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Fracture resistance of interim restoration constructed by 3D printing versus CAD/CAM technique (In vitro study)

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Abstract

Aim: to assess the fracture resistance of interim restorations fabricated by 3D printing technique compared to milling technique.

Methodology: Typodont model of maxillary 1st molar was preprared for full coverage crowns. The prepared model was digitally scanned by extraoral scanner. Duplication of master die into sixteen epoxy resin dies. Sixteen interim crowns were constructed by two techniques include: CAD/CAM technology using TelioCAD PMMA disc and 3D printing technology using Nextdent C&B resin material. The specimens were divided into 2 equal groups (n=8). All interim crowns were cemented on their corresponding resin dies using cementation loading device. All samples were subjected to thermal cycles(1250cycles,5-55c) and mechanical cycles (37,000cycles,50N). Using SEM to assess the surface topography for samples in both groups and EDX microanalysis was used to evaluate the elemental compositions with relative values expressed in wt% and K ratio. The specimens were loaded to failure in Newton (N) using universal testing machine. Stereomicroscope was used to investigate the fracture pattern. Data was statistically analyzed used Kolmogorov-Smirnov and Shapiro-Wilk tests & Student's t tests ($\alpha = 0.05$) and failure mode (%) by the Fisher exact test & chi2 test ($p \leq 0.05$).

Results: The mean ± SD values of fracture resistance were recorded for milled group (933.46 ±104.49 N) meanwhile the mean ± SD value recorded with printed group were (1226.48±48.33 N). It was found that printed group recorded statistically significant higher fracture resistance mean value than milled group.Conclusions: Interim crowns constructed using 3-D printing technique showed higher fracture resistance compared to milled interim crowns under thermo-mechanical loading.

Keywords: 3D printing ,Rapid prototyping ,Additive manufacturing , CAD/CAM , Subtractive manufacturing , Fracture strength , PMMA, Polymer materials , TelioCaD, Nextdent resin material .

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Introduction

The interim restoration is a critical phase in fixed prosthetic treatment; it is used from the time of tooth preparation to the time of final cementation. A properly fabricated provisional restoration is important in achieving a successful final restoration . [1]. The interim restoration has a role in pulpal protection, stabilization of occlusal relationships and occlusal function. It's importance increases greatly for oral rehabilitation cases that needs long term provisionalization [2]. Many techniques are used to make temporary restorations. It began manually through direct, indirect and indirect-direct technique. However, the advances in materials and technology contributed to the introduction of CAD/CAM technique (subtractive manufacturing) and 3D printing technique (additive manufacturing) [3]. Computer-Assisted Designing and Computer-Assisted Milling (CAD/CAM). has now become a well-accepted technology in most modern dental laboratories and for some clinicians at the chairside. Subtractive methods including provisional restorations fabricated by milling the resin blocks which are cured under optimal conditions [3]. The newly introduced technique 3D printing is spreading fast and various resins are used. It's an additive manufacturing (layer upon layer). It has the ability to manufacture precise prosthesis with minimal materials waste. It considers cheaper and faster than milling technique. It is passive with no force application and can produce finer details (undercuts & better anatomy). The 3D printing methods include Stereolithography (SLA), Digital light processing (DLP), Selective Laser Sintering (SLS) and Fused Deposition Modeling (FDM) [4] . Fractures are a common cause of failure of provisional restorations, although temporary restorations should be designed to avoid failure, fractures can still occur. This may cause the patient discomfort and economic loss. Thus, the mechanical strength of provisional restorations is important and should be considered specially in long term conditions to ensure it's clinical success [5].

Data regarding the fracture resistance of 3D printed interim restoration compared to milled restoration is some-what limited and needs further investigations. That's why assessment of the fracture resistance of long term 3D printed provisional restoration was carried out in the present study.

Material and methods:

Samples preparation :

Typodont models of maxillary upper first molar were prepared to receive an all ceramic crown according to shillinberg [6] with 2 mm Occlusal reduction , 1.5mm axial reduction , 1mm deep chamfer finish line and 6 degree convergence .The preparation was carried out by an experienced prosthodontist using a silicone index of an unprepared tooth to achieve the required tooth reduction . Secondary impression was taken to the typodont model then poured using dental stone type IV and was duplicated into master cast .

Duplication of master die into epoxy resin die

Silicon mold for the master typodont die was made using duplicating addition silicon material . The master die was placed in the center of container , then removed after setting of silicon mold .The mixture of epoxy resin material was then poured in the silicon duplicates on the laboratory vibrator to eliminate voids and air bubbles .Epoxy resin dies were left in place for 24 hours to ensure complete setting **Scanning the preparation :**

3Shape D850 extra-oral scanner was used to scan the master cast and scan die separately to get 3D virtual cast. The entire process of the scanning took approximately 1 minute .

Restoration designing :

The 3Shape software calculated a virtual model from scanned pictures which was ready for identification of the finish line and an automatic margin finder was used for margin detection **.** Selecting the tooth anatomy from dental databases libraries was carried out that match the anatomy of tooth 16. Detecting the presence of undercut in the abutment, and detecting the preparation depth from all aspects , The cement space was set up through software where the cement gap was 0.030 mm[7] . The occlusal thickness was then measured from central fossa and adjusted to be 1.5mm for the standardization of all samples.

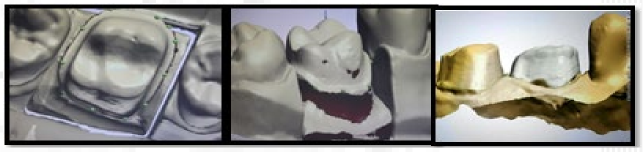


Fig (1) : (A): Tracing the finish line, occlusal view , (B): Detecting the presence of undercut in the abutment , (C): Setting up of cement space in 3shape software

Designing of the printed crown by 3Shape cambridge software was carried out . Ten supporting structures were placed on the buccal surface of the crown ,and then detecting the printing direction of the crown in vertical orientation was performed. Adjusting the printing process parameters also was carried out (Build height :13.17mm , layer count: 264).When the final virtual restoration was designed , the information was sent through STL file to the milling unit and printer.

Fig (2); (A); Placing of the ten supporting structures on the buccal surface of the printed crown , (B):Determining of the printing direction on the platform , vertical orientation

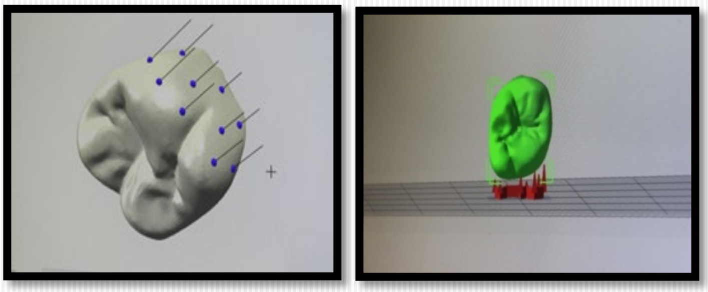


Fig (3):(A):DWX shape milling machine, (B): Rapidshape D30 printer

Crown Fabrication

I. Milling process :

The type and size of disc was selected to fabricate interim crowns . The selected disc was inserted in the spindle of the milling chamber of the DGshape DWX-520. Dry milling of selected PMMA disc was carried out. The carbide burs were used for milling the selected TelioCAD disc. The interim crown produced has 1.5mm axially and 2mm occlusal thickness.

II. 3D Printing process:

When the design was finished , it was sent to 3Shape Cambridge software as STL file. This software was used for preparing the file for printing and for transferring the information about the to modify the STL file accordingly. After choosing the correct build style and calibrating of the stereolithography machine the STL file was sent to the Rapidshape D30 printer. After adjusting the printing parameters the building process can begin. Next dent C&B resin was used and poured in a container specially fabricated to be accurately fit in the Rapidshape printer. Objects were built in a layer-by-layer, the UV light cures and hardens a thin layer of the polymer, and then the platform lowered or raised , while the UV light cured the next layer with previous one . The process continued until the completion of the full object .The layer thickness was about 50 µm and the numbers of layers was 307 with supporting structures. The printing cycle has taken about 30 minutes for partial curing of each interim crown .

Post processing :

The LC-3DPrint Box is an Ultraviolet light box suitable for post curing 3D printing resin materials to ensure that NextDent materials obtain the full polymerization and superior mechanical properties.

Cementation procedure

For the cementation of crowns on their corresponding epoxy resin dies , Meta temp ZONE temporary cement was used. A specially constructed loading device was used during cementation of each crown that carry a load of 3 kg [8] during the cementation

Thermocycling :

Samples were subjected to thermocycling ; the cycles used were **1250 cycles** which corresponds to **3 months** of service inside the oral cavity [9] . Thermal cycles with a temperature extremes of **5°C and 55°C** in distilled water (dwell time: 25 seconds, pause time:10 seconds) was performed in the computerized thermocycling unit . The specimens were placed in a container in thermocycler , then dried and inspected for cracks, chipping or fracture after each loading phase.

Mechanical aging:

ROBOTA chewing simulator which has four chambers simulating the vertical and horizontal movements simultaneously in the dynamic condition. Samples were exposed to mechanical aging that was repeated for **37,500 cycles** which simulate **3 months** clinically [10]. A weight of 5Kg was applied which is equivalent to 50 N of chewing force.

Measurement:

Scanning electron microscope SEM (with magnification x1000) was used before fracture resistance test to detect the morphological difference between interim crowns fabricated by both techniques and to evaluate the surface topography for both tested groups . Also Energy dispersive x-ray micro analysis was used to analyze the chemical compositions of both resin based materials used in the present study , including the elements with relative values expressed in weight % and K-ratio .

Fracture resistance

All samples were individually mounted on a computer controlled universal testing machine . A load cell of 5 kN and data were recorded using computer software. Fracture test was done by compressive mode of load applied occlusally using a metallic rod with spherical tip (5.6 mm diameter at cross-head speed of 1mm/min with tin foil sheet in-between to achieve homogenous stress distribution and to avoid contact damage with steel indenter. The load at failure manifested by an audible crack and confirmed by a sharp drop at load-deflection curve recorded using software .

Mode of fracture of samples :

Evaluation of fractured pattern of the tested samples was done using stereomicroscope and it was reported according to Burke's classification [11] .

Statistical analysis

Data were presented as mean, standard deviation (SD), range (Minimum – Maximum) for values. Data were explored for normality by checking the data distribution and using Kolmogorov-Smirnov and Shapiro-Wilk tests. Student t-test used to compare mean values. The significance level was set at $P \leq 0.05$ and 95% Confidence interval. Statistical analysis was performed using Graph Pad Instat (Graph Pad, Inc.) software for windows

Results

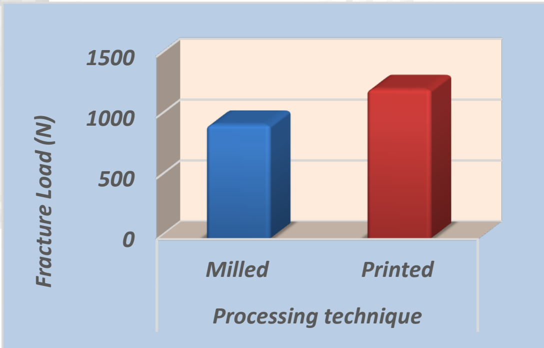
Results of the effect of two constructing techniques (CAD/CAM versus 3Dprinting) on the fracture resistance of interim crowns

Descriptive statistics showed mean values and standard deviation of the results of the effect of two techniques (CAD/CAM versus 3D printing) on the **fracture resistance** test results measured in Newton (N) as a function of constructing technique are summarized in **table (1)** and graphically drawn in **figure (4).** The mean ± SD value of fracture resistance recorded for **the milled** group was (933.46 ±104.49 N), meanwhile the mean ± SD value recorded for the **printed** group was (1226.48±48.33 N). It was found that **printed** group recorded statistically **significant** higher fracture resistance mean value than **milled** group as indicated by t-test (t=7.2, P=<0.0001<0.05) **.**

Table (1) Results of the effect of two constructing techniques (CAD/CAM versus 3D printing) on the fracture resistance of interim crowns (Mean±SD) *in Newton (N)* :

Variables		*Mean*	*S*	*95% Cl*		*Range*	
				Lo	*Up*	*Mi*	*Maxi.*
constru techni	*Mi*	933.46	104	846	102	765	1052.1
	Pri	122(	48	1186.1	12(	114(	132
t-tes	*t-va*	7.2					
	P va	<0.0001*					

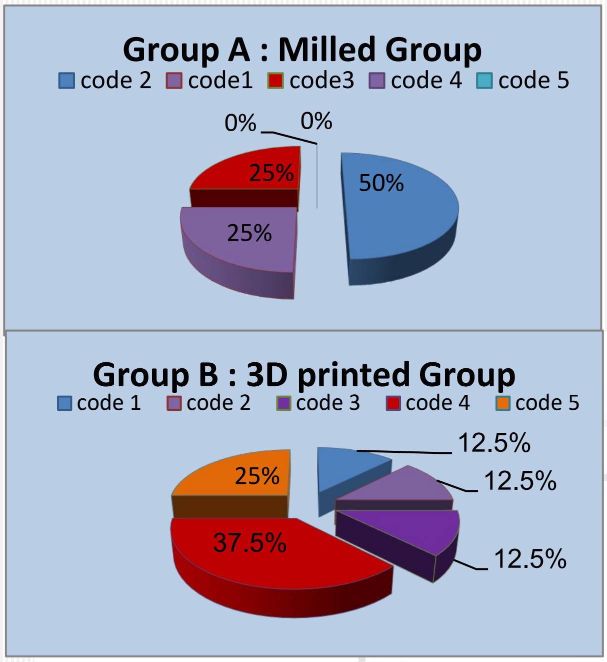
Fig (4): Column chart showing the results of two techniques on the fracture resistance



Results of the fracture mode analysis using stereomicroscope:

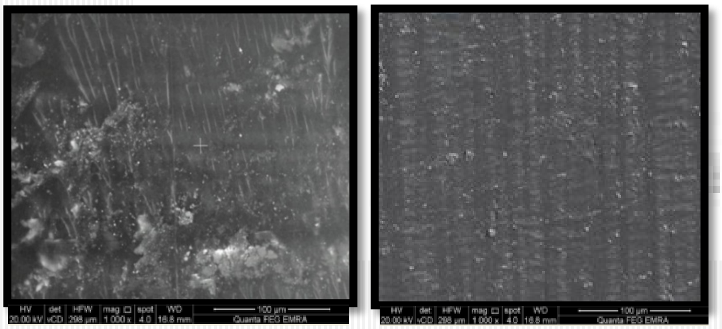
The fracture mode of the samples was reported according to Burke's classification[11].These recorded results of fracture mode analysis were statistically analyzed using Chi square test. The frequent distribution of failure modes scores (%) for groups and pie chart was created to show the frequent distribution of fracture pattern for both groups as shown in **figures(5)**. Qualitative data were presented as frequencies and percentages. Fisher's Exact test was used for comparison between mode of failures in the two groups. There was **no statistically significant** difference between failure modes in both tested groups at (*P*-value = 0.126, Effect size = 0.683) .

Fig (5): Pie chart showing distribution of fracture pattern in the milled and printed group



Results of Surface topography examination using scanning electron microscope Parallel lines and fine grooves were seen on the surface of the milled samples which could be correlated to the nature of milling technique as shown in the **figure (6A)** , these lines may have the potential to cause a defect or fracture with longer use. While the vertical orientation pattern was seen in 3D printed samples which could correlated to the nature of 3D printing technique as shown in the **figure (6B)** .

Fig(6): (A): SEM image (magx1000) of milled surface of TelioCAD crown B) : SEM image (mag × 1000) of 3D printed surface of Nextdent resin crown



Results of (EDX) analysis using scanning electron microscope:

Similar elements such as carbon, oxygen, and silicon were detected in both groups . However the concentration was different in every material used. The filler contents showed differences in elemental composition and concentration [12].Carbon elements represents the organic part of resin (resin matrix) , while Zinic , Aluminum , Silicon & Calcium elements represents the inorganic part of resin (filler contents). where the findings showed that the elements (Zn , Al , Si and Ca) that represent the inorganic part are found in higher wt % and K ratio in printed group . Where the findings showed that the elements (C and O) that represents the organic part are found in higher wt % and K Ratio in milled group.

Discussion :

Interim restoration is essential component of fixed prosthodontics treatment. it must satisfy biologic, esthetic, and mechanical requirements such as resistance to functional loads, resistance to removal forces, and maintenance of abutment alignment. [13]CAD/CAM technology was recently used for fabrication of interim restorations and has demonstrated clinical success owing to advances in CAD/CAM systems and materials used, but it was reported to have some deficiencies as marginal discrepancies, wastage of large amount of material, and long fabrication time. Also among the drawbacks of CAD/CAM technology is being expensive. In addition, its accuracy is limited by complexity of the object, the size of tooling and the properties of the material.[14] Recently 3D printing technology have been introduced in manufacturing of interim restorations and it has many advantages over milling subtractive technique: as it has the ability to print tiny and large objects not limited to the size of blocks as in subtractive milling technique. It is called rapid prototyping as it is a faster manufacturing technique. In the 3D printing processes, the material was deposited layer by layer to produce the final 3D shape so less material was wasted, decreasing expenses and mechanical properties were improved as there is no cracks in addition to producing a cheaper interim restoration, high level of building resolution, smooth printing surfaces and high strength in z-axis (between layers) due to chemical bonding between layers. [15] Fracture strength was reported to be affected by the machining of milled restorations. And limited information is available concerning the fracture resistance of 3D printed interim restoration compared to milled one. That is why the present study was carried out to assess the fracture resistance of interim restorations fabricated by 3D printing technique compared to CAD/CAM technique. In the current study**, it was hypothesized** that there will be no difference between the fracture resistance of interim crowns fabricated by CAD/CAM and 3D printing techniques. However, the null hypothesis was rejected and the results showed that 3D printed interim crowns had higher fracture resistance than milled crowns. In the present study to achieve standardization, the extra-oral scanner of the same manufacturer (3Shape D850) was used for scanning. All the fabricated interim restorations were designed by 3shape software and the STL file was used for both techniques**.** In the present study; the cement space was measured and adjusted for all specimens during designing procedures using 3D shape software for standardization, it was about 0.030 mm [7] . The occlusal thickness of all crowns was standardized through the same software, it was about 1.5mm from central fossa. The samples of both groups were subjected to thermocycling and cyclic loading to simulate the clinical condition. This gives an idea about longevity of provisional restorations inside the oral cavity. Several recent studies applied 5000 thermocycles to represent 1 year of in vivo services, therefore; **1250 thermocycles** were applied in this study to simulate **3 months** clinically. Wet conditions and thermocycling were also considered to imitate the chemical effect of aqueous environment and temperature fluctuation on resin based restorations. [9]An occlusal force between **10 &120 N** has been frequently accepted as sufficient values to represent the occlusal load during chewing. Thus, specimens in the current study were loaded in with **50 N for 37,500 mechanical cycles** to simulate the masticatory forces received by posterior teeth intra-orally during function. [16-18] Several recent studies applied 750,000 **mechanical cycles** to represent 5 years of *in vivo* service considering that 150,000 cycles represent one clinical year. Therefore; 37,500 cycles were applied in the present study to simulate 3 clinical months. [10,19,20] **.Scanning electron microscope** was used to evaluate the surface topography of the samples constructed by both tested techniques. It is a powerful tool that produces high resolution images at the nano scale level by scanning the surface of a sample of interest with a focused electron beam.[21] **Energy dispersive X-ray analysis** (**EDX**) was carried out using scanning electron microscope. It is an analytical technique used for analyzing different organic and inorganic elements weight % and ratio in both resin based materials in the tested printed and milled group.[22]When the results of **fracture resistance** were considered**,** the mean ± SD values of fracture resistance was recorded for the **milled** group (933.46 ±104.49 N), meanwhile the mean ± SD value recorded for the **printed** group was (1226.48±48.33 N). It was found that the **printed** group recorded statistically **significant** higher fracture resistance mean value than **milled** group at $P \leq 0.05$**.**The values of the printed group produced are beyond the normal masticatory forces which clinically range between **360 - 900 N** [16,17] at the molar region. This means it is within the clinically acceptable range. The superior fracture resistance of printed group could be attributed to the **layered nature** of the 3D-printed structure. The relatively good strength is because of the chemical bonding between layers. The increased values of the fracture resistance of the printed group could be also due to the **vertical building orientation** of the 3D printed interim crowns employed in the present study. This result coincides with the finding of **Alharbi et al. (2016)[23]** who found that the vertically printed specimens with layers perpendicular to the load direction have higher fracture resistance than the horizontally printed specimens with layers parallel to load direction. In addition, the higher fracture resistance of the printed group could be attributed to the **thin printed layer thickness** used in the current study. It was about **50 µm** during building process. These findings were concurrent with **Tahayeri et al. (2018)**[24] who showed that the layer thickness could be an important contributor to the mechanical properties of samples and they found that the lower the layer thickness, the more layer to layer interfaces available, the better degree of polymerization for each layer and the more mechanical performance affects positively. Also the results of the present study could be attributed to the **post-curing process** of 3D printed crowns that was carried out in special Nextdent curing unit. These findings were in agreement with **Tahayeri et al. (2018)**[24] who concluded that the postcuring process of 3D printed crowns can result in a higher degree of conversion and decrease the presence of residual monomers then enhance the fracture toughness and strength. However, the results of the current study were not in agreement with the findings of **Hazeveld et al. (2014)** and other studies [25,26] who found that the interim crowns fabricated by 3D printing technique produced lower fracture resistance than CAD/CAM technique. They attributed this to the shrinkage of the specimen during building and post-curing. In addition; data conversion and manipulation while formatting into an STL format could also result in some changes. Also the results of the present study were not coordinate with **Digholkar et al. (2016) [27]** who analyzed and compared the mean flexural strength values of interim crowns constructed by three different techniques. The milled group were higher (104.20 MPa) compared to the specimens of conventional group (95.58 MPa) and the least flexural strength was recorded for the printed group (79.54MPa).On the other hand, the **decreased values** of fracture resistance of **milled group** could be due the presence of **parallel lines and fine grooves** that is shown on the surface of the milled samples. This could be correlated to the nature of milling technique , these lines can have the potential to cause a defect or fracture with longer use.[28]Also the lower values of fracture resistance of milled group could be attributed to the **presence of the residual monomers** release from the CAD/CAM based PMMA blank after aging. The result of the present study was in agreement with **Engler et al. (2019)[29]** who showed that the Teliocad PMMA blank might not be fully achieved in the process of polymerization as it happens with conventional PMMA; this result in releasing residual monomers after aging. Yet, the higher elution started to take place after 48 h and increased continually until the 60th day of aging. Based on the results of fracture mode analysis no statistically significant difference was encountered between both tested groups. According to the results of **EDX analysis** using scanning electron microscope; it was found that the elements (Zn, Al, Si, S and Ca) that represent the inorganic part are found in a **higher wt %** and ratio in the **printed group** compared to the milled group. This might explain the higher fracture resistance of 3D printed group and it is remarkably enhanced by the presence of **higher filler contents** in Nextdent resin based material used if it compared to the resin material used in milled group. According to the results of **EDX analysis**; it was found that the elements (C and O) which represent the organic part are found in **higher** wt % and K ratio in **milled group** that suggesting that **TelioCAD PMMA** resin material contains **lower filler contents** than the other printed group.

Conclusion:

1. Interim crowns constructed using 3-D printing technique showed higher fracture resistance compared to milled interim crowns under thermo-mechanical loading.
2. Additive manufacturing of interim crowns using 3-D printing technique could be considered a reliable and conservative method for production of stronger interim restorations.
3. Fracture resistance of milled interim crowns showed clinically acceptable values under thermo-mechanical loading

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