# EVALUATION OF FLEXURAL STRENGTH, MODULUS, TRANSLUCENCY, STAIN RESISTANCE, AND GLOSS OF DIFFERENT 3D PRINTING MATERIALS.

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ABSTRACT

**Background:** 3D printing, the next step in digital dentistry, has improved the technical accuracy in treating patients. There are many advantages of 3D-printed techniques in the field of prosthodontics. It can be clearly experienced from an intraoral scanner, with its digital data, making many physical working models. With the recent 3D-printed, we can eliminate the traditional impression technique, similar to the fabrication procedure. The milling method, which includes a computerized programmed pattern of cutting the material with, but can be a wastage of materials along with producing noise, heat, and other components (Park, Ahn, Cha, & Lee, 2018)

**Objectives:** To evaluate the flexural strength, modulus, translucency, color stability, and gloss of three types of 3-D printed materials (provisional crown materials, denture base materials, occlusal bite splint materials) compared to control groups of conventionally processed materials.

**Methods:** The flexural strength and modulus were calculated using a universal testing machine. The translucency and stain resistance which was measured by spectrophotometer. The gloss measurement was performed using a gloss meter.

**Results:** Part 1: Most 3D-printed crown and bridge materials had lower flexural strength than traditional materials. One-way ANOVA ($p<0.05$) showed a significant difference between the materials. However, according to Tukey's HSD test, Saremco-Crowntec from the 3D-printed material had similar values to Luxa temp traditional material.

All the denture base materials had higher flexural strength than the traditional material. One-way ANOVA ($p<0.05$) showed that there was a significant difference between the materials. However, according to Tukey's HSD test, only Dentona-Mack 4d showed similar flexural strength to traditional material.

Part 2: The majority of 3D-printed materials had a lower modulus than the traditional materials, one-way ANOVA ($p<0.05$) showed a significant difference between the materials. However, according to Tukey's HSD test, Saremco-Crowntec from the 3D-printed material had similar values to Tempsmart traditional material.

Almost all the 3D-printed denture base materials had higher modulus than the traditional materials except the Dentca-Denture base. One-way ANOVA ($p<0.05$) showed that there was a significant difference between the materials. However, according to Tukey's HSD test, Dentca-Denture base, Asiga-Denture base, and NextDent-Denture base had similar value to the traditional material.

Part 3: Almost all the 3D-printed crown and bridge materials had similar gloss value to traditional material. One-way ANOVA ($p<0.05$) showed that there was a significant difference between the materials. However, according to Tukey's HSD test, Dentca-Denture had the highest gloss measurement while 3D Materials-Teeth A1 had the lowest. All other 3D-printed materials had similar values to some of the traditional materials.

Part 4: All 3D-printed crown and bridge materials had higher translucency properties than the traditional materials. One-way ANOVA ($p<0.05$) showed that there was a significant difference between the materials. Tukey's HSD showed no similar values since all then 3D-printed materials had higher translucency values.

Almost all the 3D-printed denture base materials had higher translucency except Qura-Qura base material. One-way ANOVA ($p<0.05$) showed that there was a significant difference between the materials. However, Tukey's HSD test showed similar values to traditional materials.

Part 5: Most 3D-printed crown and bridge materials showed higher staining properties than traditional materials. One-way ANOVA ($p<0.05$) showed that there was a significant difference between the materials. However, according to Tukey's HSD test, only Dentca-Dentca teeth A1 showed similar staining properties to traditional materials.

The majority of the 3D-printed denture base materials had higher staining properties than the traditional material. One-way ANOVA ($p<0.05$) showed that there was a significant difference between the materials. However, according to Tukey's HSD test, the Qura-Qura base and NextDent-Denture base showed similar staining properties to the traditional material.

**Conclusions:** Overall, within the limitations of this study, even though a significant similarity between the 3D-printed and traditional materials could not be found, this study was able to showcase the different properties of each of the materials allowing the user to choose, based on the use and requirements in each of the patients. Because of the inherent benefits of 3D-printed technology, this study highlights the need for further research on the existing 3D-printed material to outperform the existing conventional materials and improve the durability of the 3D-printed structures and the complete patient experience. A more complete understanding of each of these materials' physical and chemical properties and their performance could help choose the best 3D-printed materials to be used and help improve their properties by considering other means of enhancing the overall performance of these materials.

**Keywords:** Flexural strength, modulus, translucency & color stability (staining), 3D-printed materials, and traditional materials.

## DEDICATION

This thesis is dedicated to my parents; without their support and motivation, I would never get this opportunity to be a part of this university and this research project. To my undergraduate teachers, who had made me this capable and knowledgeable, with their teaching only I gain confidence and belief in myself to come this far.

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## LIST OF ABBREVIATIONS

CAD- Computer-Aided Design

CAM- Computer-Aided Manufacturing

DLP- Digital Light Processing

SLA- Stereolithography

PMMA- Polymethyl methacrylate

C&B- Crown and Bridge

DB- Denture base

OBS- Occlusal bite splint

RP- Rapid prototyping

# 1. INTRODUCTION

Since the advent of 3D printing technology, its use in dentistry has evolved and expanded over the past 25 years in various fields such as Orthodontics, Periodontics, Pediatric dentistry, Restorative dentistry, Endodontics, Implant, and Prosthetic Dentistry, among others. The use of Computer Aided Designing and Manufacturing (CAD/CAM) concept was introduced and patented by Dr. Francois Duret in 1973 and saw increased usage and advancement in the 2000s. Digital oral impression and 3D printing and milling using CAD/ CAM for constructing different types of dental products such as models, templates for implants, and restoration using temporary materials can now be used instead of the traditional manual manufacturing of oral impressions for increased accuracy and ease (Zaharia et al., 2017),(Jeong et al., 2018).

3D printing, the next step in digital dentistry, has been an advancement in the technical accuracy in treating patients. There are many advantages of 3D printing techniques in the field of prosthodontics. It can be clearly experienced from an intraoral scanner, with digital data, making many physical working models. With 3D printing, digital impressions can be utilized to create a completely digital workflow, similar to that used for milling. However, the milling method includes a computerized programmed pattern of cutting materials, creates material waste, and produces noise, heat, and other components. Here 3D printing can be a significant change that will not lead to any wastage of materials without an unfavorable force (Park et al., 2018).

The application of 3D printing has also extended in oral and maxillofacial prosthesis (Neto et al., 2015) (Fernandes et al., 2016). Based on its machining procedure, a working model utilizing a 3D printer may be categorized into two classifications: processing or 3D printing using quiet oral information procured with an intraoral scanner. (Patzelt et al., 2014). Additionally, the benefits of 3D printing include the creation of prostheses and models with a minimal amount of material, and the capacity to make numerous items one after another (Yau et al., 2016)

3D printing uses the additive process where selective dental material creates a complex structure based on the 3D design file produced after scanning. 3D printing involves four primary stages: 1. 3D modeling using software/ intra-oral scanning/ computed tomographic data, 2. slicing the 3D model and processing it into 2D layers, 3. printing the various 2D layers to re-create the 3D model end product, and post-processing of the 3D model end product (Oberoi et al., 2018). The materials used for 3D printing include poly-methyl methacrylate (PMMA), resin polymers, resin composites, wax, and some metals. (Rekow, 2020). Based on the fabrication process, 3D printing technology can be categorized into extrusion printing, ink-jet printing, laser melting/ sintering, and lithography printing (Tahayeri et al., 2018).

3D printing is different from the subtractive milling process used earlier to create a replica like the previous tooth structure manual by trimming and grinding and recently using the multi-axis CAD/ CAM milling process. The manual or digitalized milling process results in increased waste of the material as the dental structure is carved out from an intact material, microscopic wear and tear of the raw material, difficulties associated with recycling raw materials, and the wear of the milling devices (Dehurtevent et al., 2017)(Yau, Yang & Lin, 2016), (S. Y. Kim et al., 2018), (Prasad et al., 2018). The benefits of using digital impressions are the ease of production without the need for storage, ease of replication and reproduction of complex dental structures, the ease of transportation of the product to an external facility, improved patient perception, and the comfort of the patient, among others (Brown et al., 2018). Improvements in 3D printing in dentistry involve improvements in 3D printers, such as their smaller size, ease of operation, and improved affordability. The following improvements needed in dental 3D printing is improvement in the product outcome. This concern with low-quality printed products raises the need to research different dental 3D printing materials and the quality of the final product to identify and provide the best service for patients.

The 3D printing techniques used are material extrusion, material jetting, binder jetting, vat polymerization, powder bed fusion, direct energy deposition, and sheet lamination (Santoliquido et al., 2019), (Ye et al., 2019). Out of the various 3D printing techniques, dentistry's standard methods are Stereolithography, Digital light processing, material jetting, and material extrusion (Rekow, 2020).

According to a study by Tahayeri, 2018; 3D printing materials are widely used for provisional crowns and bridges. Also, these provisional crown and bridge materials are appropriate for intro oral use (Tahayeri et al., 2018). Along with its use in the fabrication of surgical guides (G. de A. P. Di Giacomo et al., 2016), (Fathi et al., 2016), (G. Di

Giacomo et al., 2014), diagnostic modules (Salmi, 2016), occlusal bite splints (Salmi et al., 2013), and many more.

From the past decade, due to the substantial use of CAD/CAM in dentistry, numerous technical approaches and a large number of novels have been instigated for the digital workflow of manufacturing of the complete denture (Srinivasan et al., 2020), (Schweiger et al., 2018), (Millet et al., 2020), (Kraemer Fernandez et al., 2020). Using additive technologies, well-fitted dentures are produced using 3D-printed denture base materials (Lin et al., 2018), (Unkovskiy et al., 2019). The digital workflow for edentulism rehabilitation revealed positive reports using 3D-printed denture base materials (Cristache et al., 2020). Coating materials can be opted for the additively-produced denture base as an alternative (Choi et al., 2020). According to a study, self-designed denture teeth sets can reduce chair time after fabricating it by CAD/CAM and RP for esthetics and occlusion (Bilgin et al., 2015). According to a study by Park et al., 2018; reported that there was no significant difference in wear resistance between 3D-printed resin material and self-cure resin material (Park et al., 2018)

3D printing materials are widely used in interim restorations. A study conducted by Lee et al., 2017 to evaluate the internal fit of interim crown fabrication with CAD/CAM milling and 3D-printed materials showed higher fitting accuracy than the milling materials (W. S. Lee et al., 2017). Another study by Peng, 2020; reported that 3D-printed materials had a better marginal discrepancy and internal fit than the interim crowns fabricated manually (Peng et al., 2020).

Occlusal bite splints are occlusal orthopedic to treat temporomandibular disorders and bruxism. Most ordinarily, they are made of polymethylmethacrylate, which is the highest quality level. Further advancement of innovation empowered the manufacture of occlusal supports utilizing CAD/CAM and added substance advances (Prpić et al., 2020).

There are various methods for the fabrication of occlusal bite splints. The conventional approach is used by sprinkling the acrylic resin, vacuum thermoforming, or combining both methods (Bohnenkamp, 1996). According to the recent CAM process, there are two ways of making occlusal bite splints, the splints can be manufactured additively or milled out of a prefabricated blank. There is a waste of material and a lot of wear in the subtractive method; especially while doing ceramic materials, there is high wear of milling burs; moreover, it can be time-consuming. Several devices can be made concurrently, and only the supporting structure must be discarded in the additive method (Strub et al., 2006).

According to Joshi, 2019; there is a lack of studies on the properties of 3D-printed materials compared to traditional materials (Joshi, 2019). This study will have 13 groups, including crown and bridge materials, denture materials, and occlusal bite splint materials. This study evaluated flexural strength and modulus, gloss measurement, translucency, and stain resistance of 3D-printed materials.

# 2. OBJECTIVES

The main objective is to evaluate the flexural strength, modulus, translucency, color stability, and gloss of three types of 3D-printed materials (provisional crown materials, denture base materials, occlusal bite splint materials) to control groups of conventionally processed materials.

## 2.1 To evaluate the flexural strength and modulus of provisional crown materials, denture base material, and occlusal bite splint materials.

The objective is to measure and compare the flexural strength and modulus of 3D- printed materials and the control group.

## 2.2 To evaluate the translucency and color stability of provisional crown materials, denture base material, and occlusal bite splint materials.

The objective is to measure and compare the translucency and color stability of 3D- printed materials and the control group.

## 2.3 To evaluate the gloss of provisional crown materials, denture base material, and occlusal bite splint materials.

The objective is to measure and compare the gloss of 3D-printed materials and the control group.

## 3. NULL HYPOTHESES

1. There will be no significant difference between the **flexural strength** and **modulus** in 3D-printed materials and the control group.

2. There will be no difference significant between the **translucency and color stability** in the 3D-printed materials and the control group.

3. There will be no significant difference between the **gloss measurement** in 3D-printed materials and the control group.

## 4. MATERIALS

### 4.1 Six 3D-printed Provisional Crown Materials

1. Dentona – Optiprint – C&B
2. Dentca – Dentca teeth A1 – C&B
3. Saremco – Crowntec – C&B
4. 3D Materials – Teeth A1 – C&B
5. NextDent – MFH resin A1 – C&B
6. Asiga – Denta Tooth – C&B

*Table 1: Trade names and pictorial representation of crown and bridge 3D-printed materials used in the study.*

| Group | Material Type | Manufacturer | Material Name | Pictorial Representation |
|---|---|---|---|---|
| **3D-printed Material** | Crown & Bridge Material | Dentona | Optiprint |   |
| **3D-printed Material** | Crown & Bridge Material | Dentca | Dentca teeth A1 |   |

| | | | | |
|---|---|---|---|---|
| **3D-printed Material** | Crown & Bridge Material | Saremco | Crowntec |  |
| **3D-printed Material** | Crown & Bridge Material | 3D Materials | Teeth A1 |  |
| **3D-printed Material** | Crown & Bridge Material | NextDent | MFH resin A1 |  |
| **3D-printed Material** | Crown & Bridge Material | Asiga | Denta tooth |  |

**4.2 Five 3D-printed Denture Base Materials**

1. Dentona – Mack 4D – DB
2. Qura – Qurabase – DB
3. NextDent – Denture base – DB
4. Asiga – Denta Base – DB
5. Dentca – Denture base – DB

*Table 2: Trade names and pictorial representation of denture base 3D-printed materials used in the study.*

| Group | Material Type | Manufacturer | Material Name | Pictorial Representation |
|---|---|---|---|---|
| **3D-printed Material** | Denture Base Material | Dentona | Mack 4D |   |
| **3D-printed Material** | Denture Base Material | Qura | Qurabase |   |

| | | | | |
|---|---|---|---|---|
| **3D-printed Material** | Denture Base Material | NextDent | Denture Base |  |
| **3D-printed Material** | Denture Base Material | Asiga | Denta Base |  |
| **3D-printed Material** | Denture Base Material | Dentca | Denture Base |  |

### 4.3 Two 3D-printed Occlusal Bite Splint Materials

1. Voco – Vprint Ortho – OBS
2. Dentona – Splint – OBS

*Table 3: Trade names and pictorial representation of occlusal bite splint 3D-printed materials used in the study.*

| **Group** | **Material Type** | **Manufacturer** | **Material Name** | **Pictorial Representation** |
|---|---|---|---|---|
| **3D-printed Material** | Occlusal Bite Splint Material (Occlusal guard) | Voco | Vprint Ortho |  |
| **3D-printed Material** | Occlusal Bite Splint Material (Occlusal guard) | Dentona | Splint |  |

**4.4 Four Provisional Crown Materials as control and Self-cure Material as a control for Denture Base Materials.**

1. Tempsmart – C&B
2. Alike – C&B
3. Luxacrown – C&B
4. Luxa Temp –C&B
5. Self-Cure – DB

*Table 4: Trade names and pictorial representation of traditional materials used in the study.*

| Group | Material Type | Manufacturer | Material Name | Pictorial Representation |
|---|---|---|---|---|
| **Traditional Material (Control)** | Crown and Bridge Material | GC (Gas Chromatography) America | Tempsmart |  |
| **Traditional Material (Control)** | Crown and Bridge Material | GC America | Alike |  |
| **Traditional Material (Control)** | Crown and Bridge Material | DMG America | Luxacrown |  |
| **Traditional Material (Control)** | Crown and Bridge Material | DMG America | Luxa Temp |  |

| | | | | |
|---|---|---|---|---|
| **Traditional Material (Control)** | Denture Base Material | Yates Motloid | Self-Cure |  |

All 3D-printed materials were obtained from our collaborator at MUSC School of Dentistry. All materials were coded with a number. Four provisional crown materials were included as controls (Bisacryl: Tempsmart, Luxacrown, Luxa temp; and PMMA: Alike). One self-cure acrylic denture base material was added as a control.

## 5. METHODS

5.1 Flexural strength and modulus:

The three-point bend flexural strength bars of the materials were fabricated. For 3D-printed materials, a .stl file was designed in AutoCAD measuring (2 mm x 4 mm x 25 mm). The materials were then printed and cured according to the manufacturer's directions. For self-cure control, materials were prepared by dispensing material into Teflon molds producing bars measuring 2 mm x 4 mm x 25 mm. The molds were covered by a mylar strip and glass slide and allowed to polymerize. All excess material was removed by polishing with 600 grits SiC paper. Specimens were stored in water for 7 days.

Specimens (n=10) were placed in a universal testing machine on 20-mm separated supports and loaded to failure at 1 mm/min (Figure 1). The maximum failure load was used to calculate the flexural strength and fracture toughness.

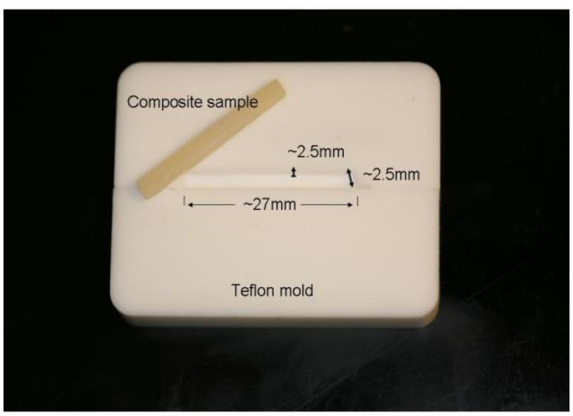


Figure 1. Flexural strength specimen mold

Figure 2. Flexural strength set-up on Instron

5.2 Gloss

2mm thick flat specimens were fabricated from all materials to be tested by 3D-printed or using Teflon molds as described above. All specimens were wet polished with 600 grits SiC paper before measuring gloss (Figure 3). All the specimens were polished by the same operator to ensure the same pressure on the polishing paper. The polishing was divided into two steps. Step 1 included polishing with the 600-grit sandpaper; step 2 had polishing with the 2 step Brasseler polishing kit.

Figure 3. Buehler polisher

The specimens were sonicated to remove surface debris, cleaned with strong water spray, and blotted with a clean laboratory absorbent wipe. Gloss measurements were then recorded using a gloss meter (Novo-Curve, Rhopoint Instruments, East Sussex, UK) using 60-degree geometry (Figure 4). Gloss measurements were made by aligning the specimens in 2 perpendicular directions (Figure 5). Two gloss unit (GU) values were recorded from each specimen and averaged.


Figure 4: Gloss meter

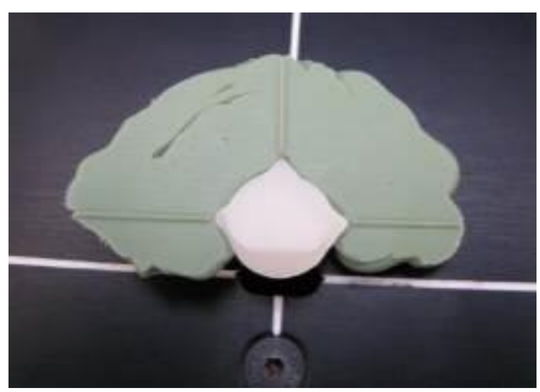

Figure 5: A Specimen on the gloss meter

Step 2 included polishing the specimens with an SWR22F ET ProviPro Medium Orange Provisional Polishing Buff (Figure 6) for 30 seconds dry at 15000 RPM and then an SWR22M ET ProviPro Fine Pink Provisional Polishing Buff (Figure 7) for 30 seconds dry at 15000 RPM. Gloss was remeasured.

Figure 6. Medium Orange Buff

Figure 7. Fine Pink Buff

5.3 Translucency and staining

2mm thick flat specimens were fabricated from all materials to be tested by 3D-printed or using Teflon molds as described above. The specimens were not polished before testing.

Initial L*a*b* values were taken using a spectrophotometer (CM-700d; Konica Minolta, Ramsey, NJ) against a white and black background made from a poster board (Figure 8). Silicone putty fixtures for the spectrophotometer were produced, and a one-second sampling delay was used to minimize instrument vibrations during measurement. CIE lab

1976 formulas were used, SCE (specular component excluded), SAV, 10-degree geometry, with each sample measured twice and then averaged together by the spectrophotometer.

Figure 8. Spectrophotometer


Figure 9. Staining solution ingredients

Specimens of each material were then stored in a staining solution composed of 600mL of red wine, 3 black tea bags, and 50mL instant coffee (Figure 9) at 37 C in darkness for 12 days (1-year simulation).

After storage, specimens were cleaned in distilled water in an ultrasonic bath for 10 minutes. L*a*b* measurements were taken in the same orientations as the initial values against a white background.

Translucency was measured as delta E2000 between the specimens tested against white and black backgrounds. Staining was calculated as the delta E2000 between the specimens before and after staining.

## 6. STATISTICAL ANALYSIS

A one-way ANOVA was used to compare 3D-printed provisional materials with traditional provisional materials and 3D-printed denture base materials with self-cure traditional material. ($p<.005$).

Tukey post-hoc analysis was used to compare and divide all groups into statistically similar groups.

Statistical analyses were conducted using the SPSS® computer software system, release 27 (IBM SPSS Statistics; IBM Co., NY, USA).

# 7. RESULT

## 7.1 Flexural Strength of 3D-printed materials and Traditional materials

### *7.1.1 Flexural Strength*

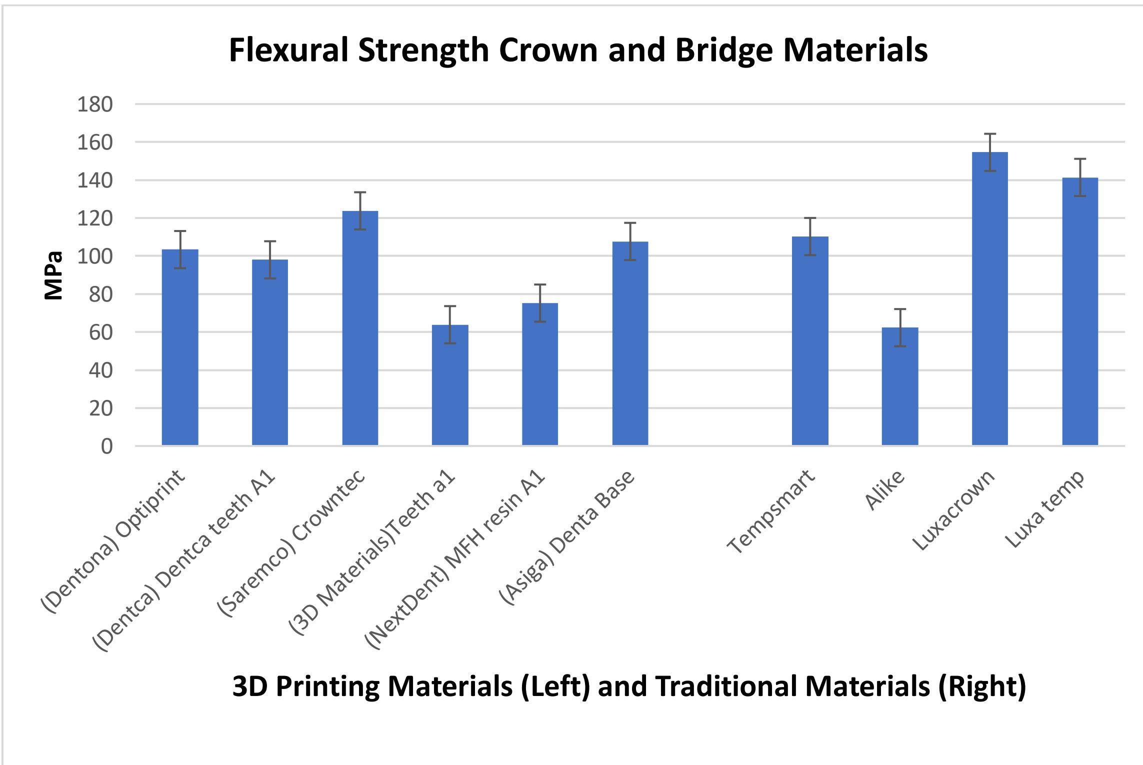


Figure.10 Flexural Strength Crown and Bridge Materials and Traditional Materials

### *7.1.2 Flexural Strength for 3D-printed Crown & Bridge Materials and Traditional Materials Mean and Standard Deviation*

*Table 5. Flexural strength for 3D materials (N=118) and traditional material (N=50)*

| Type | Material | Mean±SD |
|---|---|---|
| 3D-printed C&B Material | (Dentona) Optiprint | $103.3844\pm21.93031^{b}$ |

| | | |
|---|---|---|
| | (Dentca) | 98.0123±6.89181[b] |
| | (Saremco) Crowntech* | 124.9378±10.52362[c] |
| | (3D materials) Teeth a1* | 63.8423±9.99996[a] |
| | (NextDent) MFH resin A1 | 75.2204±7.25443[a] |
| | (Asiga) Denta Base | 108.9088±11.48383[b] |
| Traditional C&B Material | Tempsmart | 110.2699±5.63215[c] |
| | Alike** | 62.2838±3.45313[a] |
| | Luxacrown** | 154.5741±13.92231[d] |
| | Luxa Temp | 141.3962±9.02918[d] |

* Out of all the 3D-printed crown and bridge materials, Saremco-Crowntech 124.9378±10.52362 and Asiga- Denta base 108.9088±11.48383 has the highest flexural strength while Tempsmart 110.2699±5.63215 and Alike had the lowest flexural strength in the traditional materials

### *7.1.3 Statistical Analysis*

*Table 6. One Way ANOVA of flexural strength for crown and bridge 3D-printed materials*

**ANOVA**

VAR00002

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 86745.957 | 9 | 9638.440 | 77.561 | .000 |
| Within Groups | 11184.196 | 90 | 124.269 | | |
| Total | 97930.153 | 99 | | | |

There was a statistically significant difference between the crown and bridge 3D materials and traditional materials as per the one-way ANOVA test. Overall [$F(9,90)=77.561$, $p<0.001$]. Most 3D-printed materials fell in the lower flexural strength range except for Saremco-Crowntec. The highest flexural strength was seen with the Luxa temp (141.3962) and Luxacrown (154.5741) from the traditional material group, whereas Tempsmart (110.2699) was in the average range sharing similarities with the 3D material Asiga-Dentabase and Saremco-Crowntec. Alike materials had the least flexural strength of all shared similarities with 3D Materials-teeth A1 and NextDent-MFH resin A1 materials. Asiga-Dentabase (108.9088) had the second-highest flexural strength amongst the 3D materials.

*Table 7. Tukey HSD of flexural strength for crown and bridge 3D-printed materials and traditional materials.*

Tukey HSD[a]

| | | Subset for alpha = 0.05 | | | |
|---|---|---|---|---|---|
| VAR00001 | N | 1 | 2 | 3 | 4 |
| Alike | 10 | 62.2838 | | | |
| (3D Materials) teeth A1 | 10 | 63.8423 | | | |
| (NextDent) MFH resin A1 | 10 | 75.2204 | | | |
| (Dentca) Dentca teeth A1 | 10 | | 98.0123 | | |
| (Dentona) Optiprint | 10 | | 103.3844 | | |
| (Asiga) Denta Base | 10 | | 108.9088 | 108.9088 | |
| Tempsmart | 10 | | 110.2699 | 110.2699 | |
| (Saremco) Crowntec | 10 | | | 124.9378 | |

| | | | | | |
|---|---|---|---|---|---|
| Luxa temp | 10 | | | | 141.3962 |
| Luxacrown | 10 | | | | 154.5741 |
| Sig. | | .235 | .305 | .054 | .213 |

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

## 7.2 Flexural Strength for Denture Base Materials and Traditional material

### *7.2.1 Flexural Strength*

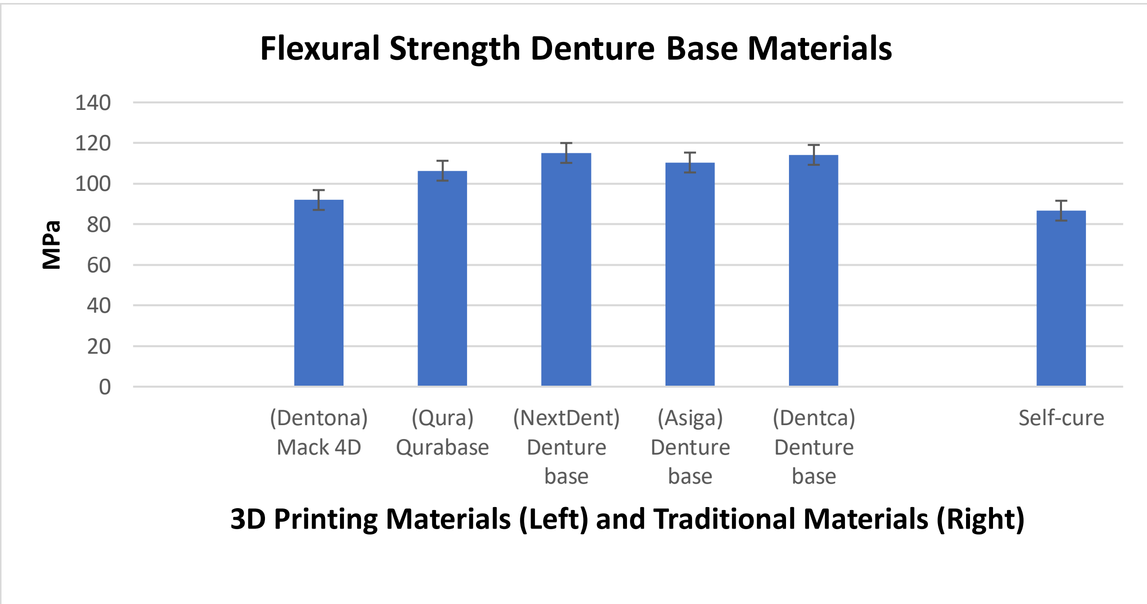


Figure.11 Flexural Strength Denture Base Materials and Traditional Material

### *7.2.2 Flexural Strength for Denture Base Materials Mean and Standard Deviation*

*Table 8. Flexural strength for 3D-printed and traditional denture base material*

| Type | Materials | Mean±SD |
|---|---|---|
| 3D-printed DB Materials | (Dentona) Mack 4D* | 91.9328±10.98471[a] |
| | (Qura) Qurabase | 106.3591±7.25492[a,b] |
| | (NextDent) Denture base* | 115.1018±22.78657[b] |
| | (Asiga) Denture base | 110.3839±14.66531[b] |
| | (Dentca) Denture base | 114.1528±5.54883[b] |
| Traditional Denture Base Material | Self-Cure | 86.6843±16.16470[a] |

Out of all the 3D-printed denture base material (NextDent)Denture base (115.1018±22.78657) has the highest flexural strength, and (Dentona) Mack 4D(91.9328±10.98471) had similar values to self-cure. In contrast, self-cure had an 86.6843±16.16470 flexural strength value.

### <u>*7.2.3 Statistical Analysis*</u>

*Table 9. One Way ANOVA of flexural strength for denture base 3D-printed materials*

| | | Sum of Squares | Df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| VAR00002 | Between Groups | 3486.898 | 4 | 871.725 | 4.571 | .004 |
| | Within Groups | 8199.615 | 43 | 190.689 | | |
| | Total | 11686.513 | 47 | | | |

Based on the One-Way-ANOVA results, all the denture Base 3D-printed materials had higher flexural strength than the traditional self-cure materials. However, self-cure and

3D-printed materials Dentona-Mack-4D share similarities, whereas the 3D-printed materials Qura-Qurabase and Asiga-Dentabase share similarities with Dentca-Denture-base NextDent-Denture base (See Table 8 and Table 9).

*Table 10. Tukey HSD of flexural strength for denture base 3D-printed materials*

Tukey HSD [a,b]

| | | Subset for alpha = 0.05 | | |
|---|---|---|---|---|
| VAR00001 | N | 1 | 2 | 3 |
| Self-cure | 10 | 86.6843 | | |
| (Dentona) Mack 4D | 10 | 91.9328 | 91.9328 | |
| (Qura) Qurabase | 10 | | 106.3591 | 106.3591 |
| (Asiga) Denta base | 9 | | 110.3839 | 110.3839 |
| (Dentca) Denture base | 9 | | | 114.1528 |
| (NextDent) Denture base | 10 | | | 115.1018 |
| Sig. | | .965 | .066 | .757 |

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 9.643.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

## 7.3 Modulus for Crown and Bridge and Traditional materials

### *7.3.1 Modulus*

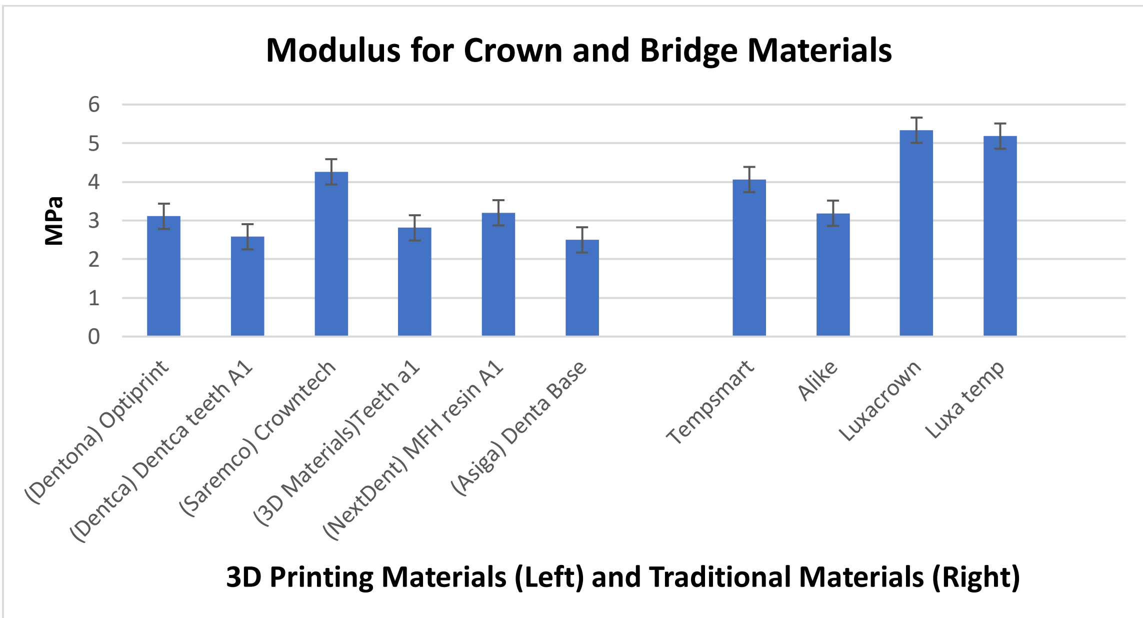


Figure.12 Modulus of Crown and Bridge Materials and Traditional Materials

### *7.3.2 Modulus of 3D-printed Crown & Bridge Materials and Traditional Materials Mean and Standard Deviation*

*Table 11. Modulus for 3D materials (N=118) and traditional material (N=50)*

| Type | Material | Mean±SD |
|---|---|---|
| 3D Material | (Dentona) Optiprint | 3.1160±.19879[c] |
| | (Dentca) Dentca teeth A1 | 2.5760±.10276[a,b] |
| | (Saremco) Crowntech* | 4.2644±.27794[d] |
| | (3D Materials) Teeth a1 | 2.8050±.32353[b] |
| | (Next Dent) MFH resin A1 | 3.1970±.22096[c] |
| | (Asiga) Denta Base | 2.5000±.08679[a] |

| | | |
|---|---|---|
| Traditional Material | Tempsmart* | 4.0600±.41952[b] |
| | Alike | 3.1890±.36290[a] |
| | Luxacrown | 5.3350±.64274[c] |
| | Luxa Temp | 5.1830±.34753[c] |

* Out of all the 3D-printed crown and bridge materials, Saremco-Crowntech 4.2644±.27794 has the highest modulus in the 3D-printed group and had similar values to Tempsmart 4.0600±.41952 from the traditional material group. Luxacrown and Luxa temp had a higher modulus than all the 3D-printed materials.

*7.3.3 Statistical Analysis*

*Table 12: One way ANOVA of modulus for crown and bridge 3D-printed materials*

**ANOVA**

VAR00002

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 95.787 | 9 | 10.643 | 93.856 | .000 |
| Within Groups | 10.092 | 89 | .113 | | |
| Total | 105.879 | 98 | | | |

There was a statistically significant difference between the crown and bridge 3D materials and traditional materials as per the one-way ANOVA test. Overall [F (9,89)=93.856, (p<0.005)].Taking a closer look at Tukey's result, even though ANOVA shows that the materials are significantly different, Saremco-Crowntec and temp-smart shared similar values, and the other three materials from the 3D-printed group had similar values to Alike material. Overall, the traditional material Luxacrown has the highest modulus, followed closely by Luxa temp in traditional materials.

*Table 13. Tukey HSD of modulus for 3D-printed materials and traditional materials*

Tukey HSD[a,b]

| | | Subset for alpha = 0.05 | | | |
|---|---|---|---|---|---|
| VAR00001 | N | 1 | 2 | 3 | 4 |
| (Asiga) Denta Tooth | 10 | 2.5000 | | | |
| (Dentca) Dentca teeth A1 | 10 | 2.5760 | | | |
| (3D Materials) Teeth a1 | 10 | 2.8050 | 2.8050 | | |
| (Dentona) Optiprint | 10 | | 3.1160 | | |
| Alike | 10 | | 3.1890 | | |
| (NextDent)MFH resin A1 | 10 | | 3.1970 | | |
| Tempsmart | 10 | | | 4.0600 | |
| (Saremco) Crowntec | 9 | | | 4.2644 | |
| Luxa temp | 10 | | | | 5.1830 |
| Luxacrown | 10 | | | | 5.3350 |
| Sig. | | .592 | .239 | .939 | .991 |

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 9.890.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

## 7.4 Modulus for Denture Base

### *7.4.1 Modulus*

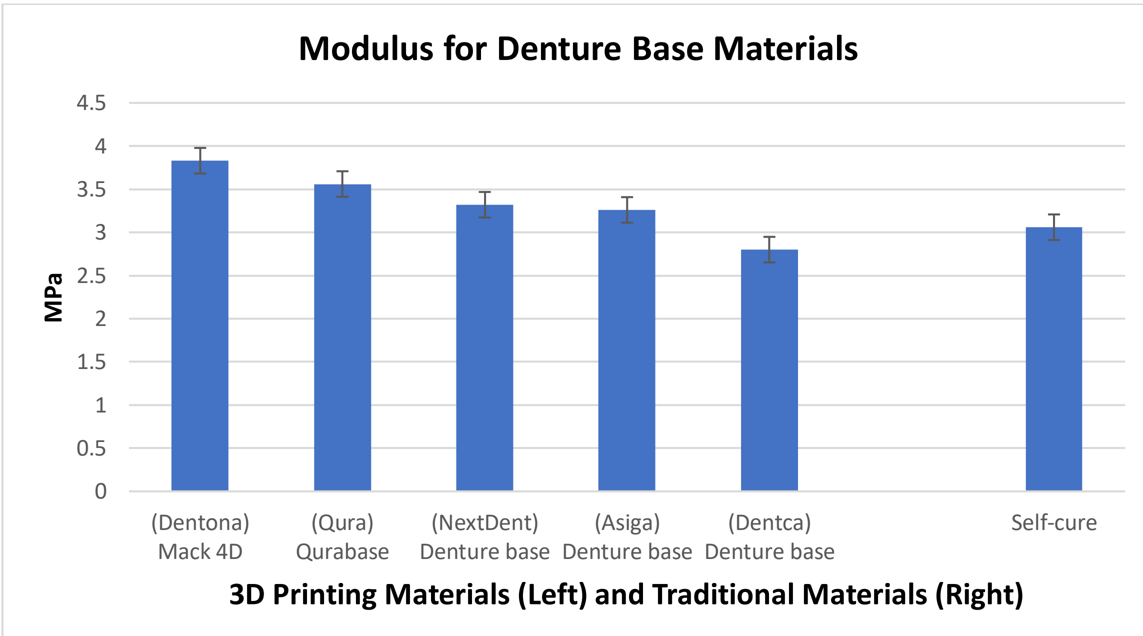


Figure.13 Modulus of Denture Base Materials and Traditional Material

### *7.4.2 Modulus of 3D Denture Base Materials and Traditional Material Mean and Standard Deviation*

*Table 14. Modulus for 3D-printed and traditional denture base materials.*

| Type | Materials | Mean±SD |
|---|---|---|
| 3D-printed Denture Base Materials | (Dentona) Mack 4D* | 4.2644±.27794[d] |
| | (Qura) Qurabase | 3.5560±.11147[c] |
| | (NextDent) Denture base | 3.3180±.15583[b] |
| | (Asiga) Denture base | 3.2610±.14579[b] |
| | (Dentca) Denture base* | 2.8044±.03432[a] |

| | | |
|---|---|---|
| Traditional Denture Base Material | Self-Cure | 3.0600±.57190[a,b] |

* Out of all the 3D-printed denture base material (Dentona) Mack 4D, 4.2644±.27794 has the highest modulus, and the majority of 3D-printed materials had higher modulus values than the self-cure traditional material. Self-Cure had the modulus 3.0600±.57190 from traditional denture base materials.

### *7.4.3 Statistical Analysis*

*Table 15. One way ANOVA of modulus for denture base 3D-printed materials*

**ANOVA**

VAR00002

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 11.532 | 5 | 2.306 | 29.303 | .000 |
| Within Groups | 4.093 | 52 | .079 | | |
| Total | 15.624 | 57 | | | |

There was a statistically significant difference between the crown and bridge 3D materials and traditional materials as per the one-way ANOVA test. Overall [F (5,52)=29.303, p<0.001]. The traditional material self-cure is very similar to most 3D-printed materials in terms of modulus. Dentca-Denture-Base has the lowest modulus; Dentona-Mack-4D has a distinctly higher modulus than traditional and 3D-printed materials. The traditional material self-cure is very similar to the 3D-printed materials Asiga-Denture-Base, and NextDent-Denture Base, which is very similar to Qura-Qurabase.

*Table 16. Tukey HSD of modulus for denture base 3D-printed materials and traditional material*

Tukey HSD[a,b]

| VAR00001 | N | Subset for alpha = 0.05 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| (Dentca) Denture base | 9 | 2.8044 | | | |
| Self-Cure | 10 | 3.0600 | 3.0600 | | |
| (Asiga) Denture Base | 10 | | 3.2610 | 3.2610 | |
| (NextDent) Denture Base | 10 | | 3.3180 | 3.3180 | |
| (Qura) Qurabase | 10 | | | 3.5560 | |
| (Dentona) Mack 4D | 9 | | | | 4.2644 |
| Sig. | | .356 | .346 | .209 | 1.000 |

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 9.643.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

## 7.5 Gloss for Crown & Bridge Materials Step I

### *7.5.1 Gloss Step I*

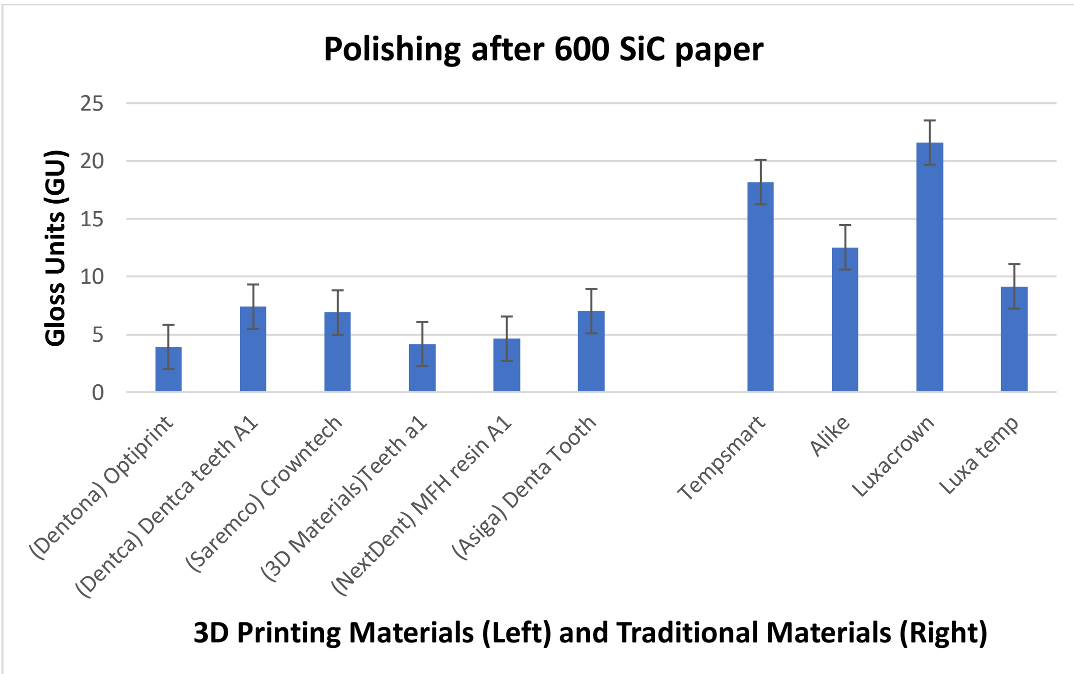


Figure.14 Gloss of Crown and Bridge Materials and Traditional Materials Step I

### *7.5.2 Gloss for Crown and Bridge Materials and Traditional Materials Mean and Standard Deviation*

*Table 17. Gloss for 3D-printed materials (N=45) and traditional material (N=40) step I and step II*

| Type | Material | Mean±SD |
|---|---|---|
| 3D Material | (Dentona) Optiprint 1* | 3.9167±.89536[a] |
| | (Dentona) Optiprint 2 | 58.5500±9.32003[c] |

| | | |
|---|---|---|
| | (Dentca) Dentca teeth A1 1 | 7.4000±2.35251[a] |
| | (Dentca) Dentca teeth A1 2 | 70.7875±11.54760[d] |
| | (Saremco) Crowntech 1 | 6.8875±1.95407[a] |
| | (Saremco) Crowntech 2 | 44.5625±6.11787[b] |
| | (3D Materials) Teeth a1 1 | 4.1625±3.33078[a] |
| | (3D Materials) Teeth a1 2 | 12.3625±6.44403[a] |
| | (Next Dent) MFH resin A1 1 | 4.6250±2.07966[a] |
| | (Next Dent) MFH resin A1 2 | 50.3000±8.21984[b,c] |
| | (Asiga) Denta Tooth 1 | 7.0143±2.23266[a] |
| | (Asiga) Denta Tooth 2* | 74.1429±6.83175[d] |
| Traditional Material | Tempsmart 1 | 18.1667±6.04007[b, c] |
| | Tempsmart 2 | 59.53±4.70883[e] |
| | Alike 1 | 12.5250±2.64939[a,b] |
| | Alike 2 | 63.1875±9.839[e, f] |
| | Luxacrown 1* | 21.5889±8.27971[c] |
| | Luxacrown 2 | 45.0333±5.62450[d] |
| | Luxa Temp 1 | 9.15±2.11358[a] |
| | Luxa Temp 2* | 69.47±3.79826[f] |

* In step 1, polishing procedure, out of all the 3D-printed crown and bridge materials (Dentca) Denta Teeth a1 7.4000±2.35251 has the highest gloss value. In contrast, Luxa temp had the lowest gloss value, 9.15±2.11358, in traditional materials.

* In step 2, polishing procedure with ET ProviPro polishing unit, out of all 3D-printed materials (Asiga) Denta Tooth had the highest gloss value 74.1429±6.83175 followed by (Dentca) Dentca Teeth a1 70.7875±11.54760 while Luxa Temp and Alike 63.1875±9.839 had the highest gloss value in traditional materials.

*7.5.3 Statistical Analysis*

*Table 18. One Way ANOVA of gloss for crown and bridge 3D-printed materials and traditional materials step1*

**ANOVA**

VAR00002

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 2786.827 | 9 | 309.647 | 19.337 | .000 |
| Within Groups | 1136.948 | 71 | 16.013 | | |
| Total | 3923.776 | 80 | | | |

There was a statistically significant difference between the crown and bridge 3D materials and traditional materials as per the one-way ANOVA test. Overall [F (9,71)=19.337, p<0.005]. in step I, all the 3D-printed materials had lower gloss than the traditional materials.

*Table 19. Tukey HSD of gloss for crown and bridge 3D-printed materials and traditional materials step 1*

Tukey HSD[a,b]

| | | Subset for alpha = 0.05 | | | |
|---|---|---|---|---|---|
| VAR00001 | N | 1 | 2 | 3 | 4 |
| (Dentona) Optiprint Step 1 | 6 | 3.9167 | | | |
| (3D Materials) Teeth a1 Step 1 | 8 | 4.1625 | | | |
| (NextDent) MFH resin A1 Step 1 | 8 | 4.6250 | | | |
| (Saremco) Crowntec Step 1 | 8 | 6.8875 | 6.8875 | | |
| (Asiga) Denta Tooth Step 1 | 7 | 7.0143 | 7.0143 | | |

| | | | | | |
|---|---|---|---|---|---|
| (Dentca) Dentca teeth A1 Step 1 | 8 | 7.4000 | 7.4000 | | |
| Luxa temp | 10 | 9.1500 | 9.1500 | | |
| Alike | 8 | | 12.5250 | 12.5250 | |
| Tempsmart | 9 | | | 18.1667 | 18.1667 |
| Luxacrown | 9 | | | | 21.5889 |
| Sig. | | .233 | .153 | .152 | .789 |

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 7.957.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

## 7.6 Gloss for Crown & Bridge Materials Step II

### *7.6.1 Gloss Step II*

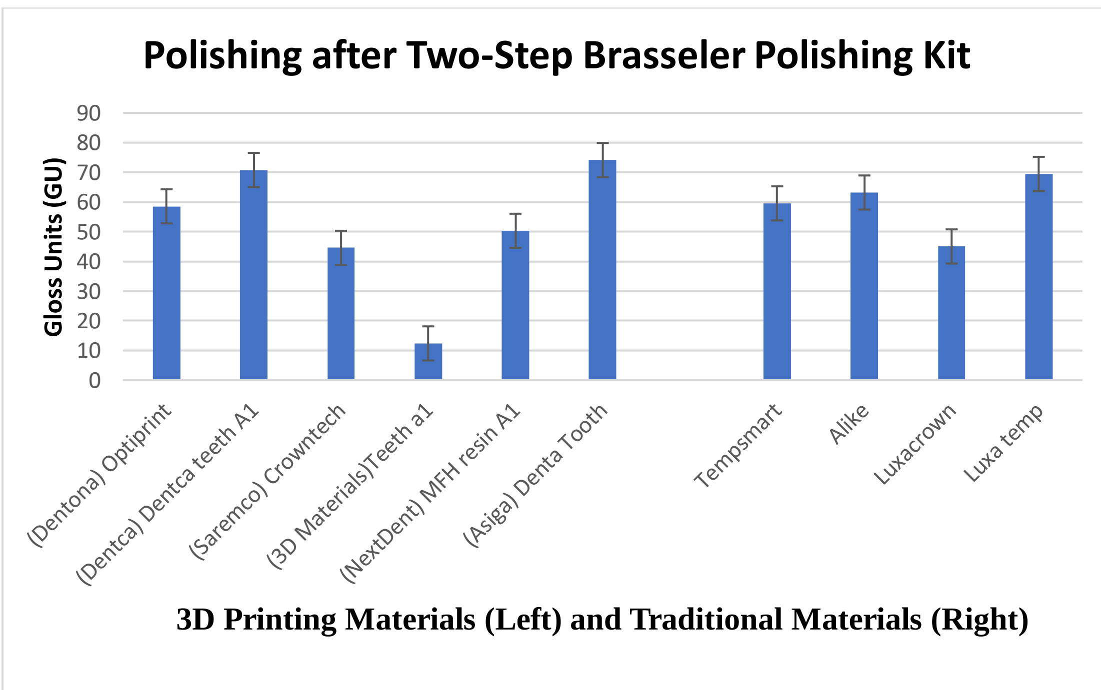


Figure.15 Gloss of Crown and Bridge Materials and Traditional Materials Step II

*7.6.2 Statistical Analysis*

*Table 20. One Way ANOVA of gloss for crown and bridge 3D-printed materials and traditional materials step 2*

**ANOVA**

VAR00002

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 23930.797 | 9 | 2658.977 | 48.265 | .000 |
| Within Groups | 3911.473 | 71 | 55.091 | | |
| Total | 27842.270 | 80 | | | |

There was a statistically significant difference between the gloss for crown and bridge 3D materials and traditional materials as per the one-way ANOVA test. Overall [F (9,71)=48.265, p<0.001]. Most of the 3D-printed materials had similar gloss values with the traditional materials, out of which Dentca-Dentca teeth A1 and Asiga-Denta tooth had higher gloss than all the traditional materials

*Table 21. Tukey HSD of gloss for crown and bridge 3D-printed materials and traditional materials Step 2*

Tukey HSD[a,b]

| VAR00001 | N | Subset for alpha = 0.05 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| (3D Materials) Teeth a1 Step 2 | 8 | 12.3625 | | | | | |
| (Saremco) Crowntec Step 2 | 8 | | 44.5625 | | | | |
| Luxacrown | 9 | | 45.0333 | | | | |
| (NextDent) MFH resin A1 Step 2 | 8 | | 50.3000 | 50.3000 | | | |
| (Dentona) Optiprint Step 2 | 6 | | | 58.5500 | 58.5500 | | |
| Tempsmart | 9 | | | 59.5300 | 59.5300 | 59.5300 | |
| Alike | 8 | | | | 63.1875 | 63.1875 | 63.1875 |
| Luxa temp | 10 | | | | 69.4700 | 69.4700 | 69.4700 |
| (Dentca) Dentca teeth A1 Step 2 | 8 | | | | | 70.7875 | 70.7875 |
| (Asiga) Denta Tooth Step 2 | 7 | | | | | | 74.1429 |
| Sig. | | 1.000 | .870 | .297 | .115 | .093 | .113 |

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 7.957.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

## 7.7 Translucency

### *7.7.1 Translucency*

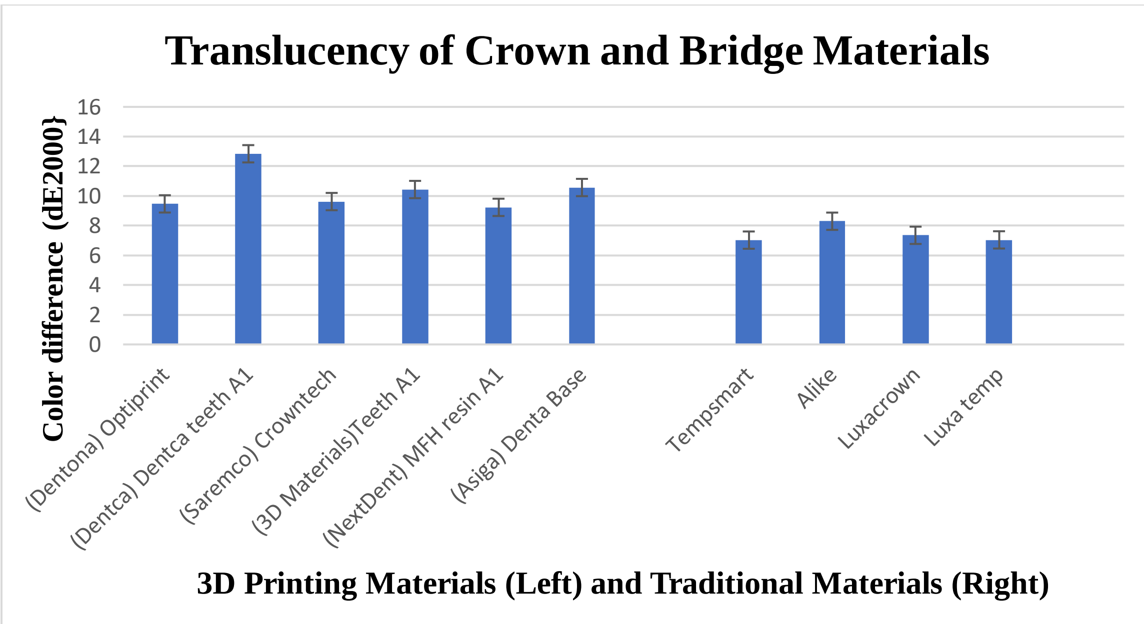


Figure.16 Translucency of Crown and Bridge Materials and Traditional Materials

### *7.7.2 Translucency of Crown and Bridge Materials and Traditional Materials Mean and Standard Deviation*

The 3D-printed materials have a higher translucency as compared to the traditional materials.

*Table 22. Translucency for 3D materials (N=107) and traditional material (N=50)*

| Type | Material | Mean±SD |
|---|---|---|
| 3D Material | (Dentona) Optiprint | $9.4671 \pm .33441^a$ |
| | (Dentca) Dentca teeth A1 | $12.8423 \pm .40299^c$ |
| | (Saremco) Crowntech | $9.6231 \pm .39282^a$ |
| | (3D Materials) Teeth a1 | $10.4336 \pm .35287^b$ |
| | (Next Dent) MFH resin A1 | $9.2335 \pm .45160^a$ |
| | (Asiga) Denta Base | $10.5702 \pm .32484^b$ |
| Traditional Material | Tempsmart* | $7.0251 \pm .65346^a$ |
| | Alike* | $8.2976 \pm .66227^b$ |
| | Luxacrown | $7.3498 \pm .78408^a$ |
| | Luxa Temp | $7.0410 \pm .35128^a$ |

Out of all the 3D-printed crown and bridge materials, Dentca-Denta teeth A1 $12.8423 \pm .40299$ has the highest translucency, and Next Dent MFH resin A1 with the lowest translucency value $9.2335 \pm .45160$ while Alike had the highest translucency value, $8.2976 \pm .66227$, which is lower than the lowest value from the 3D-printed group. This means that the 3D-printed materials are more translucent and have more aesthetic properties than traditional ones.

*7.7.3 Statistical Analysis*

*Table 23. One way ANOVA of translucency for crown and bridge 3D-printed materials and traditional materials*

**ANOVA**

VAR00002

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 301.358 | 9 | 33.484 | 132.324 | .000 |
| Within Groups | 21.762 | 86 | .253 | | |
| Total | 323.120 | 95 | | | |

There was a statistically significant difference between the crown and bridge 3D materials and traditional materials as per the one-way ANOVA test. Overall [F (9,86)=132.324, p<0.001]. All the 3D-printed materials had higher translucency properties than the traditional materials.

*Table 24. Tukey HSD of translucency for crown and bridge 3D-printed materials and traditional materials*

Tukey HSD[a,b]

| | | Subset for alpha = 0.05 | | | | |
|---|---|---|---|---|---|---|
| VAR00001 | N | 1 | 2 | 3 | 4 | 5 |
| Tempsmart | 10 | 7.0251 | | | | |
| Luxa Temp | 10 | 7.0410 | | | | |
| Luxacrown | 10 | 7.3498 | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Alike | 10 | | 8.2976 | | | |
| (NextDent) MFH resin A1 | 10 | | | 9.2335 | | |
| (Dentona) Optiprint | 8 | | | 9.4671 | | |
| (Saremco) Crowntec | 10 | | | 9.6231 | | |
| (3D Materials) Teeth A1 | 10 | | | | 10.4336 | |
| (Asiga) Denta Base | 8 | | | | 10.5702 | |
| (Dentca) Dentca teeth A1 | 10 | | | | | 12.8423 |
| Sig. | | .921 | 1.000 | .798 | 1.000 | 1.000 |

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 9.524.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

## 7.8 Translucency of Denture Base Materials

### *7.8.1 Translucency*

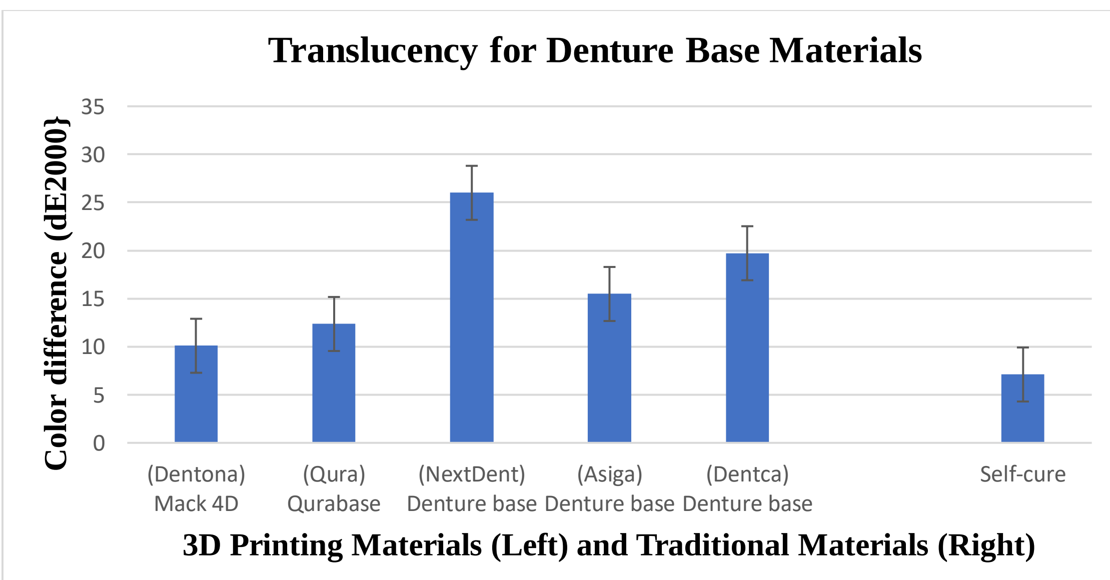


Figure.17 Translucency of Denture Base Materials and Traditional Material

*7.8.2 Translucency of Denture Base Materials and Traditional Material Mean and Standard Deviation*

*Table 25. Translucency of 3D-printed and traditional denture base materials*

| Type | Material | Mean±SD |
|---|---|---|
| 3D Material | (Dentona) Mack 4D | 11.2177±.32133[b] |
| | (Qura) Qurabase* | 6.6247±.18390[a] |
| | (NextDent) Denture base* | 25.9996±.42636[e] |
| | (Asiga) Denture base | 22.1184±1.57605[c] |
| | (Dentca) Denture base | 24.65051.01434[d] |
| Traditional Material | Self-Cure | 7.1104±1.07233[a] |

* Out of all the 3D-printed denture base material (NextDent) Denture base has the highest translucency, 25.9996±.42636 while self-cure had translucency value 7.1104±1.07233 from traditional materials.

*7.8.3 Statistical Analysis*

*Table 26. One way ANOVA of translucency for denture base 3D-printed materials*

**ANOVA**

VAR00002

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 3467.856 | 5 | 693.571 | 888.693 | .000 |
| Within Groups | 35.120 | 45 | .780 | | |
| Total | 3502.976 | 50 | | | |

Based on One-Way-ANOVA, The traditional denture base materials samples [F (5,45)=888.693, p<0.075] do have a significant difference. Traditional material self-cure is significantly different than the majority of the 3D-printed materials except for Qura-Qurabase.

*Table 27. Tukey HSD of translucency for denture base 3D-printed materials and traditional material*

Tukey HSD[a,b]

| VAR00001 | N | Subset for alpha = 0.05 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| (Qura) Qurabase | 7 | 6.6247 | | | | |
| Self-Cure | 10 | 7.1104 | | | | |
| (Dentona) Mack 4D | 9 | | 11.2177 | | | |
| (Asiga) Denture Base | 7 | | | 22.1184 | | |
| (Dentca) Denture Base | 8 | | | | 24.6505 | |
| (NextDent) Denture Base | 10 | | | | | 25.9996 |
| Sig. | | .870 | 1.000 | 1.000 | 1.000 | 1.000 |

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8.312.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

## 7.9 Staining of Crown and Bridges Materials and Traditional Material

*7.9.1 Staining*

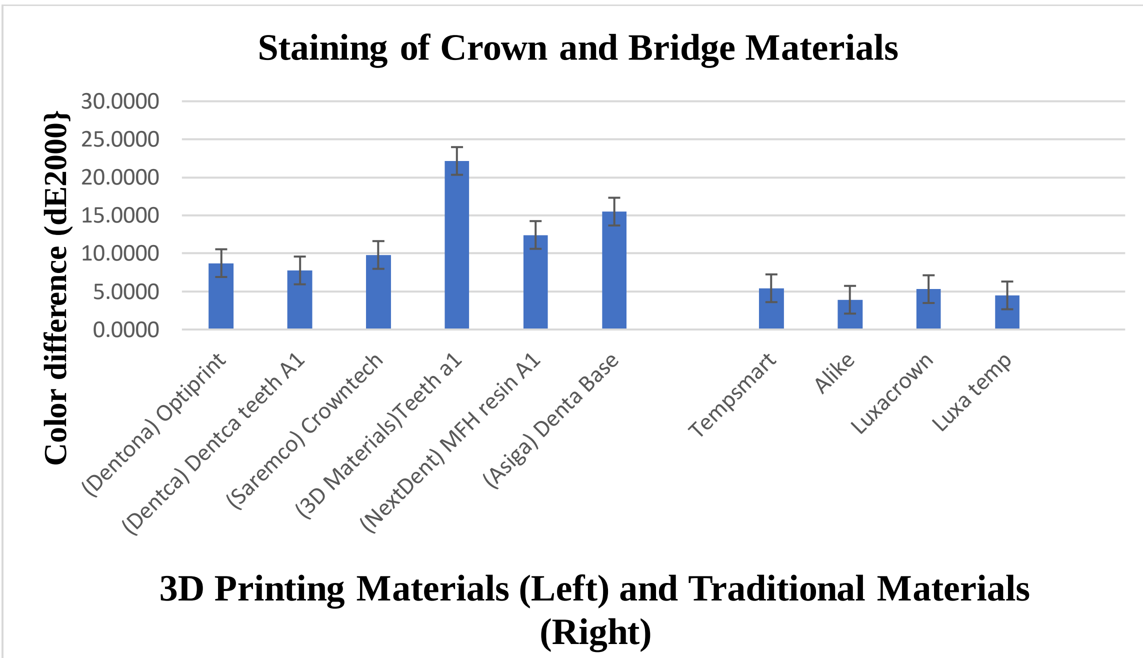


Figure.18 Staining of Crown and Bridge Materials and Traditional Materials

*7.9.2 Staining for Crown and Bridge and Traditional Materials Mean and Standard Deviation*

*Table 28: Staining data for 3D materials (N=96) and traditional material (N=49)*

| Type | Material | Mean±SD |
|---|---|---|
| 3D Material | (Dentona) Optiprint | 8.7248 ±.88184[a] |
| | (Dentca) Dentca teeth A1 | 7.7631±.2.31.034[a] |
| | (Saremco) Crowntech | 9.7972±1.52312[a] |
| | (3D Materials) Teeth a1 | 22.1527±3.52082[d] |
| | (Next Dent) MFH resin A1 | 12.4243±2.35432[b,c] |

| | | |
|---|---|---|
| | (Asiga) Denta Base | 15.4947±1.97931[c] |
| Traditional Material | Tempsmart** | 5.4233±.54504[b] |
| | Alike** | 3.9118±.1.27944[a] |
| | Luxacrown | 5.3054±1.35146[a,b] |
| | Luxa Temp | 4.4817±1.24358[a,b] |

Out of all the 3D-printed crown and bridge materials (Dentca) Dentca Teeth a1 7.7631±.2.31.034 had the lowest staining values. In contrast, Tempsmart 5.4233±.54504 and Luxacrown 5.3054±1.35146 had the highest staining values from the traditional materials.

*7.9.3 Statistical Analysis*

*Table 29. One way ANOVA of staining for crown and bridge 3D-printed materials and traditional materials*

**ANOVA**

VAR00002

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 2686.187 | 9 | 298.465 | 84.087 | .000 |
| Within Groups | 280.410 | 79 | 3.549 | | |
| Total | 2966.597 | 88 | | | |

There was a statistically significant difference between the crown and bridge 3D materials and traditional materials as per the one-way ANOVA test. Overall [$F_{(9,79)}=84.087$, $p<0.001$]. All the 3D-printed materials were stained higher than the traditional materials, out of which Dentca-Dentca teeth A1 was stained the lowest and was similar to Luxacrown and Tempsmart (Table 30).

*Table 30. Tukey HSD of staining for crown and bridge 3D-printed materials and traditional materials*

Tukey HSD[a,b]

| | | Subset for alpha = 0.05 | | | | | |
|---|---|---|---|---|---|---|---|
| VAR00001 | N | 1 | 2 | 3 | 4 | 5 | 6 |
| Alike | 10 | 3.9118 | | | | | |
| Luxa Temp | 10 | 4.4817 | | | | | |
| Luxacrown | 10 | 5.3054 | 5.3054 | | | | |
| Tempsmart | 9 | 5.4233 | 5.4233 | | | | |
| (Dentca) Dentca teeth A1 | 9 | | 7.7631 | 7.7631 | | | |
| (Dentona) Optiprint | 7 | | | 8.7248 | | | |
| (Saremco) Crowntec | 9 | | | 9.7972 | 9.7972 | | |
| (NextDent) MFH resin A1 | 9 | | | | 12.4243 | | |
| (Asiga) Denta Base | 7 | | | | | 15.4947 | |
| (3D Materials) Teeth a1 | 9 | | | | | | 22.1527 |
| Sig. | | .804 | .180 | .426 | .118 | 1.000 | 1.000 |

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8.762.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

## 7.10 Staining for Denture Base Materials and Traditional Materials

### *7.10.1 Staining*

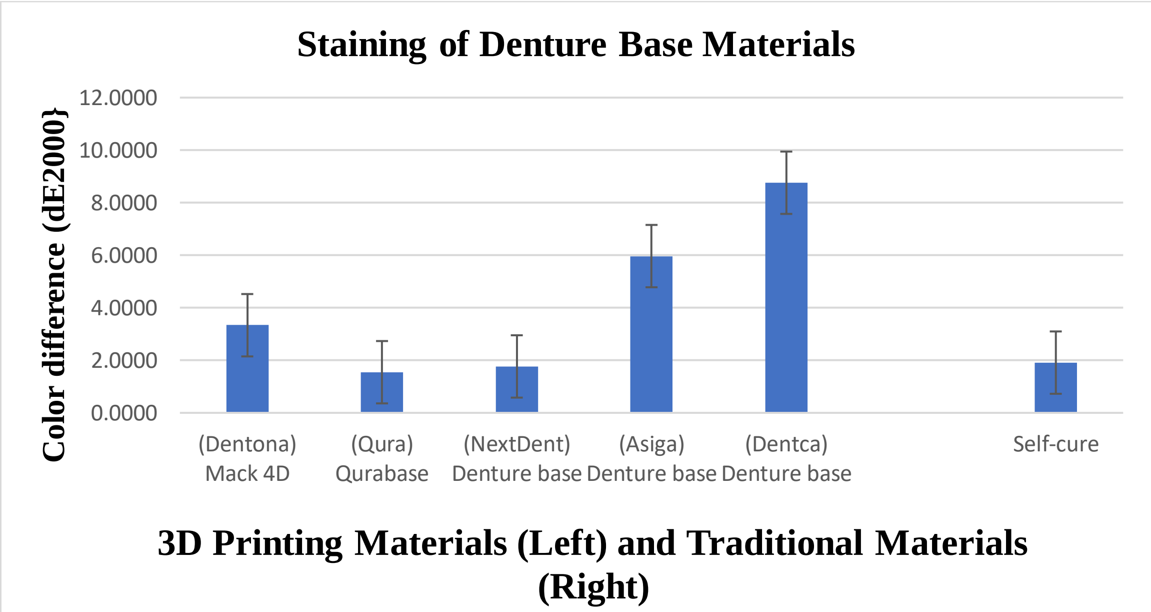


Figure.19 Staining of Denture Base Materials and Traditional Material

### *7.10.2 Staining for Denture Base and Traditional Materials Mean and Standard Deviation*

*Table 31. Staining for 3D materials and traditional denture base materials*

| Type | Material | Mean±SD |
|---|---|---|
| 3D Materials | (Dentona) Mack 4D | 3.3359±1.38719[b] |
| | (Qura) Qurabase* | 1.5475±.59532[a] |
| | (NextDent) Denture base* | 1.7671±.33658[a,b] |
| | (Asiga) Denture base | 8.9515±1.28689[c] |
| | (Dentca) Denture base | 8.7608±1.35300[c] |
| Traditional Material | Self-Cure | 1.9134±.63788[a] |

Out of all the 3D-printed denture base material (Qura) Qurabase, 1.5475±.59532 and (NextDent) Denture Base, 1.7671±.33658 has the lowest staining value, while self-cure material from traditional material's staining value was 1.9134±.59532.

*7.10.3 Statistical Analysis*

*Table 32. One way ANOVA of staining for denture base 3D-printed materials and traditional materials*

**ANOVA**

VAR00002

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 433.702 | 5 | 86.740 | 88.795 | .000 |
| Within Groups | 39.075 | 40 | .977 | | |
| Total | 472.777 | 45 | | | |

*Table 33. Tukey HSD of staining for denture base 3D-printed materials and traditional material*

Tukey HSD[a,b]

| VAR00001 | N | Subset for alpha = 0.05 | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| (Qura) Qurabase | 6 | 1.5475 | | |
| (NextDent) Denture Base | 9 | 1.7671 | | |
| Self-cure | 10 | 1.9134 | 1.9134 | |
| (Dentona) Mack 4D | 8 | | 3.3359 | |
| (Dentca) Denture Base | 7 | | | 8.7608 |
| (Asiga) Denture Base | 6 | | | 8.9515 |
| Sig. | | .979 | .084 | .999 |

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 7.386.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

There was a statistically significant difference between the crown and bridge 3D materials and Traditional materials as per the one-way ANOVA test. Overall [F (5,40)=88.795, p<0.001]. Few of the 3D-printed materials had lower staining properties than the traditional materials, out of which Qua-Qura base and NextDent-Denture base showed similar values (table 33).

**Table 34: Result summary of all similar values between each group according to Tukey's HSD**

| | | 3D-printed Materials | Traditional Materials |
|---|---|---|---|
| **Flexural Strength** | **Crown and Bridge Materials** | Saremco-Crowntec, Asiga-Denta Base | Tempsmart |
| | **Denture Base Materials** | NextDent-Denture Base, **Dentona-Mack 4D**** | **Self-cure**** |
| **Modulus** | **Crown and Bridge Materials** | Saremco-Crowntec | Tempsmart |
| | **Denture Base Materials** | Dentona-Mack 4D, **Dentca-Denture Base**** | **Self-cure**** |
| **Translucency** | **Crown and Bridge Materials** | All 3D-printed Materials | Alike |
| | **Denture Base Materials** | Qura-Qurabase | Self-cure |
| **Staining** | **Crown and Bridge Materials** | Denta-Denta teeth A1 | Tempsmart and Luxacrown |

| | | | |
|---|---|---|---|
| | **Denture Base Materials** | Qura-Qurabase and NextDent- Denture Base | Self-Cure |
| **Gloss** | **Step I** | Denta-Denta teeth A1 | Luxa Temp |
| | **Step II** | Asiga-Denta tooth and Dentca-Dentca teeth A1 | Luxa Temp and Alike |

The above table shows the materials with similar values between 3D-printed and traditional materials according to Tukey's HSD test.

** The highlighted materials from the 3D-printed and traditional material groups had similar values compared to the self-cure traditional material. However, all other materials from the 3D-printed group had higher flexural strength and modulus than the self-cure traditional material.

All 3D-printed crown and bridge materials had higher translucency values than all the traditional materials, where Alike had the highest translucency, which was lower than the lowest value from the 3D-printed material group.

Figure 20. Representation of Crown and Bridge 3D-printed Materials before and after Staining

The above picture shows the pre-and post-staining of crown and bridge 3D-printed materials. The above row shows the pre-stained materials; the lower row shows the post-staining. The order of the specimens from left to right are as follows-

1) (Dentona) Optiprint

2) (Dentca) Dentca teeth A1

3) (Saremco) Crowntec

4) (3D Materials) Teeth A1

5) (NextDent) MFH resin A1

6) (Asiga) Denta Tooth

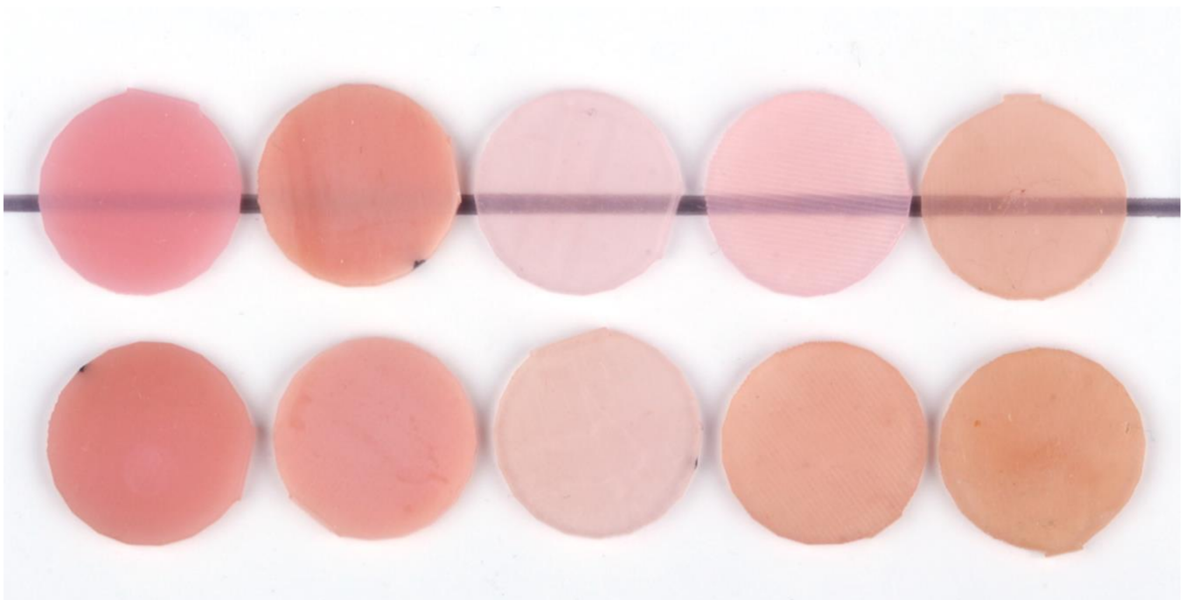

Figure 21. Representation of Denture base 3D-printed Materials before and after Staining

The above picture shows the pre-and post-staining of denture base 3D-printed materials. The above row shows the pre-stained materials, the lower row shows the post-staining. The order of the specimens from left to right are as follows-

1) (Dentona) Mack 4D

2) (Qura) Qurabase

3) (NextDent) Denture base

4) (Asiga) Denture base

5) (Dentca) Denture base

**Properties Comparing All 3D-printed and Traditional Materials**

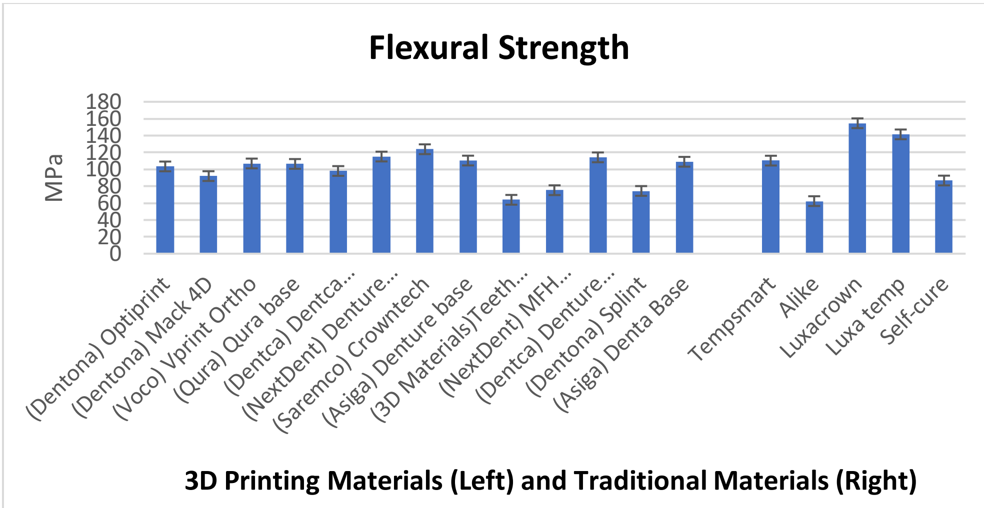


Figure 22. Flexural Strength of all the Materials

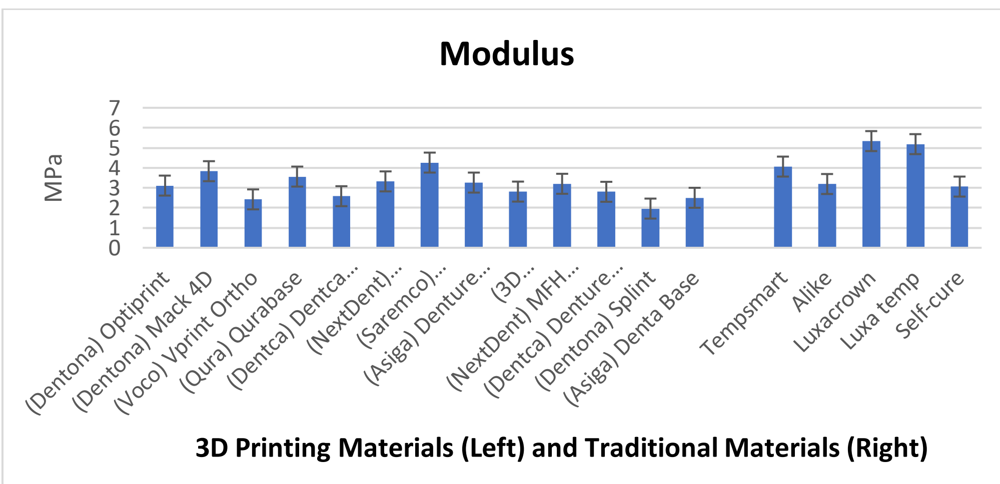


Figure 23. Modulus of all the Materials

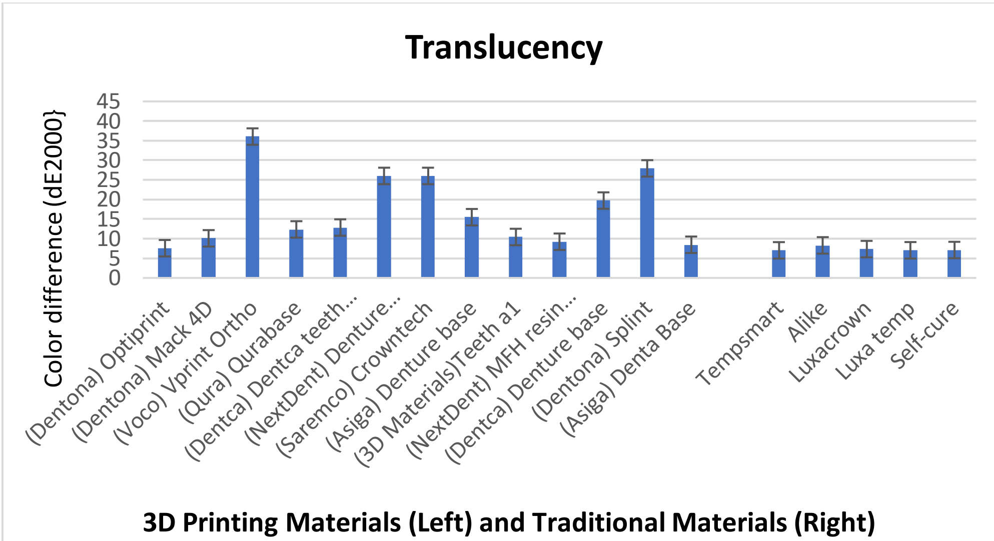


Figure 24. Translucency of all the Materials

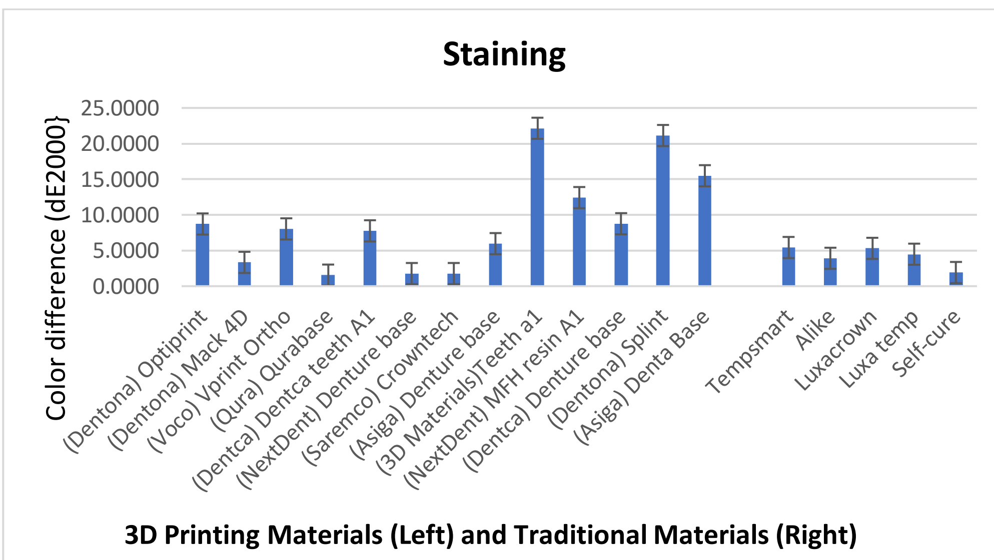


Figure 25. Staining of all the Materials

## 8. NULL HYPOTHESIS REJECTION

1) There was a significant difference between the **flexural strength** and **modulus** in 3D-printed materials and the control group. Hence the null hypothesis was rejected.

2) There was a significant difference between the **gloss measurement** in 3D-printed materials and the control group. Hence the null hypothesis was rejected.

3) There was a significant difference between the **translucence** and **stain resistance** in the 3D-printed materials and control group. Hence the null hypothesis was rejected.

# 9. DISCUSSION

Improving the quality of 3D-printed crowns and bridges to perform similar to or better than conventional materials is the key to establish 3D-printed in the field of dentistry. Clinical use of 3D-printed material to fabricate crown and bridge provisional materials is that they can be produced by the clinician in approximately 20 minutes (Tahayeri et al., 2018). Therefore, it is easy to imagine how simple it can make the fabrication of 3D printing materials in which it can be scanned, sent to the 3D printer, and processed into the full crown (Figure 26). The printed part can be detached easily by the clinician and cemented immediately. These technologies are currently available; however, there is a lack of studies on 3D-printed materials for their performance. Hence the importance of their physical properties is critical for more successful and faster treatment procedures.

Overall performance of denture base and provisional crown and bridge in terms of flexural strength, modulus, staining, gloss, and translucency have not been examined together even though their analysis provides a more complete impression when considering 3D printing against the conventional materials for temporary restoration (Joshi, 2019).

Figure. 26 3D-printed Crown

The flexural strength is the maximum bending stress applied to a material before it yields (Yalcin, 2020). Modulus is a mechanical property that measures a material's stiffness or resistance to bending action and is measured when a force is applied perpendicular to the long edge of the sample (Trenchlesspedia, 2020). The most common way of obtaining flexural strength is by employing a transverse bending test using a three-point flexural test technique. High flexural strength and modulus are necessary while considering the durability time duration for each material because it impacts the fracture ability. In this project, Saremco (3D material) showed similarities to the traditional material, Luxacrown (semi-permanent bis-acryl), which had the highest flexural strength overall. Similarly, Luxa temp (bis-acryl) exhibited the second-highest flexural strength and modulus overall.

According to Debra, 2002 et al., Tempsmart and Alike had flexural strength values of 114.6 and 83.1 MPa, respectively, similar to the present study (Haselton et al., 2002). He also reported that the flexural strength was material-specific and partly dependent on the chemical composition. They stated that methyl-methacrylate type of resins such as Alike had an overall lower strength and rigidity.

Joshi, 2019 reported a higher fracture ability amongst the PMMA group, including Next-Dent MFH for crown and bridge provisional material, even though a statistically significant difference was not found between PMMA and acrylic resin material. Dentca from the acrylic group similar to PMMA was reported to show increased resiliency and lower fracture ability. Similarly, in this project, The 3D-printed resin-based materials like Saremco-

Crowntec and Asiga-Denta base from the methacrylate resin group had an overall higher flexural strength, sharing similarities with the traditional materials (Table 7).

In this study, the other 3D-printed materials had a lower flexural strength and modulus than the traditional materials; however, all the 3D-printed materials were more translucent than the traditional materials. Dentca-Dentca teeth A1 and Asiga-Denta tooth had very high gloss in step 1 and step 2 and low staining property. Hence it can be recommended to use this material for anterior teeth for esthetic considerations. It can prove to have a decent strength with high translucency and gloss with low staining ability.

The null hypothesis stated a significant difference between the flexural strength and modulus of 3D-printed material and traditional material; hence it was rejected. Even though the null hypothesis was rejected as per One-way ANOVA, the performance of some of the 3D-printed materials was comparable to the traditional materials in terms of flexural strength and modulus as per Tukey's results. According to one-way ANOVA, the significant difference was <0.05; however, Tukey's HSD test shows some similarities between 3D-printed materials and traditional materials. Saremco-Crowntec and Asiga-Denta base had similar flexural strength with Tempsmart; hence it can be recommended for the posterior teeth due to its higher strength. According to a study by Tahayeri et al., 2018, a commercial printable resin-based NextDent crown and bridge material had low cost; hence it can be recommended in the anterior crowns (Tahayeri, 2018 et al.), however many studies showed NextDent crown and bridge material led to significant staining with particular time duration (Shin et al., 2020)

All the denture base 3D-printed materials had higher flexural strength than the traditional self-cure resin material. However, Dentona-Mack 4D had similar values to self-cure resin; both materials were seen in the same group as per Tukey's HSD. Except for the Dentca-Denture base, all the 3D-printed denture base materials had a higher modulus. However, the Dentca-Denture base materials had a similar value to self-cure resin and were seen in the same group as per Tukey's HSD. This means that most 3D-printed denture base materials have higher flexural strength and modulus than the self-cure acrylic resin material.

Gloss is an important property when considering esthetics and determines the natural shine relative to the other natural teeth and the overall success of provisional crown and bridge. Gloss is the specular light reflected from materials (Whetzel, 2019). A rough surface can also lead to halitosis, adding to patient discomfort. In this study, only the crown and bridge 3D-printed materials were evaluated against the traditional materials for gloss. According to Dwairi et al. (2019), PMMA CAD/CAM groups showed an overall lower Ra than 0.2µm as compared to the traditional material (Al Dwairi et al., 2019). The CAD/CAM material showed significant variability based on the 3D-printed material. In this project, the 3D-printed material also showed a wide range of gloss values. The majority of the 3D-printed materials were observed to have higher values and shared similarities with most traditional materials. After the second step of polishing, Dentca-Dentca teeth A1 performed better than the highest gloss value of Luxa temp from the traditional materials. Both of these 3D-printed crowns and bridge materials can be highly recommended for anterior teeth as provisional crowns due to their high translucency. Dentca-Dentca A1 showed low staining. Therefore, it could be acceptable to be used as anterior provisional crowns. Similarly, Fernandez et al. (2020) reported that 3D-printed denture base material had an overall higher gloss as compared to the traditional material (Kraemer Fernandez et al., 2020)

Translucency is the relative amount of light transmission or diffuse reflection from a substrate surface through a turbid medium (Y. K. Lee, 2015). Staining of provisional restoration is important when it comes to esthetics. According to the Department of health and human service, Food and Drug Administration, the main composition of NextDent denture base is dimethacrylic resin and photoinitiators of 3D printer setting and some pigments to give denture color (Trisler., 2017). The material is one of the best alternatives to heat cure resin. Due to dimethacrylic resin, the material does not stain easily; hence the result in the study showed lower staining properties than the traditional self-cure resin. However, many studies showed NextDent crown and bridge material led to significant staining with a particular time duration (Shin et al., 2020). Kim et al. (2021) performed an analysis focused on color stability and translucency post-curing. They found minor variations in translucency and significant differences in color over an extended period (J. E. Kim et al., 2021).

Similarly, the 3D-printed provisional crown and bridge material showed considerable variation in translucency and staining in this project. In contrast, traditional material showed a stable translucency and staining value over a one-year simulation period by placing the specimens in the staining solution. Similar results were seen in a study performed by Almejrad et al. (2021), showing considerable variation in color stability of

3D-printed materials in different staining materials over 6 months (Almejrad et al., 2021). Joshi (2019) reported that resin-based material, including NextDent MFH, had a lower translucency value because of increased surface roughness (Joshi, 2019).

3D materials have a slow polymerization rate, leading to free monomers and pigments in the printed structure. Over time as the material degrades and pores have formed, these monomers and pigments could be released, leading to changes in the physical properties of these 3D-printed materials. Hydrolysis of the methyl acrylate derivatives, a major component of the 3D-printed material post-curing, can lead to swelling and pore formation allowing diffusion of monomers and pigments (J. E. Kim et al., 2021) (Vallittu et al., 1997); hence the 3D materials are not stable and lose their color when exposed with staining solution for a particular duration.

# 10. LIMITATIONS

1. Limited materials for the project led to a limited sample size for this project. Removal of one sample from each group for photographic comparison might have affected the statistical power of the study.
2. Discrepancies during manual polishing of the samples for gloss measurement were not accounted for in the results due to the differences in the pressure applied by the polishers on the specimens.
3. Discrepancies during the three-point-bend test for flexural strength and modulus might have been caused due to the manual alignment of the horizontal sample against the upper anvil.
4. A single control group was used for denture base material testing, whereas four groups were used for the crown and bridge provisional material testing. No control group was used for the occlusal bite splint 3D-printed materials due to lack of ability of materials
5. The staining test involved the samples being artificially stained for 12 days; assuming this correlates to 1 year of in vivo staining, it might not precisely reflect the real-life clinical scenario.
6. Due to limited polishers available, a single set of polishers was used for each sample in a group, which might have compromised the efficacy of the polisher with each of the following samples.

# 11. CONCLUSION

Through this study, the following conclusions could be made:

1. Statistically, significant similarities between the 3D-printed and traditional materials could not be found.
2. The majority of 3D-printed denture base materials had higher flexural strength, which can be used for the convenience of the patients, having an advantage for faster processing and fabrication than the traditional material
3. In terms of flexural strength, modulus, and translucency, Saremco-Crowntec had the best performance out of the selected 3D-printed materials but lacked in terms of gloss and performed average in terms of staining for provisional crown and denture base materials.
4. Degradation over time and existing reactants within the matrix of the materials being used could dictate the overall increased opacity, fracture formation, compromised strength, porosity, and stain retention.
5. All the traditional materials showed comparatively lower staining as compared to the 3D-printed materials. The majority of the commonly used methyl acrylate-based derivates of 3D-printed materials can experience hydrolysis and swelling over time, allowing the staining pigments to get embedded more profound in the matrix.

6. 3D materials that performed average based on flexural strength and modulus had higher translucency and gloss values, and acceptable stain resistance property like Dencta-Dencta Teeth A1 could be recommended for 3D-printed crown and bridge in anterior teeth.
7. All the 3D-printed crown and bridge materials and denture base materials had higher translucency values, which can be considered for esthetic priorities. Some may tend to stain quickly than the traditional material. However, Dentca-Dentca Teeth A1 and Saremco-Crowntec can be considered due to their lower staining property.

## 12. FUTURE DIRECTIONS

A closer look at physical and chemical properties using a Scanning electron microscope to study the overall durability and aesthetics of the 3D-printed materials by mimicking in-vitro conditions could be the next steps for this study. Understanding the general biocompatibility of these materials over an extended period to increase the durability and retention of the provisional crown and bridge structures among patients could be considered in the future. Further testing on using different forms of enhancements or techniques to improve the performance of the 3D-printed materials could be another direction that this research can take in the future.

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