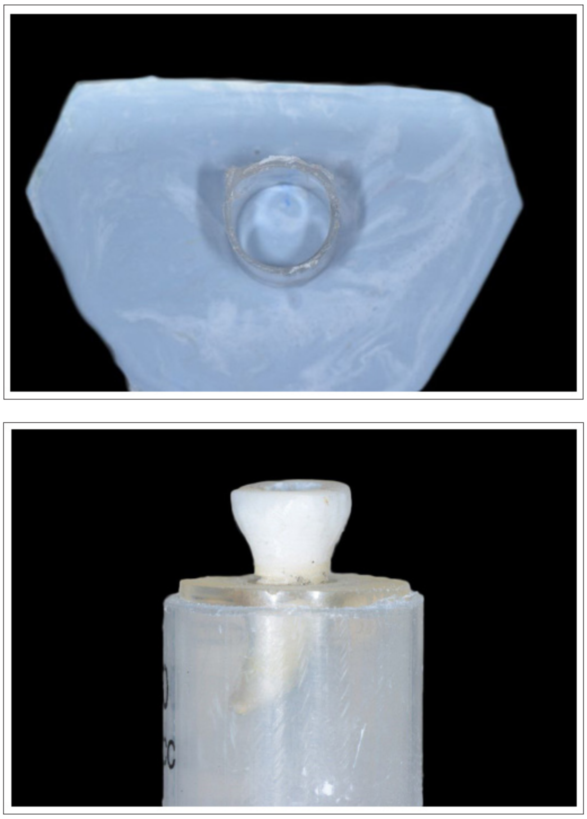

Figure 1: Prepared Tooth Embedded in Epoxy Resin Die 2mm away from (C.E.J).

Butt joint virtual preparation was selected with dimensions of (4mm buccolingual width, 3mm mesiodistal width, 4mm total depth, 20 total degree of divergence) (Figures 3,4). A 3D software (Rhinoceros 3D; Robert McNeel & Associates, North America, USA) was used to design a virtual model of the endocrown preparation, with the aforementioned dimensions (Figure 2). The virtual model was designed as a 3-dimensional trapezoid within a surrounding substrate resembling an intracoronal preparation inside a natural tooth structure. (Figure 5), then it was sent to the CAM software (hyperDENT®, Follow-me, Technology Group, Munich, Germany) as STL file. In the CAM software, (job simulation) was selected where (job steps) were only limited to those of the intracoronal preparation of the fitting surface. (Figure 6)

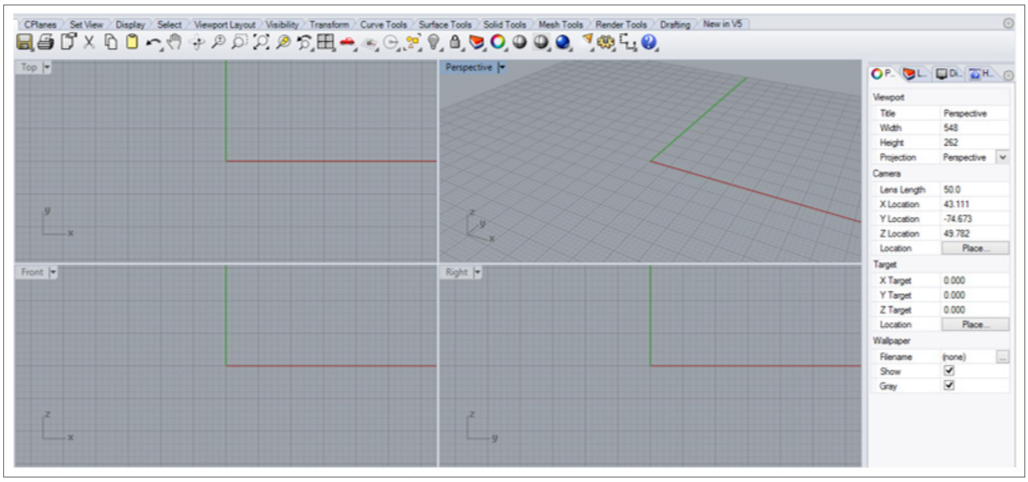

Figure 2: Rhinoceros 3D Software

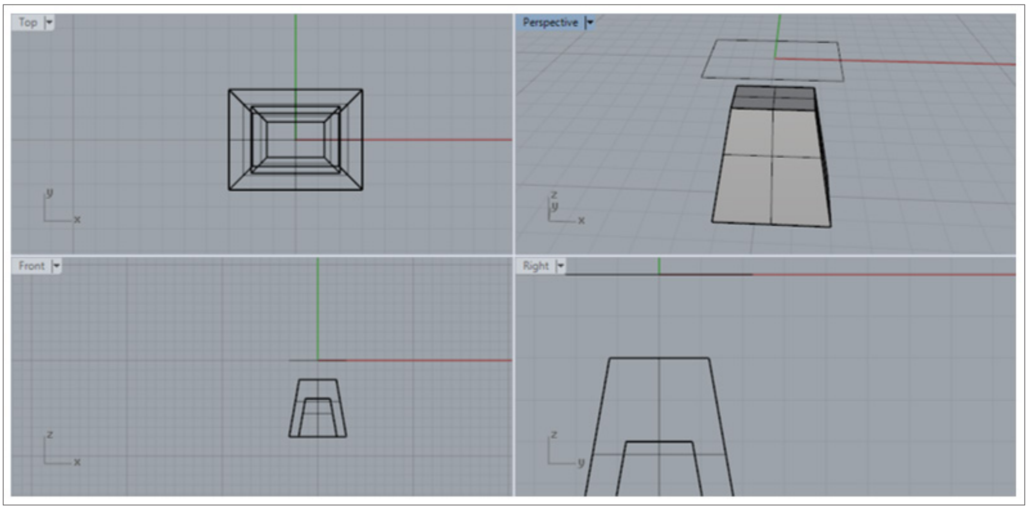

Figure 3

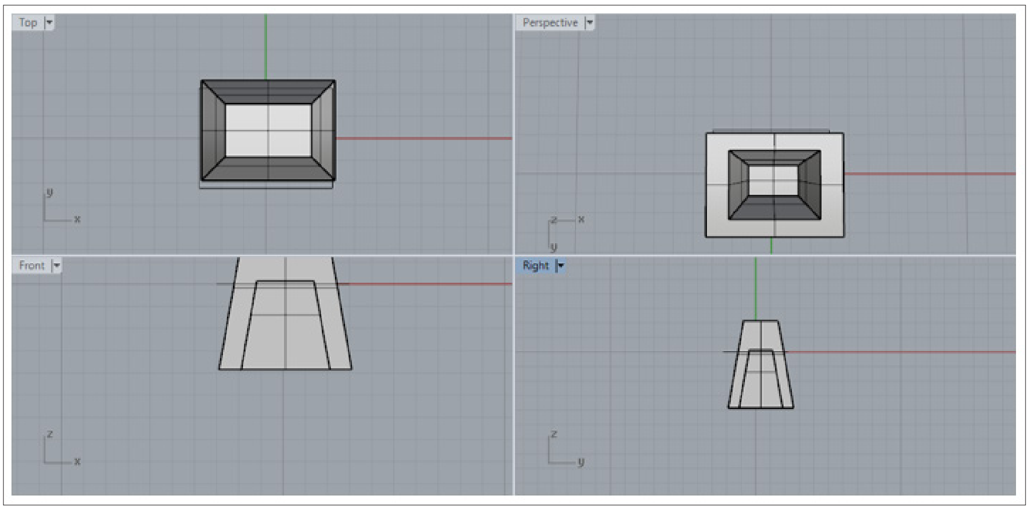

Figure 4: Digital Preparation Design of STL File with the Aforementioned Parameters

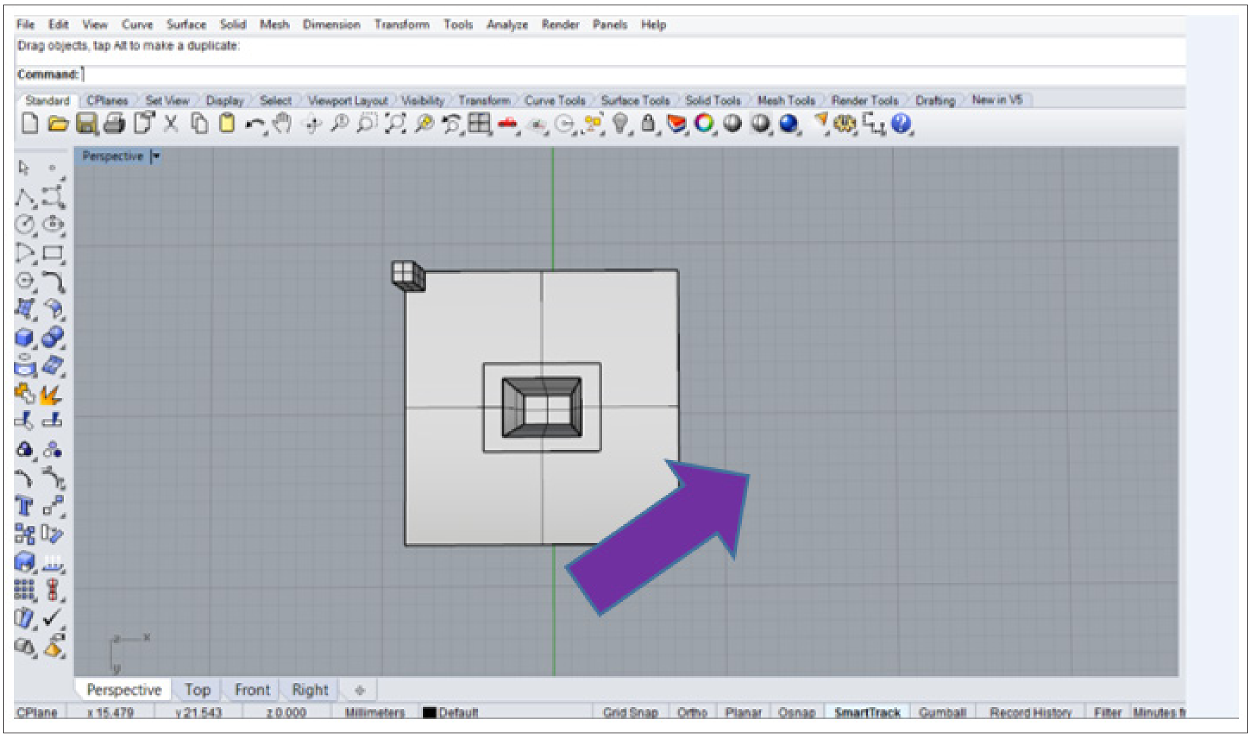

Figure 5: Digital preparation design of STL file within the substrate resembling tooth structure

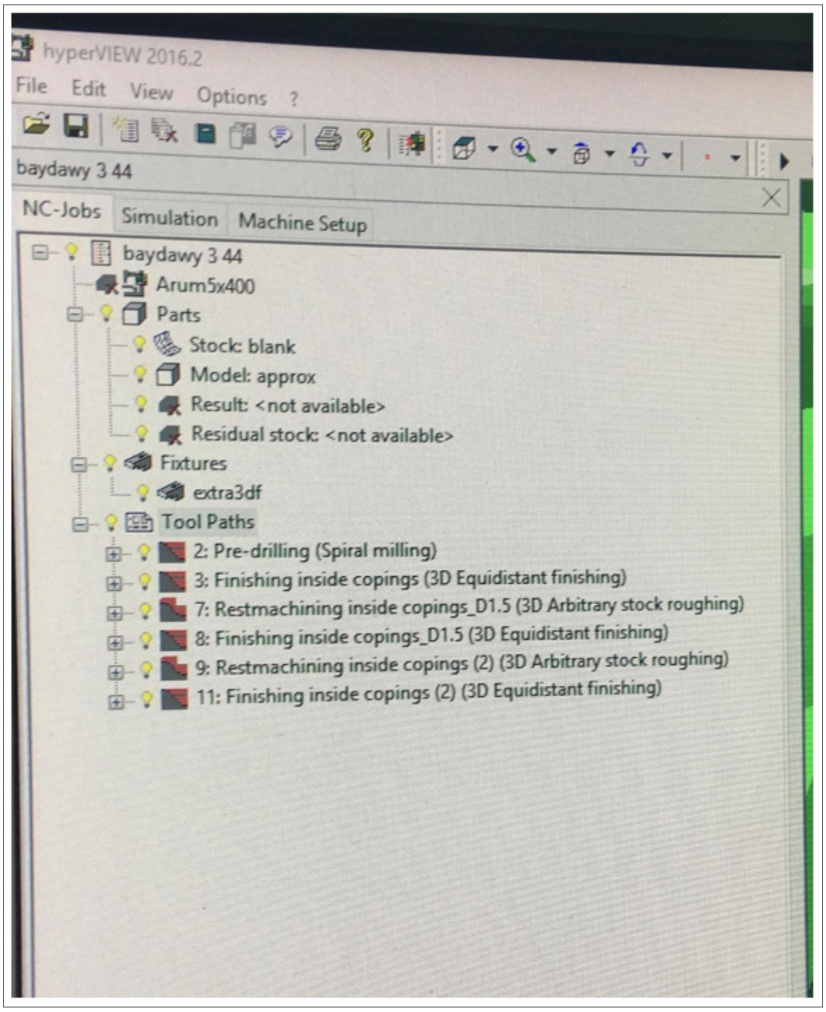

Figure 6: List of orders had been selected in CAM software

A special designed attachment including 2 holders and 2 joints was used to hold and orient tooth within the milling machine. (Figure 7,8).

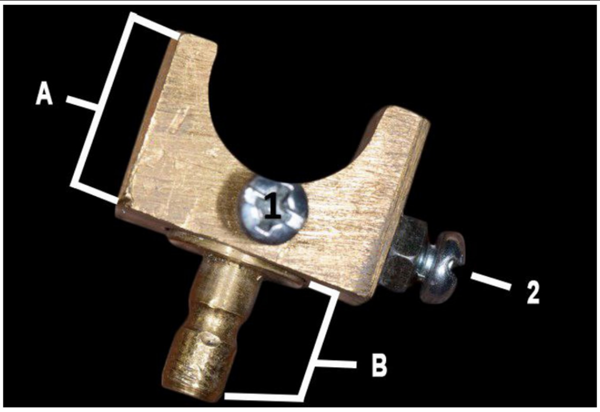

Figure 7: Specially Designed Tool housing Showing: 2 Pieces' Holder (A, B) and 2 joints (1, 2)

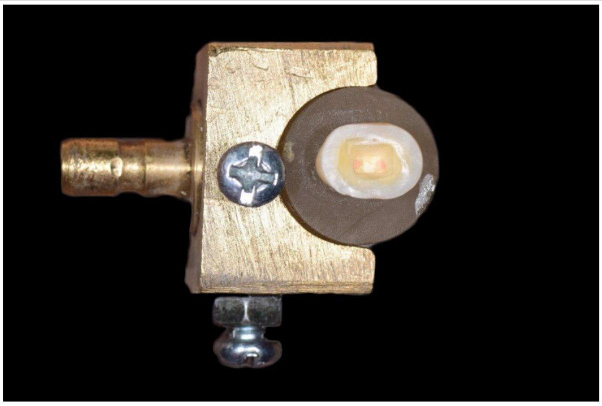

Figure 8: Tooth Specimen have been Held within Tool Housing

2-piece holder (A. to fix and enclose the specimen, **B**. to attach the fixed specimen to the milling machine)

2 joints (Joint 1 buccolingually, Joint 2 mesiodistally) to allow 1 mm movement range for the specimens.

All teeth received standardized endocrown cavity preparations following the virtual model using 5x - 400 Arum milling machine (milling machine, Arum, Puderbach, Munich, Germany) (Figures 9, 10). All teeth were then scanned using trios 3 (3 shapes, Copenhagen, Denmark) and software version (v4.4.0.41651).

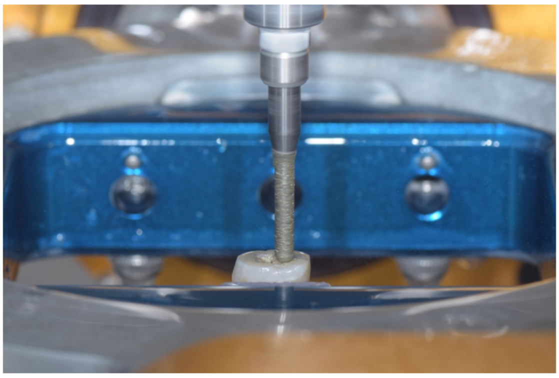

Figure 9: Preparation of Tooth Specimen using 5x - 400 Arum Milling Machine

Figure 10: Preparation of tooth specimen using 5x - 400 Arum milling machine with coolant.

The scanned teeth were checked for trueness using 3D comparing engineering software Geomagic control X 2018 (Geomagic, 3D systems, Morciville, NC, USA) by superimposition of the virtual model "STL file" as a control model to each STL file of the ten scanned teeth. (Figures 11, 12)

Figure 11

Figure 12: Natural tooth with standardized preparation

The initial alignment option was selected, then the best fit alignment was chosen to ensure the 2 compared data are positioned in one common coordinate system with the minimal possible mean deviation. Resegmentation of virtual model was obtained through planes to thousands of segments, then the area of interest was merged with the STL file of teeth specimens through the merge tool to ensure a precise superimposition.

A color map was drawn with maximum deviation range of 0.5 mm and -0.5 mm minimum deviation and no specific tolerance. The green meant matching surface, the red meant that STL file of the prepared teeth was positively positioned relative to the virtual preparation model and the blue meant that the STL file of prepared teeth was negatively positioned relative to the virtual preparation model.

When two scans were superimposed, the square of the phase difference between a number of points in 3D space was calculated (x-, y-, and z-axis). The number of points was divided by the sum of these squares, and RMS was calculated as the square root of this value. PDF and excel reports were created with all the calculated data collected from the superimposition process (Figures 13 , 14).

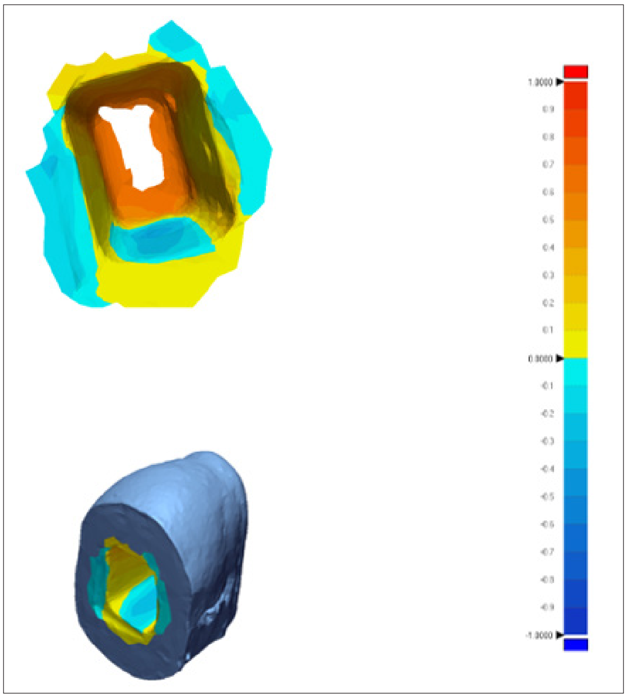

Figure 13: Superimposition of tooth specimen and the reference model showing areas of difference and similarities through color map

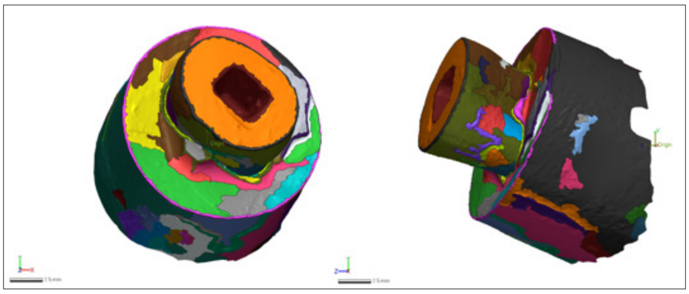

Figure 14

Results

3D comparing software called (Geomagic Control X) has been used, which permits 3D comparing of 2 or more STL files of 3D scanned objects and calculating the total similarities and difference between them. Therefore, reference (3D designed cavity preparation from Rhinoceros software) was compared with the STL files of scanned specimens, and the results were as follows:

Samples	Trueness
1	0.0865
2	0.0997
3	0.1072
4	0.0917
5	0.0804
6	0.0965
7	0.0849
8	0.1051
9	0.1046
10	0.0745
Mean	0.09311

From this table, the mean difference between the samples and the reference was 0.093 millimeters, which lies within a clinically accepted range [11].

This novel technique affords a reliable technique for standardization of teeth preparations in in-vitro studies.

These ten samples will be involved in an in vitro study which tests the mechanical properties of different restorative materials available to restore endodontically treated upper premolars.

Discussion

Standardization of preparation designs has been a critical concern highly considered in in vitro studies, especially when a study is conducted on natural teeth with anatomical variations. Many methods have been adopted in literature for preparation standardization, yet few data are available in literature regarding the reliability and accuracy of such methods. An innovative method of standardization is proposed in this study where CAD CAM technology is used. In this study, natural premolars are chosen rather than the artificial dies to allow more clinically relevant evaluation of such innovative standardization protocol. Moreover, dentin and enamel surface for bonding, the contour of the pulp chamber and root canals and the ratio between the crown and root are more accurate and clinically reliable than artificial teeth [12].

All teeth specimens received root canal treatment by the same operator, following the same steps for standardization among all specimens. Moreover, a surveyor was used to standardize vertical alignment of all samples. Pouring samples within epoxy resin (2-3 ml) away from CEJ was done aiming to resemble the natural clinical bone level in the oral cavity. All teeth were decorticated, leaving 4mm intrapulpal depth (from butt joint till the floor of the pulp chamber) in order to standardize the depth of cavity preparation in all specimens.

In order to have a simple and efficient technique to standardize the teeth preparation through CAD/CAM, three systematic steps were followed (designing of preparation parameters, transferring and recognizing of the design with the milling software and holding the teeth inside the milling machine).

Designing through CAD unit is restricted to the parameters produced by the software, thus designing the standard cavity preparations within CAD unit is a complex procedure. Hence, a 3D designing software which has the ability to design any cavity preparation and transfer the data to Cam unit directly as STL file was selected for this study.

Rhinoceros (which is a commercial 3D computer graphics and computer-aided design (CAD) application software) was used to design a 3D model for tooth preparation with standard parameters. Hyperdent® CAM software is used in the current study, since it has the ability of recognition of cavity preparation and can accept STL design file, as well as produce a standard preparation on natural teeth specimens. The software has the ability to simulate the procedures needed to produce the selected design and to standardize the intracoronal part of the endocrown preparation.

All milling procedures were excluded, except the milling of fitting surface which resembles the intracoronal preparation of the endocrown restoration.

A special holder for the specimens was designed to permit controlled movement of teeth (about 1mm range for buccolingual and mesiodistal movements). This specially designed holder ensured that the burs of the milling machine produced a standard digitally designed cavity preparation for all samples and at the same position.

Many steps included in the CAD CAM standardization procedure may involve potential source of error. Thus, each procedure in any CAD CAM workflow is very important and can affect the overall performance. Trueness is a very important factor to measure the reliability of this technique as a standardization technique.

Trueness of this innovative method is measured by obtaining STL file for the virtual preparation model to evaluate the deviation of the 10 preparation specimens and the virtual preparation model through superimposition. This procedure is performed by reverse engineering and 3d analysis software. It is to be noted that trueness has been considered a reliable and common method to measure accuracy through many studies [13, 14].

Superimposition of two surfaces after best-fit alignment has been used in several in vitro studies [15]. The superimposition of the STL files was imported to a reverse engineering 3D analysis software "Geomagic control X, 2018".

STL files of each group were superimposed 1 by 1 on the virtual preparation model to measure the trueness, and the e root mean square (RMS) of each superimposition was collected to evaluate quantitative accuracy, since it shows a high estimate of the average error. Furthermore, an average value was calculated [16].

After calculating the mean of trueness for the whole 10 samples, we found that the mean of trueness was 93 microns, which is considered within accepted clinical differences as intraoral scanners may face some difficulties during scanning deep cavities [17]. In addition, this mean is regarded a marginal gap that is considered within clinically acceptable gap range for endocrown restoration, as Taha et.al clarify [18]. By noticing the site of these discrepancies between teeth specimens, they are located at the floor of the pulp chamber and can be attributed to differences between the pulp floor of teeth, which vary according to age due to heavy restorations, calcification or malposition [19].

Conclusions

1. The mean trueness of all teeth samples was quantitively within the acceptable range (+100 ___ -100 micron), considering clinically relevant threshold in literature [20].
2. Qualitatively, the pulpal floor showed the most uneven deviation pattern.

Recommendations

1. The new digital protocol can be considered a clinically reliable standardization method.
2. More in vitro studies should be carried out to verify the new digital protocol and achieve higher level of trueness.

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