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Evaluation of microstructure and mechanical properties of PMMA Matrix composites reinforced with residual YSZ from CAD/CAM Milling process

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ABSTRACT

Background: Reinforcement of dental acrylics with fillers has yielded positive results. Different proportions of fillers have been added to strengthen the dental acrylics, but no consensus has been reached.
Aim: The purpose of this study was to investigate the effects of the addition of different concentrations of yttria-stabilized zirconium (YSZ) obtained from the residues generated from the CAD-CAM milling of YSZ on the microstructure and mechanical properties of poly-methyl-methacrylate (PMMA)-YSZ composites.
Materials and methods: Composite materials with different amounts (0.0 to 70.0% by weight) of recycled YSZ reinforced PMMA resin matrix were produced. Scanning electron microscope (SEM), energy dispersive electron spectrometer (EDS) and Fourier Transform Infrared Spectrometer (FTIR) were used for microstructural analysis. Among the mechanical properties, the Vickers micro-hardness test method for hardness, 2D profilometer for surface roughness and composite densities were evaluated by Archimedes method. Data were analyzed using a one-way analysis of variance (ANOVA) at a pre-set alpha of 0.05.
Results: Microhardness and density increased until 60% by weight YSZ addition, while surface roughness remained unchanged but increased after 60% by weight YSZ addition. The addition of more than 60% by weight of YSZ caused agglomeration in the microstructures. The mechanical properties of poly-methyl-methacrylate decreased with more than 60% YSZ by weight.
Conclusion: Reinforcement of PMMA with residue zirconia powder will increase the usage chance of residue YSZ powder and provide a safer use of PMMA.

1. Introduction

Polymethylmethacrylate (PMMA) is one of the most preferred prosthodontic material in dentistry owing to the reasons such as low-cost, simple application and easy polishing [1,2]. PMMA based provisional restoration is an important step that should not be neglected in the fixed prosthetic treatment process in order to protect the prepared tooth from heat and food to provide aesthetics, function, formation of the gum form and occlusion for a certain period [3,4].
Temporary restorations undergo repeated chewing forces and require specific mechanical properties to withstand long-span fixed prostheses, temporomandibular

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joint disorders, and parafunctional habits [5]. However, PMMA has insufficient mechanical strength and surface hardness [2], prolonged use can cause cracking or fracture of temporary restorations, especially in long-span fixed prostheses and areas with heavy occlusal load in the posterior region. When temporary restorations are broken, they can damage oral tissues and even be swallowed by the patient. The surface hardness of PMMA is low; hence the material is relatively softer and possibly become rough during the chewing process in the oral cavity. Consequent to this, the surface of PMMA are colonized easily by microorganisms [6-8].

In recent years, many different material additions such as metal wires [9], fibre [10-13], nanodiamond [14], metal oxide nanofillers such as silver [15,16], titanium [17-19], aluminum and zirconium oxide [20, 21] to resin matrix have been studied to improve the mechanical properties of PMMA. Some of these additions have the same disadvantages, such as low corrosion resistance [9], tissue irritation, etc. [7]. The hardness, density and roughness of the provisional restorative materials change according to the polymer and the reinforcement type [22]. Zirconia with superior biocompatibility, mechanical strength, high density, high surface hardness [23], good chemical resistance, good thermal stability [24] is a superior reinforcement material for PMMA.

Nowadays, the recycling and reuse of ceramic materials are even more important because of the environmental issue and the high cost of mining and transporting pure raw material [25]. The machining of crowns by CAD/CAM (Computer-assisted design/computer-assisted machining) can produce a waste of approximately 30% of the initial blank, generating a significant economic loss for the prosthetic laboratories. Zirconia residues have a high economic value and potential for recycling [26].

Therefore, this study aimed to evaluate the effect of incorporating residue YSZ on hardness, density, and roughness on PMMA. There are a few studies in the literature about YSZ reinforcement PMMA. However, they were mainly focused on low amount YSZ addition (10 wt%) to PMMA [27, 28]. However, there are no studies about the high percentage of YSZ reinforced to PMMA matrix in literature.

2. Materials and methods

In the present study, a commercially available cold cured provisional poly-methyl methacrylate (PMMA) powder and methyl methacrylate (MMA) (Integra, Ankara, Turkey) as base liquid were selected as matrix materials. Residue Yttria-stabilized zirconia-milled powder (Zirking, Huge Dental, China) were used as a reinforcing material to prepare the composite specimens.

2.1 Samples preparation

The residue yttria-stabilized ZrO2 powders and provisional PMMA powder were pre-weighted using an electronic balance (Radwag AS 60/220.R2 Dual Range Analytical Balance, Radwag USA L.L.C., FL, USA) to ensure 0.0 wt%, 12.5 wt%, 25 wt%, 30 wt%, 35 wt%, 40 wt%, 50 wt%, 60 wt%, 65 wt%, and 70 wt% concentrations (Table 1).

Zirconia blocks residue powders were added to the acrylic resin powder and mixed manually with a stainless-steel spatula until homogeneously dispersed. Subsequently, MMA liquid was added and thoroughly mixed. The dough was poured into a stainless steel mould of 10×2 mm cylindrical holes, and samples were allowed to cure in a pressure vessel (Vertex Poly Cure25, Vertex-Dental, Zeist, Netherlands) under 2.5 atmospheric pressure at 55ºC for 10 minutes. After polymerization, the specimens were wet-polished with 800-grit, 1000-grit and 1200-grit silicon carbide papers, respectively (n= 10).

The microstructure of the fractured surfaces of prepared samples was studied using a scanning electron microscope (SEM JSM-6060 LV, JEOL, Tokyo, Japan). Chemical composition was analyzed using an Electron Dispersive Spectrometer (EDS) (Hitachi SU 5000, Japan). Fourier transform infrared spectroscopy (version 660-IR FT-R Spectrometer, Agilent Technologies, Santa Clara, USA) was used to detect the functional groups. Vickers hardness of the samples was measured using a microhardness device (HMV, Shimadzu, Kyoto, Japan). Specimens of 10 mm diameter and 2 mm thickness were subjected to a load of 50 N for 10 seconds for hardness measurement. Densities of unreinforced PMMA and yttria-stabilized ZrO_2 reinforced PMMA matrix samples were measured using the Archimedes density measurement method. The surface roughness (Ra) test was performed with a profilometer (Surface Roughness Tester SJ-201, Mitutoyo, Kawasaki, Japan) to measure the arithmetic mean roughness of the surfaces. The cut off was set at 0.8 mm, and the total transverse length was 1.25 mm.

Table 1. Powder PMMA and liquid MMA weights with residue zirconia weight percentages of groups.

Groups	Zirconia (wt%)	Zirconia (g)	PMMA Powder (g)	Monomer (mL)
1	0.00	0.00	23.50	10.00
2	12.50	2.94	20.56	10.00
3	25.00	5.88	17.62	10.00
4	30.00	7.00	16.45	10.00
5	35.00	8.23	15.27	10.00
6	40.00	9.40	14.10	10.00
7	50.00	11.75	11.75	10.00
8	60.00	14.10	9.40	10.00
9	65.00	15.27	8.23	10.00
10	70.00	16.40	7.05	10.00

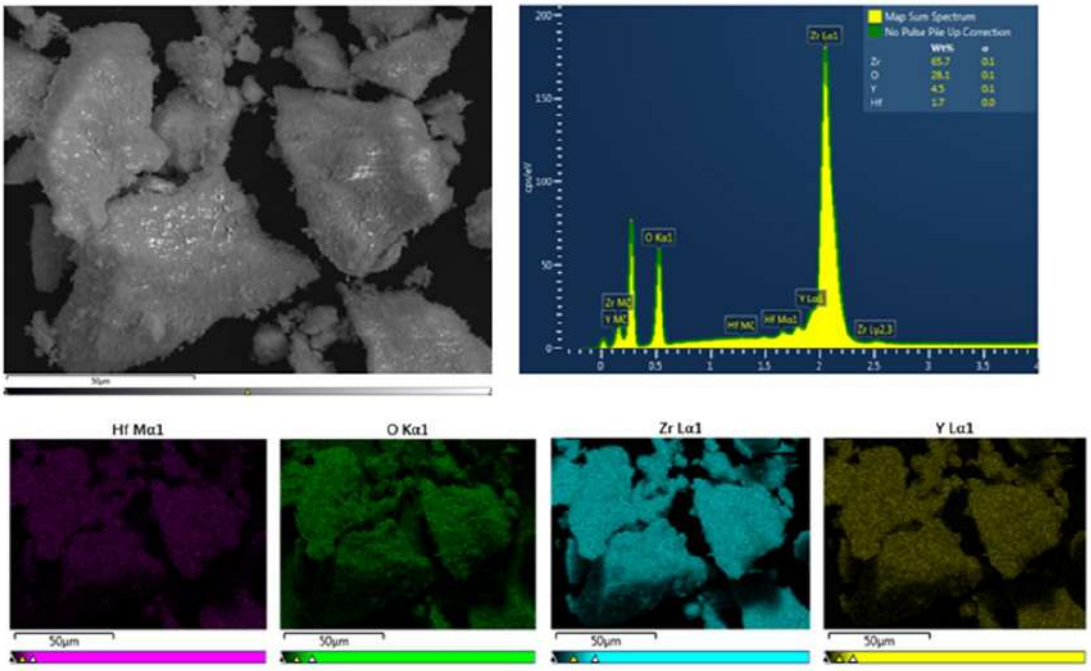

Figure 1. YSZ particles SEM image and EDS analysis.

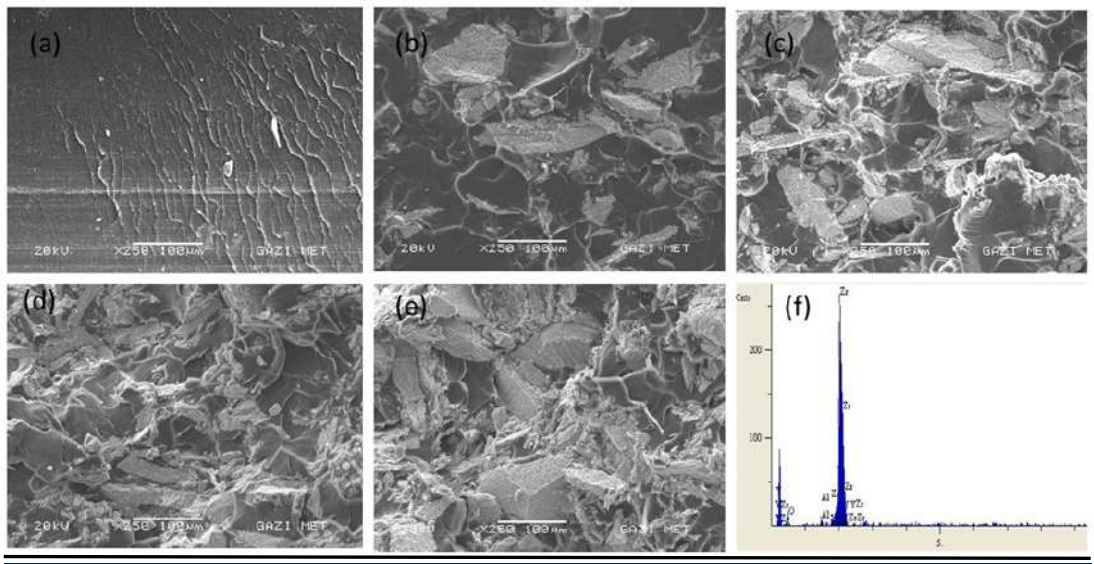

Figure 2. SEM of Recycled stabilized zirconia reinforced PMMA acrylic (a) 0.0 wt%, (b) 25 wt%, (c) 50 wt%, (d) 60 wt%, (e) 65 wt% and (f) EDS analysis

2.2 Statistical analysis

Data quality control and statistical analyses were done using IMB SPSS Statistics Version 25.0 (IBM SPSS, Chicago, IL, USA). Normal distribution and homogeneity of variance showed with Shapiro–Wilk and Levene's tests. Data were analyzed using a one-way analysis of variance (ANOVA) with the Tukey post-hoc test at a pre-set alpha of 0.05.

3. Results

3.1 SEM analysis and microstructural characteristics

According to SEM analysis (Figure 1), residue YSZ particles size was between 500 nm and 70 µm. According to EDS results, YSZ particles chemical compositions consist of 65.7 Zr wt%, 28.1 O wt%, 4.5 Y wt% and 1.7 Hf wt%. It can be seen from Figure 1 that EDS map analysis indicates homogeneous distributions of all phases in the particles. Figure 2 shows SEM microstructure and EDS analysis of unreinforced PMMA and ZrO_2 reinforced composites fracture structures.

Unreinforced PMMA fractured surfaces were very dense, smooth and homogeneous without porosity (Figure 2a). With the addition of YSZ to PMMA, the surface roughness of fractured surfaces significantly increased. Additionally, fracture surfaces roughness proportionally increased with increasing YSZ amount in structure Figures 2b-e. According to Figure 2e, over 60 wt% YSZ amounts caused YSZ agglomeration in the matrix. There are some voids among the YSZ agglomerated particles because of the unwet YSZ by PMMA matrix. These vacancies reduce the mechanical properties. FTIR test was carried out on unreinforced PMMA, and YSZ reinforced PMMA to evaluate the different active groups.

Figure 3 shows FTIR analysis results of unreinforced PMMA, 25.0 wt %, 40.0 wt%, 60.0 wt%, 70.0 wt% YSZ reinforced PMMA. Five new strong absorption picks were seen at wavenumbers of 2919.3, 1616.1, 1535.6, 598.4 and 567.7 cm^{-1} in the FTIR spectrum of YSZ reinforced PMMA composites compared to unreinforced PMMA. 1616.1 cm^{-1} resulted from the tension vibration of the hydroxyl groups for the YSZ surface. The stress vibration of the C-H bond at 2940 and 3000 cm^{-1} and that YSZ bond in the range of 1530-1620 cm^{-1} showed that PMMA successfully bond to YSZ (Figure 3). However, 70 wt% YSZ FTIR peaks are not strong as other FTIR peaks because of YSZ agglomerations and insufficient wetting by PMMA. Therefore, only weak chemical bonding between the PMMA and YSZ occurs over the 60 wt.% YSZ addition. These results were exactly matching with SEM images.

Figure 4 represents Vickers hardness and density variation with YSZ amount. Microhardness increased with increasing YSZ amount until 60 wt% YSZ addition from 23.45 to 31.18 (Table 2), indicating that surface hardness increased by over 24%. However, above 60 wt% YSZ addition, microhardness decreased because of ZrO_2 agglomeration in the composite structure. This issue proved successfully load transfer mechanisms that occur in the composite structures. Densities increased with the increasing second phase (YSZ) amount in the composite due to the higher densities of YSZ, which is 5.97 compared to the density of PMMA which is 1.17. This shows that YSZ density is 5.1 times higher than PMMA; hence density increased with the increasing YSZ amount.

As shown in Figure 5, unreinforced PMMA and YSZ reinforced PMMA matrix composites, low amount YSZ addition does not significantly affect the surface roughness of composites. However, with the increasing YSZ addition, surface roughness increased proportionally. Over 60 wt% surface roughness sharply increased due to the high amount of YSZ agglomerations.

The mean values of Vickers hardness in Table 2 showed statistically significant differences ($p<0.05$). There was no statistically significant difference between groups up to 25% YSZ addition ($p<0.05$). A maximum increase in microhardness was observed at 60 wt% zirconia ($p<0.05$) (Table 2). A sudden decrease was observed in the group containing 65 wt% zirconia, whereas 70 wt% zirconia powder addition was found to have the least microhardness ($p<0.05$).

The mean values of surface roughness in Table 2 showed statistically significant differences ($p<0.05$). The addition of 50 wt% zirconia did not make a significant difference in the roughness, while 60 wt%, 65 wt% and 70 wt% YSZ powder produced a significant increase in the roughness ($p<0.05$).

4. Discussion

This study showed that the residual powders obtained

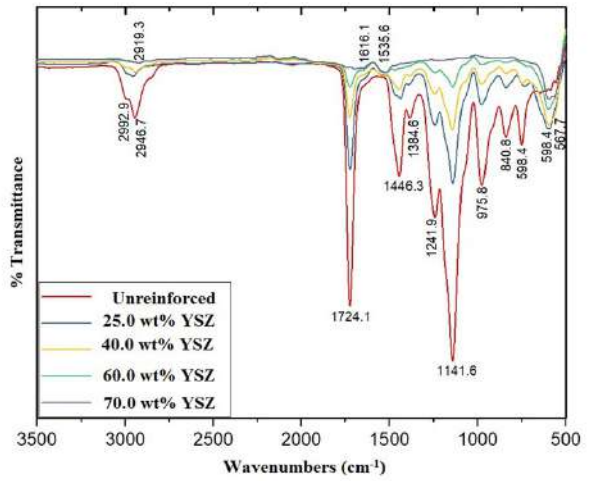

Figure 3. FTIR analysis of unreinforced, and reinforced PMMA with 25.0 wt %, 40.0 wt%, 60.0 wt%, 70.0 wt% of YSZ

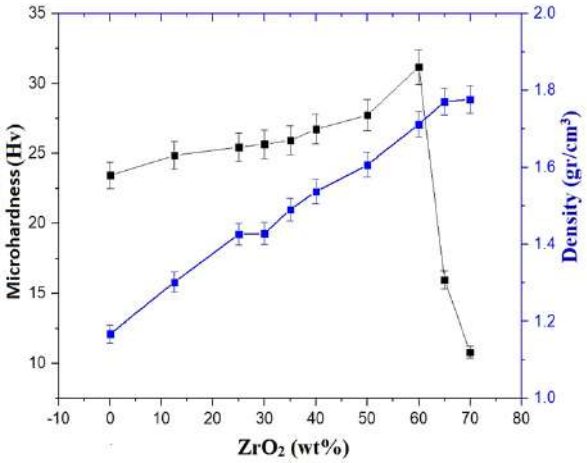

Figure 4. Microhardness and density of PMMA with various concentrations of ZrO_2 amount.

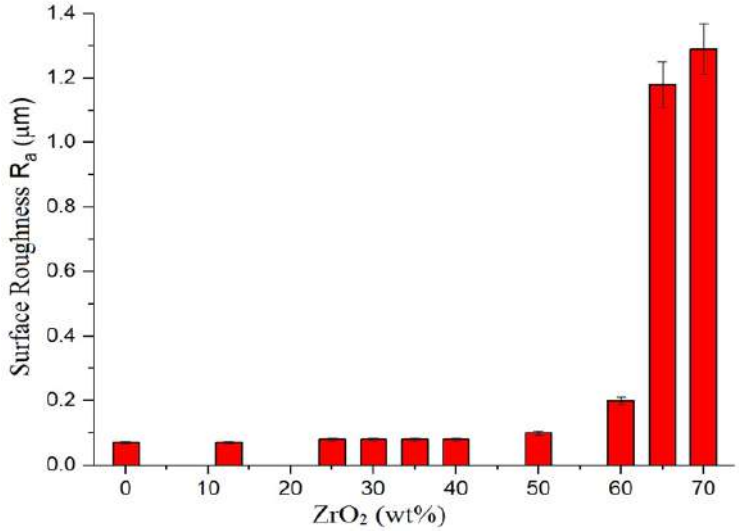

Figure 5. Surface roughness (Ra) variation with ZrO_2 concentration

Table 2. Mean and Standard deviation (SD) of Vickers hardness (kg/mm²), surface roughness and density of reinforced and unreinforced PMMA resin.

	Weight (%)	Vickers Hardness	Surface Roughness	Density
1	0.00	23.45±1.08 ^{A}	0.07±0.01 ^{A}	1.17±0.03 ^{A}
2	12.50	24.87±1.01 ^{AC}	0.07±0.01 ^{A}	1.30±0.07 ^{B}
3	25.00	25.44±3.59 ^{AC}	0.08±0.03 ^{A}	1.43±0.02 ^{C}
4	30.00	25.66±2.34 ^{AC}	0.08±0.02 ^{A}	1.43±0.05 ^{C}
5	35.00	25.03±3.12 ^{AC}	0.08±0.01 ^{A}	1.49±0.04 ^{CD}
6	40.00	26.73±1.03 ^{BC}	0.08±0.00 ^{A}	1.54±0.10 ^{DE}
7	50.00	27.73±2.49 ^{BC}	0.10±0.03 ^{A}	1.61±0.02 ^{E}
8	60.00	31.18±1.08 ^{D}	0.18±0.06 ^{B}	1.71±0.01 ^{F}
9	65.00	15.98±0.80 ^{E}	0.20±0.00 ^{C}	1.77±0.06 ^{F}
10	70.00	10.81±0.45 ^{F}	0.29±0.00 ^{D}	1.78±0.10 ^{F}

Within a column, values identified using similar upper-case letters are not significantly different.

after CAD/CAM machining had improved the mechanical properties of PMMA.

In the present study, Unreinforced and various amount residues YSZ reinforced PMMA matrix composites were successfully produced. The addition of residue zirconia powders addition at higher amounts increased Vickers hardness and density but did not affect the surface roughness of the PMMA composites.

PMMA fully covered all YSZ particles until 60 wt% YSZ addition, and good bonding between the PMMA and YSZ was observed with the formation of a very dense microstructure. Similarly, composites microhardness and densities increased with increasing YSZ amount in the composite structure.

Surface roughness was not significantly changed until 60 wt% YSZ additions. However, over the 60 wt% YSZ addition sharply increased surface roughness.

However, the microhardness and roughness values of PMMA acrylic resin groups with less than 50 wt% zirconia powder addition did not differ significantly from the control group ($p>0.05$).

Temporary crown material may wear out due to functional forces and foods; thus, it must have adequate abrasion resistance. Adding inorganic filler into PMMA can increase microhardness, especially the addition of hard fillers such as ZrO_2 [27]. By examining the acrylic resin hardness, residual monomer amount [24], resistance to abrasion [29], and ease of finishing of the material [9] are determined.

The results of the present study were in agreement with a study presented by Ahmed *et al. (2014)* that evaluated the hardness of PMMA/ZrO_2 nanocomposites with different ZrO_2 concentrations (1%, 3%, 5%, 7%) using the Vickers hardness test [27]. They found that all specimens showed hardness mean values higher than that control group, and PMMA specimen with 7% zirconium oxide nanofillers showed the highest mean hardness significantly.

Over 60 wt% YSZ additions to PMMA caused YSZ agglomeration in the structure and decreased mechanical properties because of vacancies among the agglomerated YSZ. This agglomeration can be attributed to insufficient wetting by PMMA.

With the addition of residual zirconia powder, Vickers hardness was increased up to 60wt% of YSZ, while it decreased significantly after adding 65wt% and 70wt% powder. The decrease in surface hardness with higher filler loading was caused by poor adhesion of the particles to the resin matrix and filler clustering within the matrix [28]. Zhang et al. investigated the effect of zirconia nanoparticles and aluminum borate whiskers (ABW) in PMMA denture bases on the surface hardness at concentrations of 1 wt%, 2 wt%, 3 wt% and 4 wt% [28]. The results showed an increase in surface hardness with an increase in ZrO_2/ABW content, and the optimum hardness was achieved at 3 wt% ZrO_2 nanoparticles.

In another study, Ergun *et al*. (2018) [30] investigated the physical and mechanical properties of PMMA reinforced with various ratios of zirconium oxide nanoparticles and observed a significant increase in hardness and surface roughness.

Hardness is the resistance of a material to plastic deformation. Surface hardness can be used as an indicator of density, and it can be hypothesized that a denser material would be more resistant to wear and surface deterioration [31].

Vojdani *et al*. (2012) [7] reinforced PMMA mixtures with Al_2O_3 at loadings of 0.5, 1, 2.5 and 5 wt%. They stated that Vickers hardness values increased linearly but could not find any difference in surface roughness. The Vickers hardness significantly increased after the incorporation of 2.5 and 5 wt% Al_2O_3 addition. No significant difference was detected in surface roughness between the reinforced and control groups.

The addition of recycled zirconium powder has been shown to increase microhardness, as in previous studies. This microhardness increase is due to the hard zirconium oxide (ZrO_2). An increase in microhardness was observed due to the crushing tip of the microhardness device hitting zirconium metal oxides.

One of the problems that surface roughness can cause in temporary dentures is colour change, adhesion of food and plaque formation, depending on the amount of roughness [32].

In the present study, with the addition of 60% or more recycled zirconia powder by weight, the roughness increase was found to be below 0.2micrometres, which

can be accepted as clinically [33]. The roughness was directly proportional to the amount of recycled zirconia powder incorporated into the resin matrix. This increase is because of the zirconium particles in the matrix approaching the surface.

In the study groups, a statistically significant difference in density changes up to 50% zirconia, but no difference was found with the addition of 60% or more zirconia. As the recycled zirconia powder content increased, their values increased due to decreased pores [34]. The effect of nanoparticles on the mechanical properties of PMMA depends on several factors, including polymer particle interface, particle size, fabrication method, and particle dispersion in the PMMA matrix [35].

5. Conclusion

Different amount of residual YSZ reinforced PMMA was produced within a pressure vessel system. FTIR results showed good bonding between the residue YSZ and the PMMA matrix. According to SEM results, residue YSZ was homogenously distributed in the PMMA matrix until 60 wt.%. Over 60 wt.% additions caused YZS agglomerations in the matrix. Also, a high amount of residue YSZ addition (60 wt.%) decreased mechanical properties because of unwetted residue YSZ and space between the agglomerated YSZ powders. Another effect of high amount second phase additions sharply increased surface roughness. Composite structure density was increased with increasing residue YSZ additions due to the higher density of residue YSZ.

Provisional PMMA with superior mechanical properties was created using recycled zirconia without the need for special additional processing steps. Best mechanical and structural properties were achieved with 60 wt.% residue YSZ additions.

Conflicts of interest: Authors declared no conflicts of interest.

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Evaluation of the tear strength, compressive resistance, and surface hardness of three commercially available bite registration materials: an *in vitro* study

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ABSTRACT

Background: For making a successful prosthesis, it is essential to achieve harmony between the maxillomandibular relationship. The precision and occlusal quality of the prosthesis partly depends on interocclusal bite registration material. Interocclusal bite registration material plays an important role in recording and transferring of existing patient's occlusal records. The procedure used to record and transfer interocclusal relation should be performed with the utmost care and understanding to prevent clinical error.

Aim: This study aimed to evaluate the tear strength, compressive resistance and surface hardness of three commercially available bite registration materials .

Materials and methods: Three types of commercially available bite registration materials, Bis-acrylate (BA), Polyvinylsiloxane (PVS), and Polyether (PE), were made in Dumbbell and cylindrical shaped samples to evaluate the tear strength and compressive resistance, respectively and were analysed using the universal testing machine. The surface hardness was assessed using a microhardness tester. The obtained data were subjected to statistical analysis using SPSS 16.0 version (Chicago, Inc., USA). ANOVA/Kruskal-Wallis test was used to compare study parameters among the groups. Tukey's post-hoc test was used for inter-group comparisons.

Results: Bis-Acrylate exhibited the greatest tear strength, followed by Poly vinylsiloxane and Polyether showed the least tear strength. More compressive resistance was observed in Polyether followed by Bis-Acrylate and lowest in Polyvinylsiloxane. A similar pattern was seen in the surface hardness among the three materials.

Conclusion: Bis-acrylate showed greater tear strength and surface hardness, and it can be considered a better bite registration material.

1. Introduction

Interocclusal bite registration materials are partly responsible for accurate precision and occlusal quality of final prosthetic restorations used for mounting casts on the articulators. Accurate mountings can lead to restorations that require minimal occlusal modifications intraorally, thus reducing the chairside time [1]. Diagnosis and treatment planning procedures may be inadequate if casts are fixed in an inaccurate position. The procedure used to record and transfer interocclusal relations should be performed with the utmost care and understanding [1].

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Historically, various materials used for inter-occlusal registration are thermoplastic materials like waxes or chemically set materials such as dental plaster, Zinc Oxide Eugenol (ZOE) paste and recently developed elastomeric impression materials [3,4]. The first material used was impression plaster with some filler materials. However, dental plaster is difficult to manipulate, making space for dental waxes [4]. Waxes are used alone or in combination with other materials. However, waxes tend to undergo distortion if not appropriately handled. ZOE paste was considered as one of the best interocclusal recording material. However, this paste has few shortcomings like longer setting time, sticky to the teeth and brittleness. Vital portions of the record are lost through breakage on removal from the mouth. Hence, ZOE records are rarely used.

Some clinicians also tried acrylic resin, and it is most frequently used in the fabrication of single stop centric occlusion records. Acrylic resin is accurate and rigid after setting with few demerits like dimensional instability and rigidity [5]. A modelling compound was used to fabricate segmental interocclusal records. Errors observed were the flow of the material over axial surfaces of teeth and soft tissues, which invites errors in re-positioning working casts within the bite registration and abrasion of the working cast during mounting [5].

Recently, addition silicones and polyether impression materials have been modified by adding plasticisers and catalysts in order to be used as interocclusal records. They are popular because of their resistance to compression, surface hardness, high tear strength, dimensional accuracy and stability [6]. A compressive force is commonly exerted on the interocclusal recording material during the articulation procedure, which may cause inaccuracy during mounting of cast and distortion during fabrication of the restoration. The ability of an interocclusal recording material to resist compressive force is critical because of the potential for inaccuracies. The deformation may vary with the thickness and the properties of the recording materials used[1]. Similarly, the hardness of the material can reduce shrinkage and resist deformation [7]. Tear strength can likewise record the bite with precision and accuracy [8]. The present study was undertaken to evaluate and compare the tear strength (TS), compressive resistance (CR) and surface hardness (SH) of three commercially available bite registration materials to determine the one with the least inaccuracies.

2. Materials and methods

Three commercially available bite registration materials used in the study were PVS bite registration material (3M™ Imprint™ 4 VPS Impression Material) (Figure 1), PE bite registration material (3M™ ESPE™ RAMITEC™) (Figure 2), and BA bite registration material (LuxaBite™ Bisacryl Registration Material) (Figure 3).

A total of 90 samples were prepared, which comprises 30 samples from each bite registration material. The specimens from each bite registration material were subdivided into three subgroups with ten specimens (n=10) in each used to evaluate tear strength, compressive resistance, and surface hardness, respectively.

2.1 Preparation specimens to evaluate tear strength (TS)

Dumbbell-shaped aluminium metal jigs were fabricated with 2mm in thickness, 80mm in length, a width of 5mm (periphery) and 3mm (centre) as per ASTM638. The jigs were then placed in the dental flask filled with dental stone to form moulds. The selected bite registration materials were mixed as per the manufacturer's instructions and packed into the mould. Care was taken to prevent air entrapment into the prepared samples. The set material (Figure 4) was then retrieved and stored in a container for further testing.

2.2 Preparation of specimens to evaluate compressive resistance (CR), and surface hardness (SH)

A cylindrical hollow tube of internal diameter 10mm and length of 5mm was made. Both sides were kept open for easy retrieval of the samples after setting. Each die was coated with a lubricating agent for ease of removal of set materials. The materials were mixed and packed into the mould and covered by two metallic plates for uniform distribution of pressure. The set material (Figure 5) was then retrieved and stored in a container for further testing.

2.3 Evaluation of tear strength

The dumbbell-shaped specimens from each material group were subjected to a tensile stress using the universal testing machine (Mecmesin Multitest 10i, United Kingdom) at a crosshead speed of 5mm/min.

Figures 1—3. Bite registration materials used in the study.
Where 1. Polyvinyl siloxane 2. Polyether and 3. Bis-acrylate.

Figure 4. Dumbbell-shaped specimens for evaluating tear strength.
Figure 5. Cylindrical-shaped specimens for evaluating compressive resistance, and surface hardness.

The load at which tear occurred was recorded. Tear Strength was calculated using the formulae:

TS (MPa) = F/A.

Where, F is the force magnitude at rupture, and A is the cross-sectional area of unstrained samples (mm^2).

2.4 Evaluation of compressive resistance

The cylindrical specimens (n=10) from each material group were subjected to the Compressive Resistance test using a Universal Testing Machine (UTM). A constant increasing load was applied until the specimen started deforming. The compressive resistance was recorded from the apparatus.

2.5 Evaluation of Surface hardness

The remaining ten cylindrical specimens (n=10) from each material group were tested for SH using a Vickers microhardness tester (FM-110Series, Japan). A load of 2.0kg force for 5 seconds was applied, and the indentations were made on the surface of each sample. The lens was focussed, and the length of diagonals was measured. The average length of the diagonals was considered as the surface hardness of the specimens.

The obtained data were subjected to statistical analysis using SPSS 16.0 version (Chicago, Inc., USA). All the study variables were tested for normal distribution by using the Kolomogrove test. The one way (ANOVA)/ Kruskal-Wallis test was used to compare study parameters among the groups. Tukey's post-hoc test was used for inter-group comparisons.

3. Results

The mean and standard deviation of all the tests are presented in table 1. Among the three materials tested, Bis-acrylate material showed the maximum tear strength followed by Polyvinyl siloxane. Polyether exhibited the greatest resistance to the compression followed by Bis-acrylate material. Bis-acrylate showed more surface hardness followed by polyether material (Table 1). The ANOVA showed a significant difference in tear strength (p=0.0001), compressive resistance (p=0.0001) and surface hardness (p=0.01) among three materials (Table 1).

The inter-group comparison (post-hoc analysis) showed significant differences (p=0.000) between the materials in compressive resistance and tear strength (Table 2). In surface hardness, a significant difference (p=0.000) was observed between polyvinyl siloxane and Bis-acrylate materials (Table 2).

Table 1: Comparison of tear strength, compressive resistance and surface hardness (One way ANOVA).

Groups	Tear strength (Mean±SD)	Significance (p-value)	Compressive strength (Mean±SD)	Significance (p-value)	Surface hardness (Mean±SD)	Significance (p-value)
Polyvinyl siloxane	37.51±13.45		4337.60±6562.49		4.76±0.45	
Bisacrylate	429.60±62.38	0.0001*	11955.39±2378.98	0.0001*	27.17±28.63	0.01*
Polyether	8.20±3.93		66960.09±14323.08		8.84±2.69	

* Statically significant differences

Table 2: Inter-group comparison (post-hoc analysis) of compressive resistance, tear strength, and surface hardness

Properties	Bite registration materials		Mean Difference ± Standard error	Significance (p-value)
Compressive resistance	Poly vinyl siloxane	Polyether	63294.56±3185.77	0.000
		Bis-acrylate	12013.83±3185.77	0.000
	Polyether	Bis-acrylate	51280.73±3185.77	0.000
Tear strength	Poly vinyl siloxane	Polyether	31.00±6.78	0.000
		Bis-acrylate	385.09±6.78	0.000
	Polyether	Bis-acrylate	416.10±6.78	0.000
Surface hardness	Poly vinyl siloxane	Polyether	4.39±2.625	0.098
		Bis-acrylate	14.58±2.625	0.000
	Polyether	Bis-acrylate	10.19667±2.625	0.000

4. Discussion

Oral rehabilitation involves a series of sequential steps that must be followed very judiciously to obtain the desired results [9]. The success of any prosthetic rehabilitation depends on various aspects related to the precise mounting of casts in an articulator. An accurate interocclusal record transfer is required for occlusal quality and the essential fabrication of a prosthetic restoration [10]. The degree of accuracy of the record between the articulator and the patient depends on the type of articulator, biologic factors and the recording material. In cases where the number of teeth present are satisfactory and will provide cast stability, the casts can be mounted by manual articulation. On the other hand, when large edentulous spaces are present, cast mounting is considerably more complex. It increases the need for accurate transfer of the interocclusal relationship and vertical dimension [9].

The 3D maxillomandibular relationship depends not only on the facebow and articulator but also on the recording material [11]. There are various methods of recording maxillomandibular relationships, viz, graphic, functional, cephalometric and direct interocclusal recordings. Direct interocclusal records are most commonly used to record maxillomandibular relationships because of their simplicity [1]. A recording medium is necessary to register the patient's inter-arch relationship. Some of the critical requirements of interocclusal materials include limited initial resistance to closure to avoid the displacement of periodontally compromised teeth or the mandible during record-making, dimensional stability, resistance to compression, ease of manipulation, biocompatibility, accurate recording and ease of verification.

Studies conducted previously stated that wax and ZOE are not reliable as interocclusal records because of significant linear changes. There can be mounting inaccuracies if not used immediately [12]. The various drawbacks of commonly used materials like dental waxes, dental plaster and ZOE include distortion,

compression and tearing. The flowability and flexibility of Polyether are significantly less, making it a stiff material easily subjected to breakage. On the other hand, polyvinylsiloxane undergoes shrinkage due to the loss of by-products, leading to questionable dimensional stability; however, its accuracy has been studied to be the best [2].

The present study encompassed three commonly used bite registration media, namely Polyether, polyvinylsiloxane and bis-acrylate. Each material was tested for Tear Strength, Compressive Resistance and Surface Hardness. Co-relation studies were done to compare the properties and find the one with the least distortion.

Bite registration materials should resist tearing when tensile stresses are applied during removal of the record and mounted cast separation. They are most susceptible to tearing in the interproximal areas. Tear in the bite record causes defects, will affect the accuracy of the final restoration. Additionally, some record material remnants in the interdental area may precipitate inflammation. Therefore, impression materials must have maximum tear Strength at the time of removal [8].

In this study, Bis-acrylate material displayed the maximum tear strength followed by Polyvinyl siloxane (Table 1). The reason for the high TS in Bis-acrylate is possibly the highly-dense polymer structure, which permits the material to resist tearing forces.

An ideal bite registering material should have high compressive resistance to prevent distortion caused by handling or processing. In the present study, Polyether bite registration material exhibited more resistance to compression compared to the remaining two materials (Table 1). The probable reason for the greater CR could be its low dimensional changes compared to other bite registration materials [16].

The hardness of a bite registration material after setting is critical, as it can ensure a distortion-free interocclusal recording. A hard, highly filled interocclusal bite registering material is expected to exhibit fewer vertical discrepancies due to reduced setting shrinkage and high resistance to deformation, thereby ensuring a more accurate fit on stone models [13]. In this study, Bis-acrylates exhibited the greatest surface hardness compared to PVS and PE materials (Table 1). This can be attributed to the presence of maximum fillers in the Bis-acrylate materials.

The conversion of carbon double bonds causes immediate shrinkage in a polymer. For each monomer segment of the chain, the larger Vander Waals intermolecular spacing is replaced by smaller intramolecular covalent bonds, resulting in changes in dimension and density [14]. Bis-acryl composite was introduced to overcome these negatives of methacrylate. Bisacryl composite consists of bi-functional substrates to provide cross-linkage with one another and form monomer chain cross-linkage, leading to increased impact strength and toughness. They also contain inorganic fillers to increase their abrasion resistance. They have low polymerisation shrinkage, low exothermic reaction, reduced tissue toxicity, good wear resistance and strength. But these materials are expensive, brittle and some show allergic reactions.

Bis-acrylate (LuxaBite) can be considered the bite registration material of choice. It showed a higher degree of stiffness, adequate compressive resistance, and highest tear strength than any other available material.

The present study evaluated and compared the tear TS, CR and SH of only three commercially available interocclusal bite registration materials. In addition, this is an in vitro study and cannot reflect the conditions of clinical applications exactly. Therefore, further studies may be focused on evaluating the other critical physical and mechanical properties of different materials of various brands in clinical situations.

5. Conclusion

Within the limitation of this in-vitro study, the following conclusions can be drawn.

- Bis-acrylate was found to have the maximum tear strength and surface hardness.
- Polyether was examined to have the highest compressive resistance.
- Polyvinylsiloxane showed median values for all three properties (surface hardness, compressive resistance and tear strength).
- Case specificity and necessary precautions to overcome the drawbacks of each material plays an integral role in the choice of the bite registration medium in order to achieve accurate results.

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Repair bond strength of aged resin composite using different surface treatments and bonding protocols

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ABSTRACT

Background: Repair of direct composites are less invasive than replacement, diminishing the risk of iatrogenic exposure of the pulp and the risk of detrimental to adjacent teeth, all in all, reducing the procession of the "restoration death spiral".

Aim: This study aimed to evaluate the repair bond strength of aged resin composites using different surface treatments and bonding protocols.

Materials and methods: A total of 45 discs (n=45) were fabricated of Nano-hybrid composite measuring about 2.5 mm in height and 3.5 mm in diameter and were mounted in acrylic resin and subjected to 10,000 thermal cycles between 5-55° C with 30 seconds of dwell time in a thermocycler in order to simulate artificial ageing. All these samples were assigned into three groups (n=15) based on the surface treatment protocol. According to the bonding protocol, the samples in each group are further divided into three subgroups (n=5). After surface treatments of the aged composites, the application of bonding agent followed by new composite material was performed. All the samples were stored in distilled water at 37° C for 24 hours. The shear bond strength of the samples was measured using a universal testing machine at a crosshead speed of 1mm/min.

Results: Among the groups, the mean bond strength in medium grain diamond bur and 37% phosphoric acid etchant with the universal bonding agent subgroup was higher 852.56±27.71 than the remaining groups. The lowest mean bond strength of 200.9±10.62 was observed in 37% Etchant with direct composite subgroup.

Conclusion: Different combinations of surface treatments and bonding protocols affect shear bond strength differently. The highest shear bond strength values were achieved for the group where surface treatment was done with the combination of blue diamond bur and 37% phosphoric acid along with a universal bonding agent.

1. Introduction

Resin composites are commonly used as direct restorative materials for the esthetic restoration of both anterior and posterior teeth in dental practice [1]. They have critical applications in contemporary restorative dentistry, including but not limited to restorative materials, cavity liners, pit and fissure sealants, core buildup, luting of indirect restorations, provisional restorations, cements for single or multiple tooth prostheses and orthodontic devices, endodontic sealers

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and post bonding [2]. They have considered as the 'material of choice' for use in direct, minimal intervention approaches with adhesive techniques due to their aesthetic and physical properties [3,4].

Composites present various advantages, such as ease of handling, satisfactory physical and mechanical properties and the most excellent esthetic appearance [5]. They also have several disadvantages like secondary caries, marginal staining, marginal defects, marginal or body fracture, discoloration, degradation and loss of anatomical form, unsatisfactory shade, and painful symptoms [6].

Although composite materials are adhesively bonded to the tooth structure, they are subjected to different degenerative changes [7]. The degradation of resin composites is complex and includes intraoral degradation (mechanical, physical, or chemical) and extraoral degradation (storage and shelf life of the material) [8]. Composites are less stable in fluids and have a higher degradation rate in saliva simulating conditions. The enzymes present in the saliva of the oral cavity degrade the composite matrix. All these factors affect the clinical longevity and success of composite restorations [9,10].

Therefore, to effectively improve the longevity of composite restorations, they need to be either refurbished, repaired or replaced [11]. Refurbishment refers to the addition of restorative material without removing material or dental structure [12]. Repair refers to removing defective parts and adding new composite resin to remaining aged resin composite restorations and/or adjacent tissues, leaving the intact part in place [13]. Replacement refers to the complete removal of restorative material for the placement of new material [14].

Replacement was used to treat defective composite restorations traditionally. But repairing serviceable composite restorations have gained wider acceptance regarding the modern concept of minimally invasive dentistry [15].

The success of the repair is dependent on the magnitude of the bond strength obtained at the interface of old and new restoration [16]. The bonding and shear bond strength are improved due to the presence of Camphoroquinone in the new composite layer, which is essential for complete polymerization of the oxygen inhibited layer at the inter-phase [17]. Therefore, adequate surface treatment of the old resin, section of an adhesive system, and the appropriate restorative material are required to repair an existing restoration successfully [18,19].

Numerous surface treatments promote mechanical interlocking, surface wetting, and chemical bonding during composite repair [12]. The surface treatments include surface roughening with diamond burs [20], silicon papers, carborundum stones [21], finishing discs [22], sandblasting [21,23], airborne particle abrasion with aluminium oxide particles with or without silanated silica coating [24], acid etching with phosphoric or hydrofluoric acid [25], silane coupling agent application [22,26], and resin-based adhesive systems application.

These surface treatments and bonding protocols showed variable results on the composite repair bond strength. Therefore, this study was designed to evaluate composite restorations' repair bond strength through different surface treatments and bonding protocols. The null hypothesis was that there were no differences between the bond strength values of repairs performed on composites, and the surface treatment protocols applied have no influence on these repairs' bond strength.

2. Materials and methods

The armamentarium of the present study was presented in Figure 1. In this in vitro study, 45 discs (n=45) were fabricated of composite (Herculite Ultra, Kerr, United States) measuring about 2.5 mm in height and 3.5 mm in diameter. All the samples were mounted in acrylic resin. they were subjected to 10,000 thermal cycles between 5-55° C with 30 seconds of dwell time in a thermocycler (Model TS130, Weiss Umwelttechnik Gmbh, Germany) in order to simulate artificial ageing.

The samples were assigned into three groups based on the surface treatment protocol, with fifteen samples (n=15) (Figure 2) in each group. In Group I, the samples (n=15) were surface treated with the application of 37% phosphoric acid (d-tech, India) for 20 seconds (Figure 3). In Group II, the samples (n=15) were surface treated with the use of medium grain diamond bur driven in a high-speed airrotor handpiece (NSK, Japan) (Figure 4). In Group III, the samples (n=15) were surface treated with the combination of medium

grain diamond bur driven in a high-speed airrotor handpiece (NSK) followed by the application of 37% phosphoric acid (d-tech, India) for 20 seconds.

The samples (n=15) of each group were further divided into three subgroups with five specimens in each (n=5) for repairing. In the group I, all the three subgroups were treated with 37% phosphoric acid (d-tech). Then, the first subgroup was restored with direct composite (Beautifil-II composite, SHOFU Dental ASIA-Pacific P. Ltd., Singapore) with a Teflon coated composite instrument and light-cured for 30 seconds. The second subgroup specimens were applied with a universal bonding agent for 10 seconds with an applicator tip. The specimens in the third subgroup were restored with flowable composite (Flow plus composite, SHOFU Dental ASIA-Pacific P. Ltd, Singapore) and light-cured for 30 seconds.

In the group II, all the three subgroups were surface treated with medium grain diamond bur driven in a high-speed airrotor handpiece (NSK Japan). Then the specimens were restored with direct composite and a universal bonding agent and flowable composite as disrobed in the group I. In group III, all the specimens in the subgroups were surface treated with medium grain diamond bur driven in a high-speed airrotor handpiece (NSK), followed by treating with 37% phosphoric acid (d-tech). Then, the specimens were restored as described in the group I and II.

Various surface treatments of the aged composite were performed prior to the application of the bonding agent and then followed by the addition of new composite material. All the samples were stored in distilled water at 37°C for 24 hours. Shear bond testing for the samples was measured using a universal testing machine (Instron, UK) at a crosshead speed of 1mm/minute. Statistical analysis was done by using Kruskal-Wallis and Analysis of Variance (ANOVA) tests.

3. Results

Results of Kruskal-Wallis and Analysis of Variance tests showed a statistically significant difference between the groups. Mean shear bond strength (kN/m2) and standard deviation of all the combinations of surface treatment and bonding protocol and flowable composite application were presented in table 1. The highest shear bond strength values were observed in Group III (surface treatment with medium grain blue diamond bur and 37% phosphoric acid) (Table 1 and figure 5).

In the subgroups, placement of new composite material over the aged composite in situ with the application of bonding agent showed higher shear bond strength values than other subgroups (Table 1 and figure 5). The least mean shear bond strength was observed in the direct composite specimens etched with 37% etchant. Significant differences in the shear bond strength were observed among the groups (Table 1).

4. Discussion

Composite resins are tooth-coloured materials commonly used for aesthetic restorations of anterior and posterior teeth. Composites are polymer matrix filled materials, which derives their physical properties and handling characteristics from loading with reinforcing filler particles and the viscosity of the resin matrix [27-29]. They need the application of adhesive systems for adequate bonding and sealing of the restorations [30]. The primary aim of dental adhesives is to provide retention to composite restorations, withstand mechanical forces and prevent leakage along the restorative margins [31]. Bonding to the enamel can be achieved effectively due to its uniform composition of hydroxyapatite. In contrast, adhesion to dentin has several challenges due to the presence of water, smear layer, smear plugs and heterogeneous nature [32, 33].

Table 1. Shear bond strength in kN/m2 (Mean ± standard deviation) of all combinations of surface treatments and restored with direct composite, bonding agent and flowable composite.

Groups	37% Etchant	Medium grain diamond bur	Medium grain diamond bur and 37% Etchant	Significance (p-Value)
Direct Composite	200.9±10.62	368.84±46.4	417.12±38.77	0.004
Universal Bonding Agent	400.82±70.4	576.52±105.4	852.56±27.71	0.002
Flowable Composite	524.3±28.4	557.8±28.4	660.4±34.3	0.008
Significance (p-Value)	0.002	0.008	0.002	

Figure 1. Materials used in the study.

Figure 2. Groups based on surface treatment.

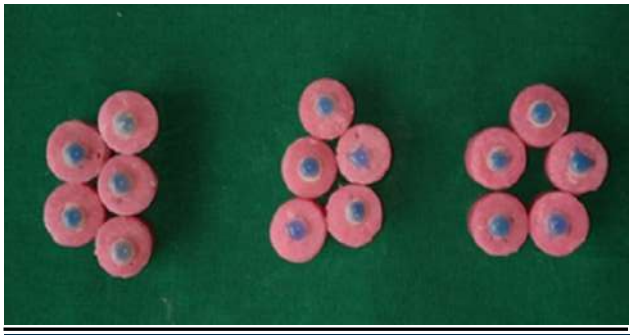

Figure 3. Surface treatment with 37% phosphoric acid.

Figure 4. Surface treatment with medium grain diamond bur.

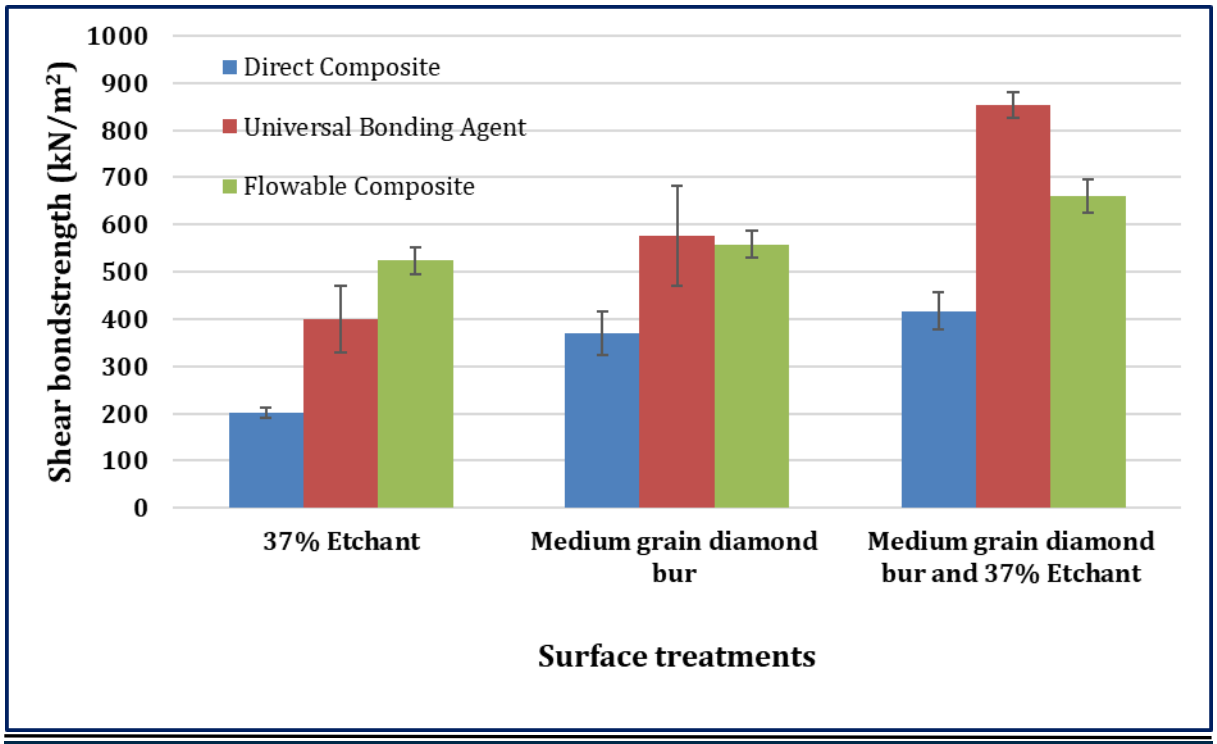

Figure 5. Comparison of shear bond strength of samples within the groups

Composite restorations are prone to ageing or failure in the long term. Artificial ageing of composite resins can be done through thermal cycling, boiling, and storage of the dry material at 37° C in acids, immersion in water, sodium chloride, artificial saliva or hot water [34-36]. In the present study, thermocycling of the samples was done to simulate hydrothermal ageing. Thermal temperatures between 5° C and 55° C coupled with water contributed to ageing in this study.

Repairing of aged composite restoration was considered as the treatment of choice rather than replacement [37]. Since the repair process results in weaker restorations, successful repair requires the development of an adequate interfacial bond between aged and new resin composites [23]. Repair bond strength can be influenced by several factors such as organic matrix composition, filler load, filler size, surface treatment for repair, conditioning prior bonding, application of silane coupling agent and adhesive system [13,38].

The interface between aged and new composite is the weakest link of the restoration [39]. Therefore, several ways have been proposed to improve the interfacial bond between aged and new composite, including surface treatments, either physical or chemical, to improve mechanical keying and chemical coupling at the adhesive interface [20,25,40]. In the present study, surface treatments were carried out using 37% phosphoric acid, medium grain diamond bur and a combination of both for the samples, respectively.

The phosphoric acid acts by the infiltration of resin monomers into the microporosities created by the dissolution of enamel and subsequent dissociation of the exposed hydroxyapatite crystals with polymerized monomers within the pores on the enamel surface, thereby accomplishing micromechanical retention [41]. Surface treatment with diamond bur resulted in creating macro irregularities. The conditioning of the aged composite surface aimed to obtain a cleansing effect, removal of debris and particles that have remained after treatment [42].

The present study showed the highest shear bond strength among the samples treated with medium grain diamond bur and 37% phosphoric acid (Table 1). This can be supported by the fact that prior surface treatment with diamond bur removed the superficial layer of the old composite. Later etching resulted in more penetration of composite into the microporosities, thus, enhancing the shear bond strength. The results of this study were consistent with the study done by Eliguzeloglu E *et al*. (2008) [43] reported that high surface roughness created with bur might have increased the dentin surface, promoting for better contact between the dental substrate and adhesive [43].

Lower shear bond strength values were observed in samples treated with 37% phosphoric acid and diamond bur, respectively (Table 1). Lower shear bond strength values with the treatment of 37% phosphoric acid were due to the collapse of resin matrix of composite in situ, creating improper bonding, which was in accordance with the study done by Sabatini C. (2013) [44] stated that surface treatment with acid etching might lead to incomplete adhesive infiltration into the denuded collagen network and also residual hydroxyapatites removal from collagen mesh due to sub-optimal removal of the phosphoric acid all together compromises the potential for chemical adhesion.

The results of the present study also presented higher shear bond strength values in subgroups characterized by the placement of new composite material over the old composite with the application of universal bonding agent, i.e., water/ethanol-based and both self-etch one-step adhesives when compared to other subgroups (Table 1), that was in accordance with the study done by Eliasson ST *et al*. (2017) [45] stated that the Scotchbond Universal promotes adhesion as it contains small amounts of silane or increases wettability as a coupling agent, thus enhancing bond strength.

Long-term water storage affects the mechanical properties of composite materials. For this reason, the samples in the present study were stored in distilled water only for 24 hours that was in accordance with study b Ferracane JL *et al*. (1998) [46] stated that water storage shows less significant effect on mechanical properties and indicates limited decomposition of composites in water.

In the present study, shear bond strength testing was done using a universal testing machine consisting of a notched cross-head designed to match the bonded specimen's diameter and apply a specific testing load in concurrence with the study done by Sabatini C. (2013) [44].

5. Conclusion

Different combinations of surface treatments and bonding protocols affect shear bond strength differently. The highest shear bond strength values were achieved for the group where surface treatment was done with the combination of blue diamond bur and 37% phosphoric acid along with a universal bonding agent. In contrast, the lowest values were observed with 37% phosphoric acid as the surface treatment agent and placement of direct composite.

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Obstructive sleep apnea: oral appliances and materials

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ABSTRACT

For the dental profession in general and in prosthodontists speciality, the subject of sleep medicine continues to offer great challenges and opportunities in diagnosis, treatment planning, and treatment based on qualitative evidence. Though the role contends by the prosthodontists is still in its infancy, there is a lot to find out and understand in the rapidly evolving field of sleep medicine because the recognition of co-managing patients with sleep disorders by the prosthodontists is quick changing into a reality. This article discusses the prosthodontic perspectives, particularly on obstructive sleep apnea.

1. Introduction

Obstructive sleep apnea has become more common nowadays. It is the most common respiratory disease associated with chronic insomnia. OSA causes a partial or complete narrowing of the upper airway during sleep by stopping/ reducing airflow, leading to regular sleep disturbances [1]. The different varieties of sleep apnea are obstructive, central and mixed. Obstructive is the most common of all three [2]. The role of prosthodontics is becoming more significant in treating sleep disorders especially in patients with mild to moderate obstructive sleep apnea (OSA). This article describes the epidemiology, etiology, pathophysiology, clinical features, and types of oral appliances used to treat obstructive sleep apnea.

2. Epidemiology

It has been reported that 10% and 5% of men and women, respectively, in the 30–40-year age group are common snorers, reaching at least 20% for males and 15% for females in the 50-60 year age group. It has been reported that 5% of the world population is affected by OSA, with the prevalence of 4% for men and 2% for women in the aged of 30-60 years [1,3-5].

3. Predisposing factors

Obesity is an important risk factor with prevalence ranging from 55 to 100% [6]. Cranio-facial abnormalities like micrognathia, retrognathia, enlarged palatine tonsils, enlarged uvula, high arched palate, nasal deviation, longer anterior facial height, enlarged tongue, long soft palate, decreased posterior airway space. In addition to age, genetic, ethnic and gender predilection and various habits such as alcohol consumption, smoking and drugs use, the existing OSA is aggravated [7].

4. Pathophysiology

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The upper airway is a soft tissue tube, the patency of which is maintained, in part, by muscles such as tensor veli and genioglossus. The base of the tongue obstructs the upper airway resulting in snoring. The upper airway is composed of the nasopharynx, oropharynx, and hypopharynx. When the patient falls asleep in the supine position, muscle relaxation causes the base of the tongue to approach the posterior wall of the pharynx. With the consequent reduction of airflow, the patient must increase the airflow speed to maintain the required oxygen supply to the lungs. This increase in airflow velocity causes the vibration of soft tissues that produces snoring.

The total volume of fat has been shown to be greater in OSA patients. Increase in thickness of the lateral pharyngeal wall predisposed to OSA development [7,8]. The various clinical symptoms observed in patients with OSA presented in Table 1 [9-14].

5. Diagnosis

Diagnosis of OSA can be made on history, examination, polysomnography [15], lateral cephalograms, computed tomography scanning, acoustic reflection test, limited channel testing and oximetry [16,17].

The severity of OSA is classified based on the patient's AHI (APNEA-HYPOPNEA INDEX) index. It is the average number of disordered breathing events per hour [5,18,19]. They include mild OSA (5 to 15 events per hour), moderate OSA (15 to 30 events per hour), and Severe OSA (more than 30 events per hour).

6. Treatment

OSA therapies include behavioural modification, positive air pressure (continuous positive airway pressure), oral and surgical procedures [20]. Oral appliances are widely used in patients with mild to moderate apnea.

7. Rationale behind using oral appliances

Oral appliances are worn solely during sleep and work to enlarge the airway by moving the tongue anteriorly or the mandible to enlarge the airway. Oral appliances help in preventing the tongue from blocking the throat, and/or pushing the mandible forward is often done. These devices help to keep the airway open during sleep. Proposed mechanisms for the action of oral appliances include increased upper airway size, decreased upper airway collapsibility, activation of upper airway dilator muscles, and stabilization of mandibular posture [21,22].

8. Materials used for fabricating oral appliances

Two different materials used for the fabrication of oral appliances, such as hard acrylics and thermal acrylics.

8.1 Hard acrylics

Hard acrylics are either chemically or heat processed, resulting in hard and rigid tooth-borne and occlusal surfaces. These are the common materials for fabricating oral appliances. They can be adjusted or repaired chair side easily without the need for an entirely new appliance and are easy to insert and remove. Hard acrylic appliances are more retentive when the shape of the clinical crown has good undercuts. Clasps can be used for additional retention.

Acrylic resins are known as PMMA which can be packed or injected into moulds and solidifies through a chemical reaction of polymerization. The disadvantages of heat-cured acrylic resins connected to increased porosity, high water retention, volume variations, and irritating effect of the residual monomer have led to alternative materials such as polycarbonate resins and polyamides, acetal resins and epoxy resins [23,24].

8.2 Thermal acrylics

They are soft and pliable at a warm temperature. Thermal acrylics allow comfort and easy seating, minimize the occlusal derangement. The major drawback of this

Table 1. Clinical features of obstructive sleep apnea [9-14]

- Memory problems
- Excessive day time sleepiness
- Difficulty in concentrating
- Night drooling of saliva
- Depression
- Irritability
- Xerostomia
- Gasping for breath at night and witnessed apneas.
- Poor work performance
- Occupational accidents

materials is it requires more frequent replacement than hard acrylics, especially for bruxers. They are manufactured through the thermoforming procedure from Essix type-A co-polyester or polypropylene copolymer [24].

9. Oral appliances

Oral appliances were first referred to in 1923 in books by the French paediatrician Pierre Robin [25], who described the fall of the tongue base as a cause of naso-pharyngeal impairment and suggested a prosthesis to correct "dysmorphic atresia of the mandible".

However, these devices were not used in the treatment of sleep apnea until the early 1980s. They were started using after describing a tongue retaining device to treat snoring and apnea by Cartwright and Samelson [26]. A renewed interest followed this device in mandibular development devices (MADs) that re-positioned the mandible in the protrusive position to help maintain the patency of the upper airway during sleep.

There are currently more than 55 oral appliances on the market. The appliances can be broadly classified into the following 4 types.

a. Tongue re-positioning devices, such as the tongue retaining device.
b. Mandibular advancement devices (MAD) work by holding the lower jaw and the tongue forward during sleep.
c. Devices designed to lift the soft palate.
d. Uvula lifters, which are not in use now due to discomfort.

9.1 Soft palate lifting

The soft palate lifting prosthesis lifts and/or stabilizes the soft palate, preventing vibration during sleep. The palatal lift prosthesis significantly improved the upper airway passage and eliminated snoring and airway obstruction, and improved the patient's overall quality of life [27].

9.2 Mandibular repositioning devices

It advances the mandible, brings forward the tongue and other muscles of the pharynx and elevates the palato-glossus muscle; thus, airway patency is enhanced. It also holds the mandible and other structures in a stable position to prevent the mouth opening. This is usually the most widely used respiratory device for apnea and has a higher evidence base. The devices cover the upper and lower arch and have metal hinges. The mandibular advancement device requires good retention, sufficient protrusion to maintain airway, minimal vertical opening, and full occlusal coverage.

9.2.1 Disadvantages

Reduced effectiveness in patients with: TMJ, myofascial pain, tooth tenderness, excessive salivation, gum irritation and bleeding, dry mouth and edentulous patients. Long-term MAD use may lead to dental and skeletal side effects that include [28]:

- Decrease in overjet and overbite
- Retroclination of maxillary incisors
- Proclination of mandibular incisors
- Increase in the mandibular plane angle
- Increases in anterior facial height
- Decrease in the number of occlusal contact points
- Anteroposterior change in occlusion.

When MAD is used, the teeth should be free from caries and periodically healthy and sound teeth to withstand the displacement forces.

9.3 Klearway oral appliance

The Klearway oral appliance uses a maxillary orthodontic expander to move the mandible forward sequentially. Klearway is a fully adjustable oral appliance used for snoring and mild to moderate OSA. A Small increase in mandibular advancement is initiated by the patient, preventing rapid jaw movements that cause significant patient discomfort (Figure 1) [29].

9.4 PM positioner

This appliance links the upper and lower splints with bilateral orthodontic expanders. This appliance is made of thermoplastic material (Figure 2) that must be heated in hot tap water every night before it is placed in the mouth [30].

9.5 The Thornton adjustable positioner (TAP)

This enables the progressive ′0 mm advancements of the jaw through the anterior screw mechanism at the labial aspect of the upper splint. This appliance has a separate section for both the mandible and maxillary (Figure 3) [31].

9.6 Modified Herbst Appliance

This design links the upper and lower splints with a piston-post and the adjustable telescopic mechanism on both sides. It prevents side-to-side motion, but

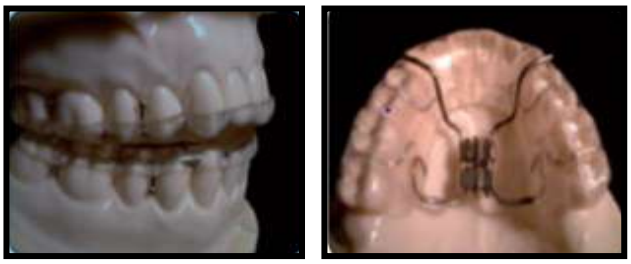

Figure1. Klearway appliance

Figure 2. PM positioner

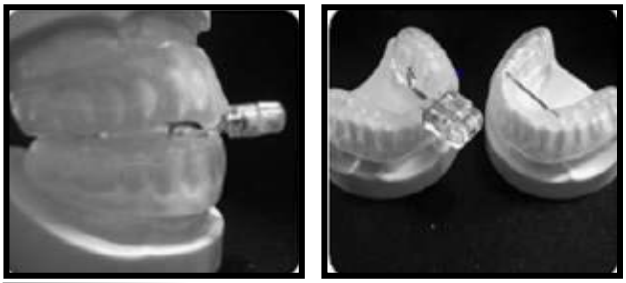

Figure 3. Thornton adjustable positioner

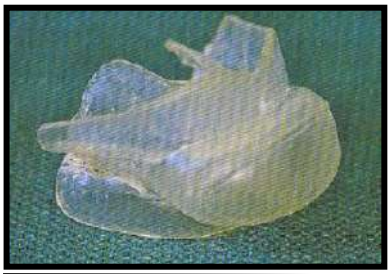

Figure 4. Tongue retaining device

since the mandible is kept close with small orthodontic rubber bands, opening the jaws is relatively easy [32,33].

9.7 The silencer system

This incorporates titanium precision attachments at the incisor level, allowing sequential 2 mm advancement of up to 8 mm, lateral movement of 6 mm, (3 mm bilaterally) and vertical pin height replacements. It is the only appliance that enables anteroposteriorly adjustment and an open and closed position since it includes a very expensive titanium metal hinge device [34,35].

9.8 Tongue retaining device (TRD)

It was first developed in 1979. It is a bubble-shaped device. TRD operates by holding the tongue in a forward position utilizing a suction bulb, which keeps the tongue from collapsing during sleep and obstructing the airway inside the throat. TRD is an excellent tool for patients or those suffering from TMJ sensitivity. This is usually a single piece of non-vinyl material without thermoplastic material to adapt to the teeth. Retention to the teeth or residual ridges is not a requirement with this device, and thus the rigidity of the device is unnecessary (Figure 4) [25]. These devices are indicated for edentulous patients, and patients with potential temporomandibular joint problems. TRDs do not require retention from dentition, Minimal adjustments are required, Cause minimal sensitivity to teeth and TMJ.

9.9 Side effects and complications

Dental malocclusion (21%), TMJ pain (15%), and TMJ dislocation (<5%), excessive salivation, tooth pain, posterior open bite are side effects of MRD. The overall incidence of side effects with MRDs is 25-60% which can be resolved with device adjustment.

Tongue abrasion, excessive salivation, and gagging are some of the TRD's reactions. The overall incidence of side effects for TRD was 25-75%. Recalls are necessary at a minimum of two weeks, one month, and after that every six months. These appliances are retained tightly by the remaining dentition and place almost orthodontic like forces on the teeth. They may also become loose or distort, or break, and hence maintenance is mandatory [36,37].

10. Conclusion

The oral appliances used to date form a group of heterogeneous devices used in the treatment of sleep apnea. Current evidence suggests that oral appliances "cure" mild to moderate sleep apnea in 40-50% of patients and significantly improved by 10-20%. A prosthodontist should have a vital role in the initial diagnosis, management, and care of patients with sleep apnea. Oral appliances play a crucial role in managing non-surgical OSA and have become the first line of treatment for almost all patients with OSA.

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Route maps for implant positioning: a review

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ABSTRACT

Dental implants are becoming a more common treatment choice in recent years, with an increasing number of patients preferring this option. Proper implant positioning is the most significant requirement for a successful implant treatment prognosis. A transfer system is necessary to ensure logical continuity between the diagnosis, prosthetic preparation, and surgical phases. Various techniques have been proposed for the fabrication of surgical guide templates in implant dentistry. This paper aims to review the associated literature and recent advancements in this field based on the design concept.

1. Introduction

The precise placement of the dental implant is essential to accomplish a pleasing result and the proper alignment to withstand occlusal forces. Dental implants inserted with a surgical guide are more precisely positioned than those placed without a guide. An implant placement guide also makes surgery less stressful for the surgeon because the critical placement factors were taken into account during the fabrication of the surgical guide. A precise reference for implant placement is provided by a stable and accurate surgical guide [1-3].

The use of prosthodontic terms and nomenclature in defining radiographic and surgical models are currently very confusing. The terms stent, guides, model, and equipment were used in the definition of these prostheses. Other terminologies often used in the identification of these prostheses include scanning equipment and radiographic equipment. [4]

2. Surgical template classification

Surgical and radiographic templates may be categorised by the type of material used in the prosthesis fabrication and the amount of restriction (drill guidance) associated with the template [5,6].

2.1 Materials

2.1.1 Clear vacuum-formed matrices

There are numerous advantages of clear vacuum-formed matrices, including cost efficiency, manufacturing ease, translucency, and variability. In addition to the clear matrix, many different materials were used, such as auto polymerizing acrylic resin, guttapercha, and metal rods.

2.1.2 Autopolymerized acrylic resin

These are composed with Poly(methyl methcrylate) resins with modifiers.

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2.1.3 Metallic guides of light polymerising composite resins

Metallic guides of light polymerising composite resins closely fit the diameter of drills or implant size. These guides are fabricated with the aid of computer-aided design/computer-aided manufacturing (CAD/CAM) technology. The accuracy and ease of manufacturing have been expanded using interactive treatment planning via CBCT imaging [7-9].

Three different surgical guide designs depending on supporting surfaces have been described [10]. They include i. tooth-supported surgical guide is placed on the remaining natural teeth, ii. mucosa-supported surgical guide is directly placed on the mucosa, allowing flapless implant placement, and iii. bone-supported surgical guide is placed on the bone following a full-thickness mucoperiosteal flap elevation.

2.2 The principles to design the Surgical guide templates [11,12]

The principles to design the Surgical guide templates are nonlimiting design, partially limiting design, and completely limiting design. These design principles are categorised based on the amount of surgical restriction offered by surgical guide templates.

2.3 Nonlimiting design

Nonlimiting designs only indicate to the surgeon where the proposed prosthesis is in relation to the selected implant site. This design suggests the ideal location of the implants without any emphasis on the angulation of the drill. Thus, allowing too much flexibility in the final positioning of the implant.

A summary of Blustein *et al.* (1986) [13] and Engelman *et al.* (1988) [14] was the technique of perforating a guide pinhole through a transparent vacuum-formed matrix. This guide pin hole suggested the optimum location of the dental implant. The angulation, however, was measured by the use of adjacent and opposing teeth. The circumference lead strip guide in which a lead strip is attached to the external surfaces of diagnostic waxing was described by Almog *et al.* (2001) [15].Thiswas used to outline the tooth position over the implant site. It has been observed that the use of these guides can lead to inappropriate access hole placement and/or inappropriate angulation of the implant. Therefore, during the surgical stage of implant placement, these will serve as imaging indicators.

2.4 Partially limiting design

The first drill used for osteotomy is guided using the surgical guide in such designs, and the remainder of the osteotomy and implant placement is then performed free-hand by the surgeon. Techniques based on this principle of design include the fabrication of a radiographic template, which is then transformed following radiographic evaluation into a surgical guide template. In the following stages of manufacturing, various authors have proposed various techniques involving modifications, including the material used to manufacture the surgical template, radiographic markers used, the type of imaging device used, and the conversion process involved in transforming the radio-graphic template into a surgical template.

2.5 Completely limiting design

The location, angulation and depth of the osteotomy are determined by guided tubes or sleeves with the complete limiting design, thereby restricting any variation by the implant surgeon. This type of guide can prevent any osteotomy error in the bucco-lingual and mesiodistal plane.

Additionally, drill stops can be incorporated to prevent over-preparing the site. Basically, with the complete limiting design, the final position of the implant is known before the actual surgery. This technique is becoming popular because the final prosthetic abutment or provisional restoration can be prefabri-cated for immediate provisionalisation after implant placement.

2.6 Free-hand technique

With the free-hand technique, the positioning accuracy of guide holes or sleeves is operator based. This approach does not exactly parallel implant positions and has the highest margin of error [16-18].

2.7 Milling

Milling is an accurate method in which the guide holes or sleeves are placed using a milling machine. This technique involves special equipment that is primarily used in dental laboratory environments, and precision depends heavily on the expertise of the technician[16].

2.8 Computer-Aided Design/Computer-Aided manufacturing

This technique uses three-dimensional images with specialized software to allow the implant guide holes and sleeves to be precisely placed. Using the reformatted CT images of the osseous morphology, done density,

opposing occlusion, and ideal implant positioning, precise final positioning can be obtained [19]. In a systematic review, John Wiley concluded that various computer-guided template-based implant treatments are available. Different types of software, template production and template stabilization, and variations of the surgical and prosthetic protocol are reported. The survival rate of implants placed with computer-guided technology is comparable to conventionally placed implants ranging from 91% to 100 % after an observation time of 12-60 months [20].

3. Surgical templates

The implant body positioning is dictated by the surgical design, which provides the best combination of support for repeated occlusion forces, esthetics, and hygiene requirements.

3.1 Requirements of a surgical template

- Should be rigid and stable in the accurate position.
- Should fit over and/or around remaining teeth in the arch to stabilise it in the proper position.
- The template should be able to extend onto un-reflected soft tissue regions if the arch has no remaining teeth. The template can then be used after the implanted soft tissues have been reflected.
- On the diagnostic wax-up, the optimal angulation for implant placement should be determined, and the template should correspond to this location during surgery. For each implant, at least two reference points are needed. The surgical guide must be raised above the edentulous bone.
- The distance between two points on the proposed abutment crown's occlusal surface (central fossa or incisal edge) and the crest of the ridge is approximately 8 mm. Consequently, a line representing the optimal implant insertion path can be drawn between these two points of reference. The perfect angulations are parallel to the most anterior abutment joined to the implant and perpendicular to the occlusal plane.
- Other criteria for fabrication of the surgical template include size, transparency, surgical asepsis, and the ability to revise the template as indicated.
- The template should not be too bulky and difficult to insert, or it should not obscure nearby land-marks.
- During bone grafts or implant placement, the surgical design must not contaminate the surgical area. It should be transparent so that when the template is in position, the bony ridge and drills can be more readily seen.
- The surgical outline must correspond to the desired facial contour. Since many edentulous ridges have lost facial bone, the template may help to decide how much augmentation is required for implant placement or lip and face support.
- The surgical template can be used in combination with a bone graft, and then the same template can be used for implant insertion and positioning.

Ideally, the surgical guide should possess the following characteristics:

- Simple and cost-effective to fabricate.
- Stable retention in surgical field (adjacent teeth or landmark).
- Easy access of drills/guide pins/osteotomes intraoperatively.
- Ability to translate pre-surgical work-up information accurately to the operating field.

The manufacture of the surgical guide template involves an arrangement of the diagnostic tooth by one of the following methods.

i. Diagnostic wax-up
ii. Checkingthe arrangement of denture teeth, or
iii. The duplication of the patient's pre-existing dentition/restoration.

4. Rationale for radiographic template

The optimal location of the final tooth position or prosthesis must be determined in order to correlate the positioning of the implant with the available bone. The implant may be surgically positioned in an inappropriate position without a specific location, resulting in biomechanical problems with potential complications. A correlation between the tooth or prosthesis location and the radiographic survey must exist to obtain this information. The ideal implant positioning will be complex and maybe difficult if no correlation exists [21].

4.1 Fabrication of radiographic template (Scanning template)

4.1.1Radiopaque Markers

A radiopaque material must be used to correlate tooth location and tissue in relation to available bone and vital structures. Barium sulphate ($BaSO_4$), an inorganic

Figure 1. A. Barium sulphate, B. Ideal homogenous mixture, C. Barium sulphate duplicated prosthesis

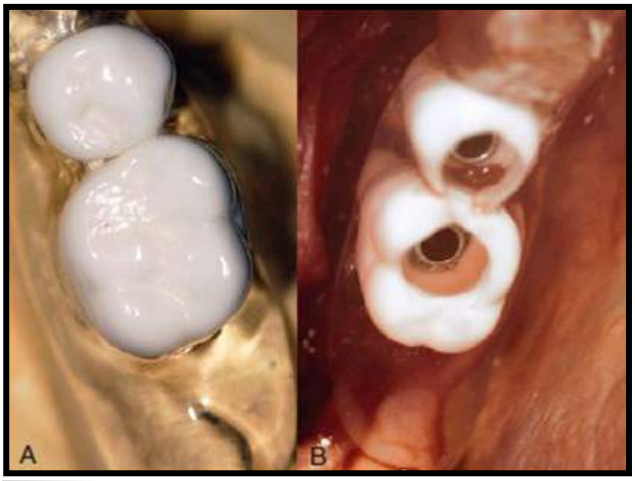

Figure 2. Radiographic template (RT). Where, A. RT is transformed into a surgical Template, and B. after completion of the scan.

compound used clinically as a radio-contrast material in medical diagnostic imaging, is the most common material used today in implant dentistry. Techniques to incorporate BaSO4 into the radiographic template include (Figure 1) filling the edentulous area with $BaSO_4$, painting the outside aspects of the buccal and lingual surfaces of the template, and use of preformed $BaSO_4$ teeth. Care must be made not to use too high of a concentration of $BaSO_4$ because it may cause excessive scatter in the scan [22,23].

4.2 Single- scan versus Double-scan technique

A radiopaque prototype with a single-scan technique (discussed later for partial and completely edentulous) is used by most planning software today. The composition of the radiopaque prototype and its functionality depending on the type of software used during the planning process. The protocol should be obtained before the scan to avoid problems with incorporating the CT data into the scanning software.

4.2.1 Single scan

Barium sulphate is used in a 20 per cent $BaSO_4$ solution to recognise the teeth from the diagnostic wax -up. If a soft tissue (flapless surgery) template is to be made, teeth are ideally identified with a 20% BaSO4 solution, and the base (soft tissue) uses a 10% mix. This helps teeth to be separated from soft tissue. A non -homogeneous mixture that exhibits areas of high radiolucency can result in poor mixing [24].

4.2.2 Double scan

It exhibits less scatter than the single scan technique. In this technique, reference markers (radiopaque material) are embedded into the radiopaque template. The patient is scanned wearing the template, and then the template is removed from the patient's mouth and scanned separately. The software program uses the markers to correlate the images. With the double-scan technique, the denture base resin and artificial teeth can be reconstructed for planning purposes. The soft tissue can be determined as the difference between the template and bone. The number and location of markers depend on the software program being used [25].

4.3 Fabrication of partially edentulous radiographic template

It is the most simple technique. The duplicate study cast is made after the fabrication of a diagnostic wax-up. A clear vacuum-formed matrix is made. With the use of $BaSO_4$, the material is added to the edentulous site. The patient then wears the prosthesis during the scanning process. A laboratory or an in-office technique may fabricate this prosthesis.

4.4 Fabrication of Fully edentulous radiographic template

If the present prosthesis of the patient requires no alteration due to aesthetics or function, the prosthesis is duplicated via a denture duplicator. During the scanning procedure, the patient wears the completely edentulous radiopaque template. Care must be taken so that the prosthesis during the scanning process is stable. Application of denture adhesive is strongly recommended before the scan to prevent inaccuracies in the position of the teeth.

4.5 Transforming a Radiographic Template into a Surgical guide

It is easy to construct a surgical guide from a radiographic template. If the diagnostic wax-up has determined the optimal positioning of the teeth, openings may be made to allow for accurate implant guidance (Figure2). There are two types of techniques for creating surgical guides from the programme for treatment planning. They are photopolymerisation by laser of liquid resin, and around CAD/CAM.

4.6 Additional forms (guides) of models

Two different models have been described and they are discussed in the following sections.

4.6.1 Models with stereolithography

A laser-dependent rapid polymerisation process using sequential layers of special polymers that can replicate the exact shape of osseous anatomy is the development of stereolithographic models [23]. These types of models are composed of i. versions of the surgical guide used in manufacturing, ii. pre-surgical models used in preoperative evaluation for implant placement, bone grafting, and orthognathic surgery, and iii. bone reduction guides (BRG). BRGs are similar to reduction copings in conventional crown and bridge, helps in reducing osseous height before implant placement.

4.6.2 Provisional restorations: "immediate smiles"

Taking the technology developed by CT to the next level involves manufacturing provisional restorations before implant insertion. Second, the implant dentist will create the virtual treatment plan, followed by the manufacturer creating the computer-generated stereolithographic surgical guides. The surgical guide and articulated diagnostic casts are used by a dental laboratory to produce provisional and (in some cases, final) prostheses. The implant dentist then places the implants and abutments using the surgical guide. Then, immediately after the positioning, the provisional (or final) prosthesis is inserted.

5. Conclusion

For the long-term success of implant therapy, the diagnostic phase of implant dentistry is very significant. In the fabrication of radiographic and surgical templates, proper mounting and evaluation of study casts are crucial. Evaluation of the edentulous sites and maxilla–mandibular relationships are an invaluable diagnostic tool in determining ideal implant positioning. Implants should ideally be placed with strict guidelines in relation to adjacent teeth, implants, and vital structures and various planes with respect to the edentulous site. With the use of radiographic and surgical templates, precision has been improved, and uncertainty and surgical time have been reduced, thus addressing complex rehabilitation with greater confidence. In addition, predictable positioning allows for better prosthetic outcome by simplifying abutment selection and avoiding complex laboratory fabrication when misalignment must be corrected. Future technical improvements likely will allow dentists to access these technologies while controlling costs, reducing surgical time, and minimising restorative steps.

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