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Evaluation of marginal fitness of two 3D printed materials using micro-computed tomography approach (μ-CT).

Othman M. Burjus , Emad F. Alkhalidi
Department of Conservative Dentistry, College of Dentistry, University of Mosul, Mosul, Iraq
*Othman.22dep27@student.uomosul.edu.iq

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Abstract: to assess the marginal fitness of two commercially available 3D printed resins with the aid of micro CT-scan
Material and methods: acrylic tooth was prepared using dental surveyor then its scanned with an intra-oral scanner to convert it to metal, 2 groups of the crown was made by DLP Asiga 3D printer, 6 for each group for Saremco and Senertek respectively. Marginal fit was evaluated at 8 points (2 points for each surface)
Result: μ-ct shows acceptable marginal fitness (126.27μm (12.71 SD), 79.41μm (6.61 SD)) for senertek and saremco respectively.
Conclusion: According to the study outcomes marginal fitness data obtained of both materials show good marginal adaptation to be used as permanent crown with some preference toward saremco over senertek company.

In dentistry, computer-aided design/computer-aided manufacturing, or CAD/CAM, was first used in the 1980s and has since expanded to many different fields[1]. It is separated into three-dimensional (3D) additive and subtractive (milling) methods techniques (such as fast prototyping and printing) based on the manufacturing process[2,3].Even though Ceramic based restorations are an important part of a dentist̓s armamentarium for durability and esthetic[4]. When contrasting the additive technique, The subtractive method's drawbacks include material waste, the need to replace worn-out equipment often, and increased risk of flaws as a result of inadequate machinability when focusing on blocks with great strength[1,3,5], On the other hand, the additive technique may be used to, and its output size is not limited. create intricate patterns without wasting any materials.It is therefore favored in dentistry[6].

The terms "additive manufacturing" (AM) and "3D printing" refer to broad categories of procedures used to create three-dimensional structures and prototypes from digital information[7]. compared to traditional subtractive manufacturing methods, 3D printing creates complex geometries or forms that are not achievable with other technologies. 3D printing technology has been used by many industries to swiftly and cheaply generate completed goods for their unique uses[8].

In additive manufacturing process we start with the main design of the object we want to form[9]. The aforementioned design was made using computer software that 3D printers may connect to. After then, this program creates a unique kind of file that is transmitted to the printer. After reading the file, the 3D printer joins layers one on top of the other to produce the output[10].

Layers are used in almost all 3D printing processes to build parts. Rather than reading the pieces as a single unit, 3D printers read the parts as one single two-dimensional layer at a time. Because 3D printers are made to read files in the Standard Tessellation Language (STL) file format, they function as depicted in Figure 1[11].

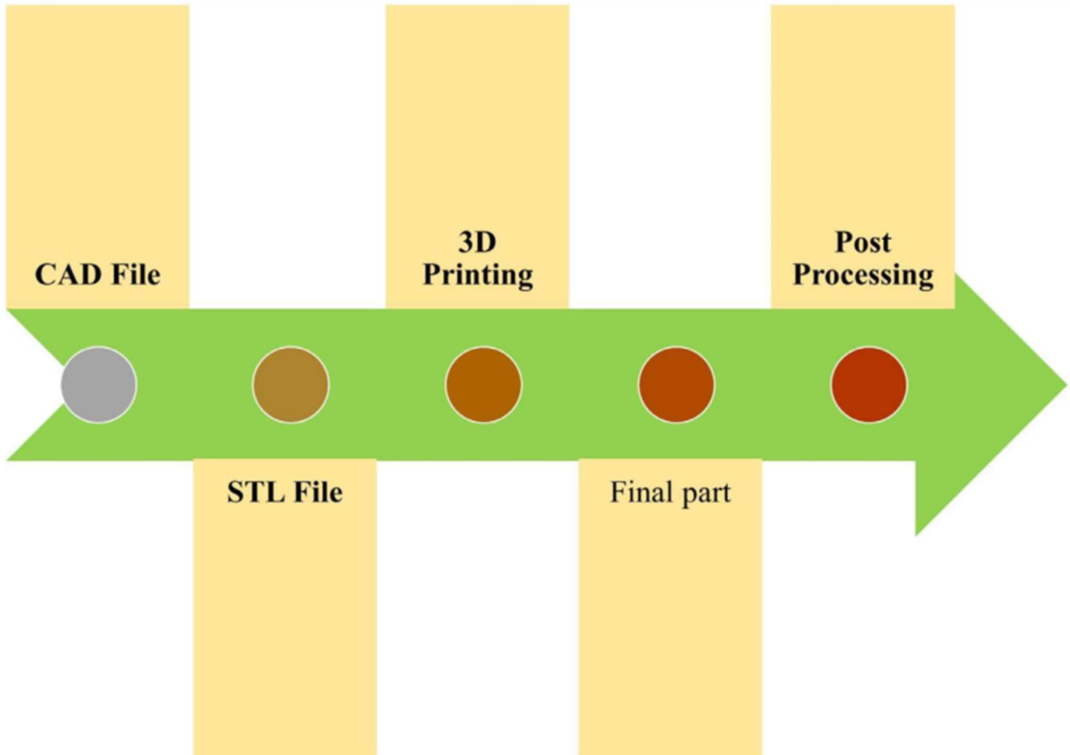

Figure 1: basic scheme of 3D printer to produce 3D object[11].

The marginal gap (MG) has a significant impact on how well dental prosthesis function over time. Greater MG heightens the possibility of leaks due to cement disintegration and wear from chemical and physical abrasion; subgingival plaque and bacterial infiltration may ensue, causing hypersensitivity, secondary caries, and prosthesis failure[12,13].

The American Dental Association Specification No. 8 states that a gap of 25 to 40 µm is adequate for best fitness of fixed prostheses, despite the fact that this distance is difficult to attain in practical practice. McLean and von Fraunhofer, however, indicated a clinically acceptable limit of 120 µm[14].Comparing 3D-printed prostheses to those created by milling or the conventional lost wax process, several investigations have found that the precision of the former falls within the clinically acceptable range[15,16].

Nondestructive methods for evaluating MG and IG include micro-computed tomography and the replica technique[17]. Some drawbacks of the replica approach include that it can be challenging to determine the margins, there could be mistakes if the silicone imprint is sliced or torn, and there are just a few measurement points available[18-21]. Furthermore, the amount of measurement sites, measuring technique, and silicone material type may all have an impact on accuracy[22].

Micro-computed tomography (CT) has been employed in prosthetic dentistry more and more recently, especially for assessing how well restorations are adapted. Although the micro CT approach is comparatively more costly than other procedures, it is non-destructive technique that able to measure the area without causing any damage to the sample, this 3D high-resolution imaging equipment offers comprehensive information while assessing how well the restoration and tooth adapt[23-26].

Since numerous companies are beginning to manufacture 3D printed resin with various qualities and prices, our research aimed to assess the marginal fitness of two commercially available resin types—one at a high cost and the other at an affordable price—and determine whether any differences existed between them. Thus, our null hypothesis states that the marginal fitness of the two resins is the same.

Material and methods

1. Tooth design and digital workflow

1.1 Tooth Design

Virtual lower first molar die representing an actual tooth preparation design for crown were made from acrylic model.

To ensure standardization and reduce errors one acrylic models preparation was used and done by skilled operator, prepatation done on three steps:

For the occlusal part, the depth of reduction was determined by using a depth cut bur (N 268E-M). The tooth then had an occlusal reduction of 1.5 mm by using the trapezoid bur (N 240-M), following the slopes of the cusps and the central groove [27].

Buccal and lingual preparation done by long fissure bur (N 152-C) with round end to obtain chamfer finishing line with a width of 1mm, preparation of both surfaces follows the curvature of the tooth to get a uniform thickness of preparation [28].

proximal surfaces was done using the same steps of buccal and lingual preparation with convergence toward occlusal surface 6º as shown in figure (2). In case of natural tooth preparation with adjacent intact tooth, it is important to use guard wedge or needle bur while leaving thin shell of proximal enamel as a guard for adjacent tooth [27].

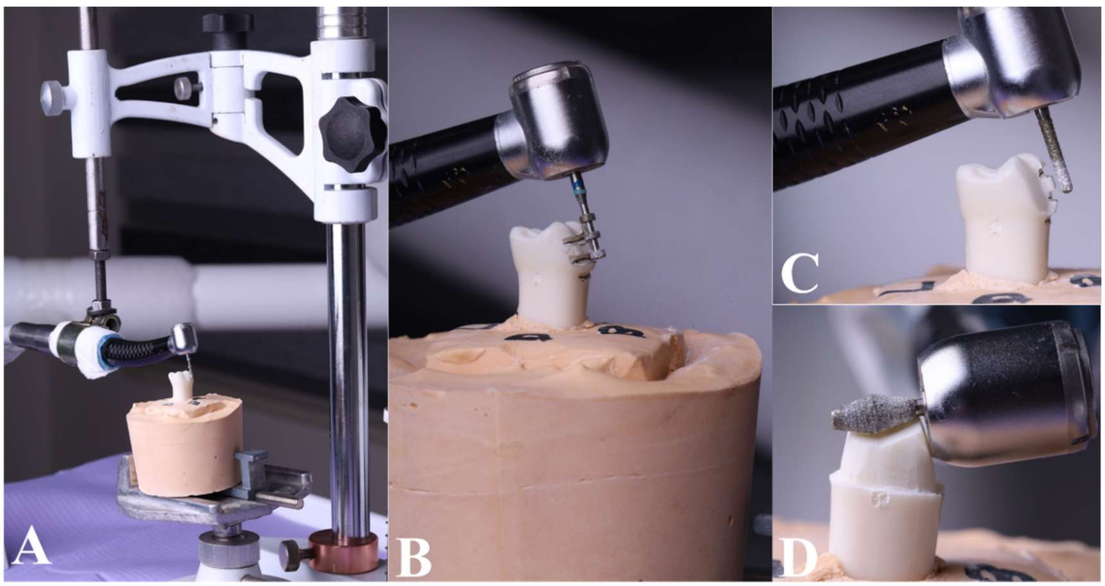

Figure 2:: A, Dental surveyor with highspeed turbine and acrylic model attached to base stone. B, depth orientation grooves to control tooth reduction. C, long fissure bure with round end to aid in labial and lingual tooth reduction, the photo shows half surface reduction with unique preservation of tooth inclination. D, occlusal tooth reduction using trapezoid bur.

All the prepared tooth surface was then finished with red coded bur (N 126-F) then by yellow coded bur (N 165-SF) to get smooth surfaces as shown in figure (3).

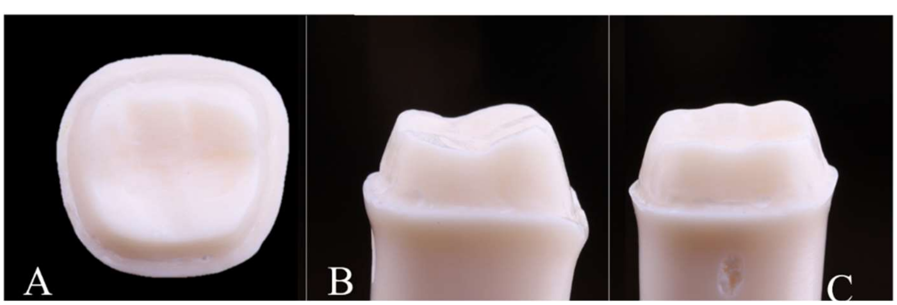

Figure 3: tooth surfaces after finishing A, occlusal view. B proximal view. C lingual view.

The model then scanned with intraoral scanner (medit I 600) and with the aid of EXO-CAD we ensure that our preparation was as the manufacture recommended for 3D printed material as shown in figure (4). preparation was done according to recommended instruction needs for both types of 3D resin (1.5mm occlusal reduction and 1mm proximal reduction with chamfer finishing line), it is recommended to make 4º-6º convergence toward occlusal surface, then its send to CNC machine to convert it to metal

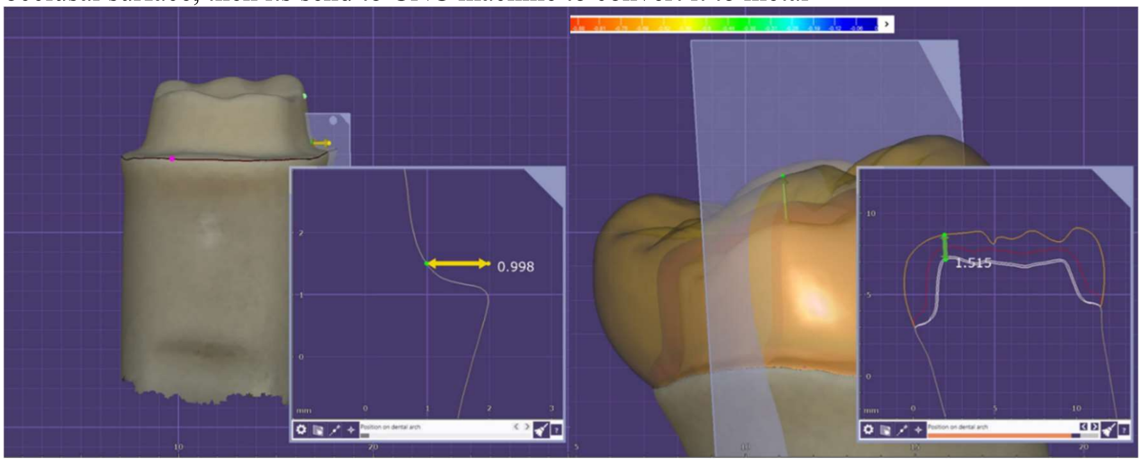

Figure 4: EXO_CAD showing the exact width of our preparation.

1.2 Digital Workflow Of Metal Tooth

After tooth design was completed its sent to CNC machine(magic print for hangbang) to to be printed with other order of the laboratory and convert it to metal tooth as shown in figure (5).

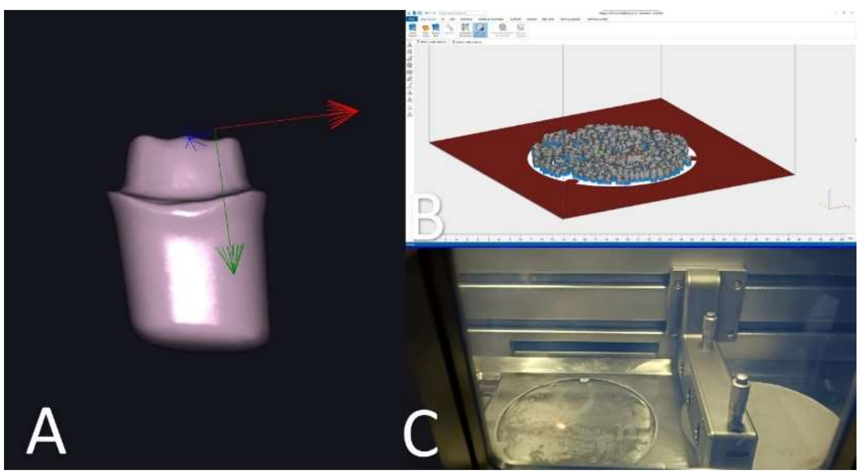

Figure 5:A starting point of print, B model placement with other orders, C machine cutting process

1.3 crown fabrication and digital workflow

a total of 12 crown (n=6 per group) was made using ASIGA 3D printer as following

I- **scan phase**

Digital intraoral scanner (medit I 600) was used to scan the model tooth.Scanning was done according to manufacturer instruction, Create a new case in Case Box and click on the Scan button to launch the I-Scan application and begin scanning ,The scanner head was positioned close to the occlusal surface of the model (5-15 mm) in the mesial direction. Then moved slowly over the occlusal surface of the tooth in a distal direction. The scanner was then rotated to the lingual surface was directed in the mesial direction over the prepared tooth across the whole lingual distance, then moved from the lingual directions to the buccal direction on the other side and directed the whole buccal distance in the mesial direction over the prepared tooth. Finally, the scanner was moved over the model's occlusal surface and rotated 15º in a wave motion in the mesial and distal direction, so a better proximal surface view was obtained.This image was then saved as (STL file format) and finally, exported to EXO_CAD software, where the subsequent steps were done.

II- Administration phase

This stage is carried out in EXO_CAD where we select the type of restoration, designing mode, tooth number, printing unit(3D printer) and material type (3D printed resin both saremco and senertik).

III- Model phase

In this phase, drawing the margin of the preparation manually by the operator as shown in figure (6). The undercut was checked,gap cement space determined, margin thickness and the insertion axis was also determined in this phase.

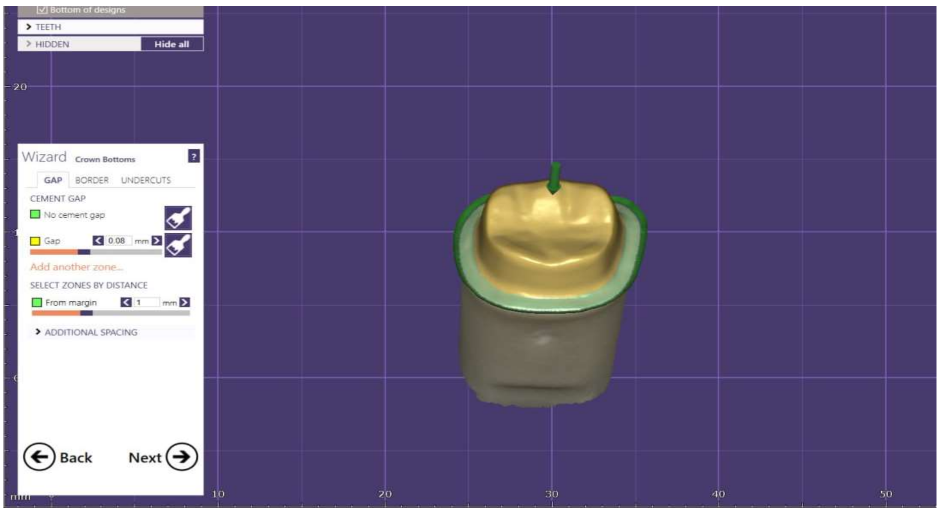

Figure 6: EXO_CAD showing finishing line position.

IV- Design phase

Crowns were designed on a virtual die-that had been scanned with intraoral scanner as shown in figure- using EXO-CAD software, the restoration parameters, anatomy and position of the restoration were determined as shown in figure (7).

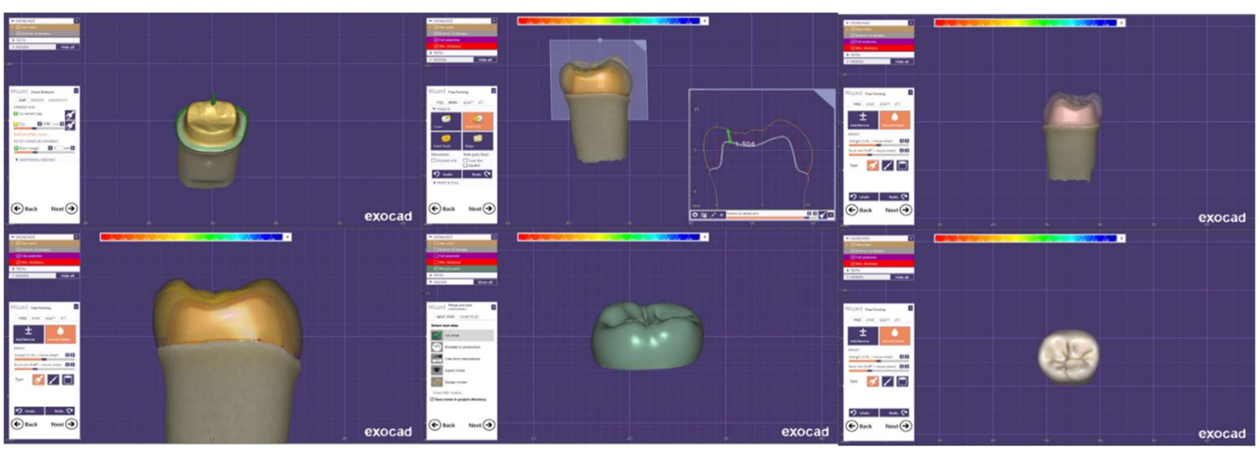

figure 7: EXO_CAD software during the designing of 3D printed crown.

V- printing phase

in this phase the crown design is selected then we adding sprue and determine the slice (which is important to convert the STL file into G-code, G-code contains printer commands, so what slicing does is takes the STL file's geometry data and creates a list of instructions the printer must follow to print the model).as shown in figure (8).

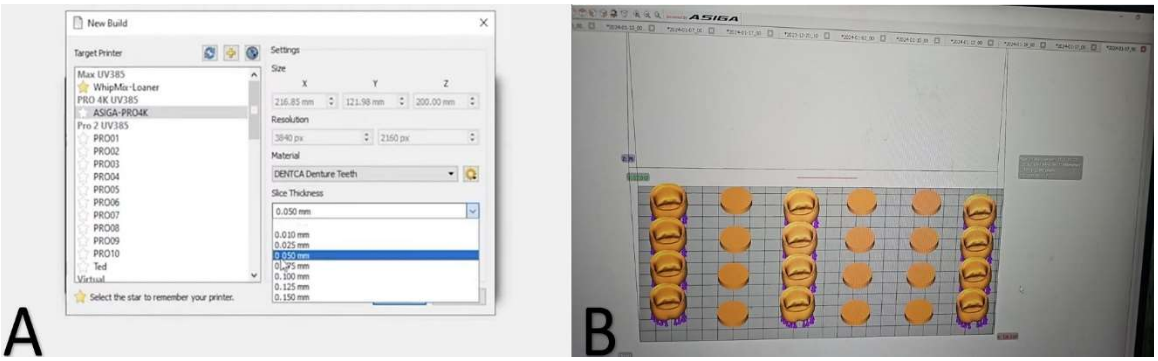

Figure 8:Figure 3.11: ASIGA software showing A slice determination. B the samples with adding sprue for the crown and disk.

Slicing gives our printer instructions based on nozzle size, filament and print profile, taking into account temperature range, speed and extrusion type.

Restoration parameter was done according to each type of material as shown in the following table(1).

Table 1: Recommended Parameter Of Two Resin For ASIGA 3D Printer.

Specification	Saremco	Senertek
Layer thickness	0.05	0.05
Layer count	6	9
Retract speed	150 mm/min	150mm/min
Exposure time	25-35	25-40
Separation velocity	4.300	2.475
Lifting distance	6	5
Lifting speed	60	65

Then we just load the material in the vat of 3D printer then give the order of printing, and the machine will do the rest.

2. post-processing steps

After completing the printing process we go for post-processing of samples to be ready for testing, all 3D printed materials need 4 steps which are device removal, cleaning, post-polymerization, and the removal of supporting structures with finishing and polishing as manufactural instruction.

3. Marginal fitness measurement

A band of 0.5 to 1.0 mm that is situated occlusal to the preparation edge is referred to as a marginal fit[27].

Various techniques for assessing marginal discrepancies have been explained, one of them is microcomputed X-ray tomography (µCT). this approach provides 2D and 3D photographs of the space between the restoration and the die with micrometer accuracy[29]. Micro-computed tomography (micro-CT) has lately gained popularity in restorative and prosthetic dentistry, notably for assessing restoration adaptability. The micro-CT methodology is usually more costly than other approaches, yet it is non-destructive. Without causing defect to the sample .This technique allows the three-dimensional investigation of small objects with high resolution. The marginal gap is obtained within the range of a few micrometers at multiple sites and in multiple directions, Furthermore, even very proximate sections are possible[30].

3.1 Micro-Computed Tomography (µct) Scan Measurement

In this study we used an in vivo X-ray Micro-Computed Tomography (micro-CT) scanner (LOTUS inVivo, Behin Negareh Co., Tehran, Iran) at the Preclinical Core Facility (TPCF) based at Tehran University of Medical Sciences as shown in figure (3.17). LOTUS-inVivo has a cone beam micro-focus X-ray source and a flat panel detector. In order to obtain best possible image quality, the X-ray tube volt age and its current were set to 90 kV and 50 µA respectively and frame exposure time set to 2 seconds by 2.8 magnification. Total scan duration was 60 minutes. Slice thicknesses of reconstructed images were set to 20 micrometers. All the protocol settings were controlled by LOTUS-inVivo-ACQ software. The acquired 3D data was reconstructed using LOTUS inVivo-REC by a standard Feldkamp, Davis, Kress (FDK) algorithm.

After post-processing and artifact reduction of the data, we obtained the two-dimensional (2D) axial projection and selected central sections for point measurements. Measurements were made at four points for coronal sections and four points for sagittal sections. In total, we conducted 48 measurements, with 8 measurements for each sample. We specifically measured the gap between the outer pixels of the two materials in the vertical direction.

Result

Descriptive statistic shows the mean and standard deviation (SD) of the measurements which were taken at points B1, M1, D1, L1, B2, M2, D2, and L2 to calculate the marginal gap, deep chamfer gap, and total gap for two systems, **Senertik** and **Saremco**. For **Senertik System**: The highest gap was observed at the deep chamfer (130.03 (24.46) µm), while the total gap was 126.27 (12.71) µm. For **Saremco System**: The highest gap was observed at the deep chamfer 90.96 (12.63) µm, while the total gap was 79.41 (6.61) µm as shown in table (2)+++++++++

Table 2: Mean And Standard Deviation (SD) Of Marginal Fit And Deep Chamfer

	N	**Points**	**Senertek**				**Saremco**			
			Marginal Gap			**Total Gap**	**Marginal Gap**			**Total Gap**
			Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (S D)
Coronal	6	a-1	120.61 (9.9)	119.18 (7.51)	122.5 (8.50)	126.27 (12.71)	66.57 (21.89	63.97 (8.43)	67.86 (8.78)	79.41 (6.61)
		a-2	117.74 (8.7)				61.38 (23.44)			
Sagittal	6	a-1	124.00 (12.0)	125.83 (8.73)			73.72 (11.83)	71.75 (7.88)		
		a-2	127.66 (9.01				69.79 (10.80)			
			Deep chamfer				**Deep chamfer**			
Coronal	6	b-1	121.42 (6.51)	127.10 (13.09)	130.03 (24.46)		93.76 (20.37)	95.63 (51.23)	90.96 (12.63)	
		b-2	132.78 (21.38)				97.51 (12.8)			
Sagittal	6	b-1	129.79 (20.86)	132.03 (24.46)			90.23 (4.00)	86.28 (8.15)		
		b-2	136.14 (29.23)				82.34 (12.86)			

Inferential Statistics

To assess the normality of the data, the **Shapiro-Wilk test** was performed for both the **Senertek** and **Saremco** systems. The results, including the test statistic, degrees of freedom (df), and p-values, are presented in Table (3). The data from these measurements follows a normal

Table 3: Shapiro-Wilk Test Shows Normality Of Data.

		Shapiro-Wilk		
		Statistic	**df**	**P value**
Senertek	Marginal Gap	0.886	6	0.8
	Deep Chamfer	0.862	6	0.1
Saremco	Marginal Gap	0.990	6	0.1
	Deep Chamfer	0.889	6	0.3

The **Independent T-test** was used to compare the mean marginal gap and deep chamfer gap between the **Senertek** and **Saremco** systems. The mean differences, 95% confidence intervals (CI), and p-values are summarized in Table (4). The mean marginal gap in the Senertek system (122.50 ± 8.50 µm) was significantly higher than that of the Saremco system (67.86 ± 8.78 µm), P = < 0.001. The mean deep chamfer gap for the Senertek system (130.03 ± 18.96µm) was significantly higher than that of the Saremco system (90.96 ± 12.63µm), P = < 0.001.

Table 4: Independent T-Test Result

	N	**Senertic**	**Saremco**	**Difference**	**95% CI**	**P-value**
		Mean ± SD	Mean ± SD			
Marginal Gap	6	122.50 ± 8.50	67.86 ± 8.78	54.64	61.96-47.32	< 0.001
Deep Chamfer	6	130.03 ± 18.96	90.96 ± 12.63	39.07	52.71-25.43	< 0.001

The mean total gap for the **Senertek** system (126.27 ± 12.71µm) was significantly higher than that for the **Saremco** system (79.41 ± 6.61µm), P = < 0.001 Table (5).

Table 5: Difference Between Mean Total Gap.

	N	Senertek	Saremco	Difference	95% CI	P-value
		Mean (SD)	Mean (SD)			
Total Gap	6	126.27 (12.71)	79.41 (6.61)	46.85	55.60-38.10	< 0.001

Discussion

Dentists are concerned with the quality of the marginal fit of a restoration because of the biological ramifications[31]. One important component influencing dental prosthesis long-term success is marginal gap (MG).Larger MG increases the chance of leakage from breakdown and wear of cement produced by physical fatigue and chemical corrosion; the consequent subgingival biofilm accumulation and bacterial invasion may lead to hypersensitivity, secondary caries, and crown failure[32].

For fixed prosthesis, it is challenging to precisely identify a clinically acceptable margin. The margin shouldn't be more than 25 µm when using type I luting cement and 40 µm when using type II luting cement, according ADA standard No. 8[33]. It is challenging to meet such requirements in clinical environments, nevertheless. McLean and von Fraunhofer[34]. found that if the cement film thickness and marginal gap were less than 120 µm, the prosthesis was deemed effective after analyzing the marginal fit of 1,000 fixed prostheses over a five-year period. Numerous researchers have utilized that outcome as a clinical criterion for a successful marginal gap, and many doctors agreed with it[35,36].

µ-CT is an accurate method, preserving the sample, computer-aided method and easily identifying the margin, however, its costly methods, need more time for processing[37].

in µ-CT the result was there is a highly significant difference between two materials as the total Gap for Saremco was (79.41 ± 6.61µm) while for Senertek was (126.27 ± 12.71µm) P = < 0.001.

so according to this study outcome the hypothesis that there is no difference in marginal fitness between to material was rejected.

The gaps were measured with micro-CT had an advantage that didn't require further sample preparation, this non-destructive approach offers a novel way to gather 3-dimensional information. Additionally, it enables precise measurement of the gap from the sectional view at different desirable positions[38,39].

The result of this sturdy was agreement with Jang et al[40]. they found that 3D printing material had a marginal ridge with the acceptable range of permanent crown if printed in 50µm layer thickness, which supposes that layer thickness has a greater impact on a marginal gap than building orientation. This is in contrast to Yang et al[41]. who found no significant effect of layer thickness on marginal fit, which is mostly affected by build orientation. This result is in agreement with Molinero *et al* [42] study as they found from all the materials examined, crowns made of (crowntec-saremco) showed the best manufacturing trueness.

This study is in contrast to Al Wadei et al [43] who found that 50µm layer thickness at 90º build orientation was the worst marginal gap result obtained and he coincided with Alharbi et al[44] who found that 50µm layer thickness gives high marginal discrepancy if it was printed for a chamfer finishing line, the cause behind this elevation is the terrain of chamfer finishing line which have a curved at the axiogingival line angle which may increase the possibility of the stair-stepping effect.

It is worth noting that the model was made from non-precious metal (the cause behind that to get good standardization) which also had some shrinkage reaching about 3.4% because it done at a high temperature[41].

This should be taken into consideration as it may affect the measurement of the crown's marginal fit. We made the scan for the plastic model (from which the crown was constructed) and then converted it to the metal model. This conversion may lead to some change in the dimension of the model, which may have a negative impact on our measurements.

Printer type, layer depth, quantity of layers, layer magnitude, printer wavelength, overall thickness, die-spacer thickness, crown design, UV quantity, post-processing technique, construct angle, and number and position of support structures all affect how accurate 3D printed materials are[45-49].

The post-curing (by means of UV light and heat) of stereolithographically generated objects is necessary to solidify unreacted or partially reacted monomers, thus increasing the mechanical properties of the stereolithographically generated objects[50].

Conclusion

According to the study outcomes marginal fitness data obtained of both materials show good marginal adaptation to be used as permanent crown with some preference toward saremco over senertek company.

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