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Apical microleakage assessment of teeth obturated with single-cone gutta-percha using two calcium silicate sealers and a resin sealer: an *in vitro* study

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ABSTRACT

Background: The most desirable outcome of endodontic treatment is to achieve a fluid-tight seal of the root canal space. Root canal sealers are used in combination with core filling materials to fill the irregularities in the root canal, resulting in a three-dimensional seal that prevents bacterial regrowth.

Aim: This study was aimed to compare the apical sealing ability of three root canal sealers AH Plus, Endosequence BC, and Endoseal MTA, using a single cone gutta-percha obturation technique.

Materials and methods: Forty extracted human single-rooted mandibular premolar teeth were decoronated to a standardized length of 15 mm and instrumented using crown down technique with the ProTaper gold rotary file system to apical file size F3. The roots were randomly allocated into three experimental groups (n=10) and two control groups (n=5). All the samples in experimental groups were obturated with a matched taper single cone: Group 1, Group 2 and Group 3 were obturated using AH Plus, Endosequence BC and Endoseal MTA sealers, respectively. Samples were immersed in 1% Methylene blue dye solution for 72 hours, and then the roots were split longitudinally and observed under a stereomicroscope. Apical microleakage was measured from the apex to the most coronal level of dye penetration. The data obtained were subjected to statistical analysis.

Results: Samples in all the groups showed evidence of leakage, except in the negative control group. One-way ANOVA showed significant differences between the groups (p=0.00132). Posthoc analysis exhibited a significant difference between group 2 and group 3 (p=0.0102).

Conclusion: Endosequence BC showed a superior seal and less microleakage compared to the two other sealers used in this study using a single cone gutta-percha obturation technique.

1. Introduction

The main intention of endodontic treatment is to eliminate microorganisms and to obtain a three-dimensional seal of the root canal space preventing it from

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reinfection [1]. Numerous bacteria are resistant to many irrigating solutions and intracanal dressings, such as calcium hydroxide, and persist in areas like lateral canals and dentinal tubules. As a result, extensive obturation is required to prevent apical or coronal leakage, as well as to entomb residual debris and recalcitrant bacteria [2,3]. An ideal root canal filling must seal all portals of exit to the periodontium, providing a fluid-tight seal of the root canal space [4].

An apical seal is the utmost essential factor for the success of endodontic therapy. About 58% of root canal treatment failures can be attributed to incomplete obturation of the root canal [5]. Hence, the apical sealing ability of root canal filling materials is considered the most vital when obturating a root canal. The commonly used filling material is gutta-percha (GP) in conjunction with sealer for obturation. Root canal sealer is essential in achieving complete seal by sealing the lateral canals, apical ramifications, with the possibility of attaining the good sealing ability to dentin, less solubility, good biocompatibility, mineralization to dentin, and formation of calcified tissues to seal the apex [6].

The single-cone obturation technique gained popularity after the increasingly widespread use of rotary nickel-titanium (NiTi) instruments and matched-taper GP cones. Moreover, this technique is considered simple, which causes less stress for both patient and practitioner [7]. New root canal sealers have recently been developed to replace traditional zinc oxide eugenol sealers. In particular, bioceramic-based sealers are gaining importance because of their alkaline pH, chemical stability, Less shrinkage, and biocompatibility [8,9]. Bioceramic based root canal sealers such as Endosequence BC sealer and Endoseal MTA sealer are offered as a pre-mixed syringe and usually contain calcium silicate. AH Plus, on the other hand, is an epoxy bisphenol resin sealant that comes in two tubes: epoxide paste and amine paste [10,11].

In endodontics, dye penetration, bacterial penetration, fluid filtering methods, and gas chromatography have been utilised to evaluate leakage. Dye penetration tests, however, appear to be most extensively utilised since they provide a quantitative result and do not require sophisticated materials and equipment [10].

This study was designed to compare the apical sealing ability of three different sealers using a single cone obturation technique with a dye penetration method using the stereomicroscope.

2. Materials and methods

2.1 Selection of samples and preparation

The sample size was assessed based on the previous studies using the G Power 3.1 software with 80% power and 5% significance. Forty extracted human mandibular premolars with a single root and canal were included in the study. The teeth with calcified canals, cracks or fractures, development defects, multiple canals, root caries, and endodontically treated teeth were excluded. For standardization, all the samples were decoronated to a length of 15mm by using a double-faced diamond disc (KG Sorensen, Barueri, SP, Brazil). Pulpal tissue extirpation was done, and the working length was determined using a size 10 K file (Dentsply, Maillefer, Tulsa, OK, USA). Biomechanical preparation for all the samples was done in crown-down motion using ProTaper Gold (PTG, Dentsply Tulsa Dental Specialities, Tulsa, OK, USA) till F3 file size. Canals were irrigated between the use of files with 5ml of 3% Sodium hypochlorite (Prime dental PVT LTD., India). To remove the smear layer, all canals were irrigated with 3ml of 17% ethylenediaminetetraacetic acid (DESmear, Anabond Stedman pharma research, India). The final rinse was performed by using 5 mL of distilled water to remove any remaining irrigating solution. All the irrigation procedure was followed using a side vented needle placed 1mm short of the apical foramen. After irrigation, the canals were dried with sterile absorbent paper points (Prime Dental PVT LTD., India). To eliminate inter-operator variability, all intracanal procedures were performed by a single operator.

2.2 Grouping and obturation of the Samples

All the forty samples were randomly divided into five groups consisting of three experimental groups (n=10) based on the sealer used for the obturation and one negative and one positive control group with five specimens (n=5) in each. Samples in the negative control group did not receive obturation, while in the positive control group, the samples were obturated with single cone GP size F3 without sealer. In Group 1, AH Plus (Dentsply, Maillefer, Ballaigues, Switzerland) sealer was manipulated according to manufacturer's instructions and was coated to canal walls using a #30 Lentulo spiral rotated at 300 rpm and 3 mm away from

the apex, and then all the samples were obturated using single cone obturation technique with sealer coated F3 size master cone GP. In Group 2, EndoSequence BC Sealer (Brasseler U.S.A., Savannah, GA) and in Group 3, Endoseal MTA sealer (Maruchi, Wonju, South Korea), the syringe tip was placed into the coronal one -third of the root canal, and sealer was deposited by compressing the plunger of the syringe. The master GP of F3 size was coated with sealer and slowly introduced into the canal, and all the samples were obturated using the single cone obturation technique. The excess GP in all the groups was seared at the orifice, and vertical compaction of the GP was performed. The canal orifices were sealed with Cavit-G (3M ESPE, Germany). The obturation quality was evaluated radiographically, and samples with inadequate obturation were excluded from the study and substituted with a new one. All samples were incubated for one week at 37°C and 100% humidity in an incubator to allow the complete setting of sealers.

2.3 Preparation of samples for Stereomicroscopic evaluation of dye penetration

The external root surfaces in the experimental and positive control groups were coated with two layers of nail varnish, excluding the apical 2 mm of the roots. However, the root surfaces of the negative control teeth were entirely coated with two layers of nail varnish. The samples were then immersed in a 1% Methylene blue dye solution for 72 hours. Following this, the samples were removed from the dye and rinsed under running tap water for 15 minutes, and dried. The nail varnish was removed with a BP blade no. 11. The samples were sectioned longitudinally with a diamond disk by placing the groove in a buccolingual direction from coronal to apical, and the filling material was removed using an endodontic explorer to allow obvious assessment of linear dye penetration. For each sample, linear dye penetration was measured in millimetres from apex to the most coronal level of dye penetration using a stereomicroscope (Olympus BX50, Japan) at 30x magnification.

2.4 Statistical analysis

The obtained data were statistically analyzed using one-way ANOVA and Tukey's post hoc test with IBM SPSS version 22 (IBM Corporation, New Orchard Road Armonk, New York 10504-1722, United States). The level of statistical significance was set at $p < 0.05$.

3. Results

The negative control group showed no linear dye penetration, while the positive control group showed complete dye penetration through the root canal space (Figure 1). The mean and standard deviation of linear dye penetration of the groups are given in Table 1. The maximum linear dye penetration was observed in group 2 and the minimum was in Group 2. The one-way ANOVA test revealed a significant difference between the groups ($p= 0.00132$) (Table 1).

In Tukey's posthoc analysis (Table 2), statistically significant differences were observed between group 2 and 3 ($p = 0.0102$). However, group 1 did not show significant differences with group 2 ($p = 0.446$) and group 3 ($p= 0.147$).

4. Discussion

The success of endodontic therapy is accredited to various crucial factors such as meticulous instrumentation, thorough debridement, and three-dimensional obturation of root canal space with a fluid-tight seal [12]. Endodontic sealers have a key role in sealing the root canal system, entombing the residual bacteria, and filling the irregularities in the prepared canal system [13]. The adhesion between the root canal dentin and GP is important in preventing microleakage, which can be attained through the use of different sealers [14]. Therefore, sealers have a great effect on the sealing of the canal space and the success of treatment.

With the introduction of matched GP, the traditional obturation is replaced with simple single cone obturation [15]. This technique has been considered less effective in sealing the root canal because of the larger bulk of cement that can be anticipated in the absence of condensation, resulting in more voids and shrinkage [16]. Recently, there has been development in the formulation of root canal sealers with properties such as alkaline pH, biocompatibility, and lack of shrinkage.

Various methods have been advocated in the literature for testing microleakage in teeth, but the dye penetration method is most widely used since it involves a simple technique and equipment and is economical [10]. Methylene Blue dye was used in this study as it has a high degree of staining, which allows easy quantitative assessment of the extent of dye penetration by linear measurement technique [6]. Furthermore, it diffuses easily and is not absorbed by the dentin ma-

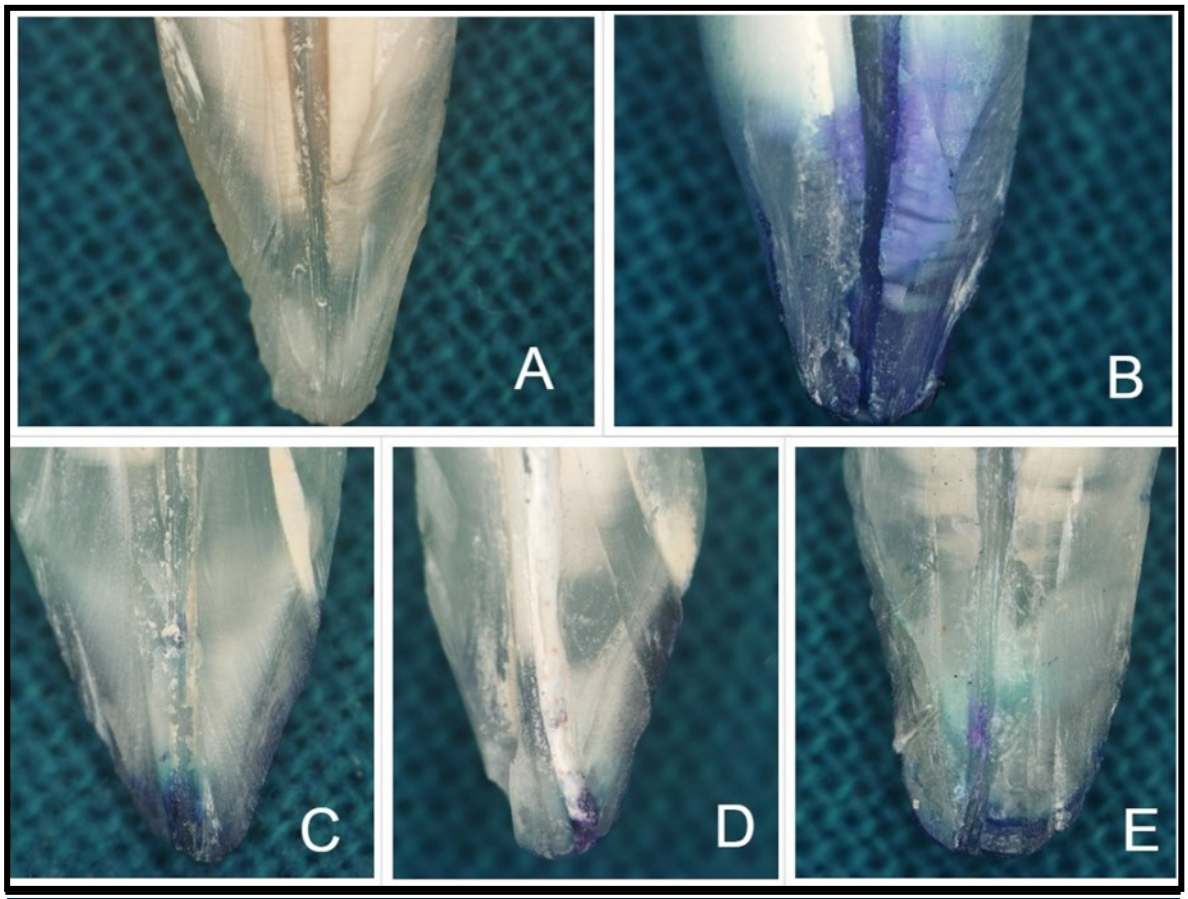

Figure 1: Stereomicroscopic images of tested samples showing linear dye penetration. Where A) negative control; B) Positive control, C) AH Plus, D) Endosequence BC, and E) Endoseal MTA

Table 2: Comparison of three experimental groups with respect to dye penetration by one-way ANOVA.

Groups	n	Mean ± Standard deviation	F value	Significance (p value)
Group 1 - (AH Plus)	10	1.8432±1.2068	5.104	0.00132
Group 2 - (Endosequence BC)	10	1.1306±0.9342		
Group 3 - (Endoseal MTA)	10	2.9670±1.6458		

Table 2: Comparison of three experimental groups with respect to dye penetration by one-way ANOVA.

Groups		Mean Difference ± Standard Error	Significance (*p* value)
Group 1 - (AH Plus)	Group 2 - (Endosequence BC)	0.713 ± 0.410	0.446
	Group 3 - (Endoseal MTA)	1.124 ± 0.410	0.147
Group 2 - (Endosequence BC)	Group 3 - (Endoseal MTA)	1.836 ±0.410	0.0102

trix apatite. Methylene blue was also the preferred choice because it has a molecular size and weight that is similar to a few bacterial by-products that have been reported to leak from the infected root canal into the periapical tissues causing irritation [17-19].

Results in the present study showed that Group 2, showed the minimum apical dye leakage with a mean value (1.1306 mm). The results of this study were in accordance with a previous study, which concluded that bioceramic sealer exhibited superior sealing compared with three different sealers by matched taper single cone obturation technique using dye penetration method [20]. Ballulaya *et al.* (2017) evaluated the microleakage of six different sealers and found that Endosequence BC had reduced microleakage, despite the fact that the obturation technique used was lateral condensation [21]. The minimum apical dye leakage value of Group 2 can be attributed to its ability to chemically bond to root canal dentin, and its extremely smaller particle size and hydrophilic nature allow it to flow into all aspects of the canal anatomy. In addition, the Endosequence BC root canal sealer exhibits a 0.2% expansion during the setting period, which supports the spread of the sealer over the dentin walls of the root canal and the filling of the lateral canals [22]. All these features may contribute to the lower apical dye leakage observed in the present study.

Group 1 showed more apical microleakage compared to Group 2 with a mean value (1.8432±1.2068 mm) but was not statistically significant (p=0.446). This result is in agreement with a study, which concluded that the Endosequence BC sealer exhibited superior sealing compared with the AH Plus sealer using the dye penetration method. This poor sealing ability of the AH Plus sealer could be due to inadequate bonding between the AH Plus sealer and the gutta-percha point due to shrinkage because of the faster setting of the sealer, allowing fluid leakage at this interface [23].

Group 3 showed more apical microleakage with a mean value (2.9670±1.6458 mm) compared to Group 2 which was statistically significant (p=0.0102) and with no significant statistical difference (p=0.147) on comparison with Group 1. This finding is consistent with a study that found Endoseal MTA to have lower sealing ability than AH Plus when employed as a root canal sealer utilising the single cone obturation technique [24]. According to a study by Lim *et al.* (2015), the decreased sealing performance of Endoseal MTA can be attributed to its higher solubility (0.7%) than AH Plus (0.06%) [25]. MTA based sealers do not bond to either dentin or gutta-percha which may be the reason for increased leakage observed in the present study [26,27].

5. Conclusion

Although none of the tested sealers prevents the apical microleakage completely, within the limitations of this study, it can be concluded that obturation with Endosequence BC sealer using a single cone technique resulted in superior apical sealability compared to the other two tested sealers.

Conflicts of interest: Authors declared no conflicts of interest.

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A comparative evaluation of properties of denture base materials processed with different processing methods: a *preliminary* study

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ABSTRACT

Background: The use of the traditional polymerization process of dentures necessitates a lot of time and energy. To depreciate these factors, a different processing method could be studied.

Aim: This study was aimed to evaluate and compare the properties of denture base resin material processed with conventional curing and pressure-pot method.

Materials and methods: A total of 30 specimens with distinct dimensions were fabricated with the denture base materials. The specimens were divided into two groups with 15 each, and they were processed using conventional heat-curing and pressure-pot processing, respectively. Each group is subdivided into three groups with five specimens in each for evaluating flexural strength, water sorption, and residual monomer, respectively. Flexural strength was measured using a 3-point bending test with a Universal testing machine. Water sorption was assessed by measuring the weight of the specimens after immersing them in distilled water. Residual monomer content was evaluated using a UV spectrophotometer. The obtained data were statistically analysed using an independent t-test.

Results: A slight increase in flexural strength was observed in the pressure processed specimens. However, no significant differences (p=0.131) were observed in the flexural strength between the groups. Less water sorption percentage was observed with the pressure processed acrylic resin specimens, and a significant difference (p=0.047) was observed between the groups. A slightly more amount of residual monomer content was seen in the acrylic specimens processed conventionally.

Conclusion: Pressure-pot curing may be used for processing denture base acrylics as it provides properties similar to that of the conventional curing method.

1. Introduction

Besides the enormous development of new materials and techniques, the rehabilitation with a removable prosthesis made of polymethyl methacrylate (PMMA) resin has been the preferred material since the 20th century [1]. PMMA

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has diverse advantages such as ease of processing, colour matching with the adjacent soft tissues, inexpensive, etc. [2] Polymerization of PMMA can be accomplished in several ways including, chemical, visible light, and heat activation (microwave energy/ hot water bath) [1-3]. Despite the availability of numerous polymerization methods, heat cure polymerization is popularly practiced [4]. The appropriate curing influences the physical and mechanical properties of denture prostheses. Improper curing may cause evaporation of monomer resulting in the formation of internal porosities and weakening the mass.

Numerous studies investigated the effect of different curing techniques on the properties of denture base acrylics. The regular processing time comprises a longer curing cycle i.e., 74^0 C for 8 hours followed by 100^0 C for 1 hour; alternatively, a short curing cycle of 74^0 C for 2 hours followed by 100^0 C for 1 hour [5]. These two curing cycles produce denture prostheses with minimum porosities. However, these two procedures require three to nine hours to complete the polymerization process. Faraj and Ellis (1979) [6] proposed that porosity would emerge in the cured resin only if the monomer's vapour pressure was greater than air pressure at temperatures above 100 degrees Celsius and that this pressure may be more than the denture flask clamping pressure. This clamping pressure is required to adapt the acrylic dough to the master cast during the curing and reduces the thermal shrinkages while polymerization and cooling. Various studies mentioned that the pressure applied to provide metal to metal halves contact during trail closures is in the range of 1500 – 4500 psi. Various studies demonstrated an improved degree of cure and flexural strength when the denture base acrylics were processed with microwave curing under pressure compared to conventional curing methods [7].

Processing acrylic dentures with a pressure cooker is another technique reported in the literature [3,8]. The advantage of this technique is that it can be used with the conventional acrylic resin material, and it requires less than one hour to complete the polymerization. However, limited research was available on the influence of pressure cooker processing on the properties of denture base materials. Therefore, this study was designed to evaluate and compare the properties of acrylic materials processed with the conventional and pressure processing methods.

2. Materials and methods

A total of 30 specimens were made using the conventional heat-cure denture base material (Dental Products of India, Mumbai, India). Among the 30 specimens, 15 specimens were processed with the conventional curing (group 1) and the remaining were cured with the Pot-pressure method (Group 2).

2.1 Sample preparation

A total of 30 wax specimens were made with the modelling wax (The Hindustan Dental Products, India) as per the ISO 20795-1:2008 to evaluate the flexural strength (65 × 10 × 3mm), water sorption (10 × 10 × 1.5mm), and residual monomer content (10 × 10 × 1.5 mm).

2.1.1 Conventional polymerization method

After the bench curing for about 30 mins/1 hour, the specimens were processed with conventional heat polymerized technique in an acrylizer (Confident A-73, India) at 73^0 for 90 minutes and then at 100^0 C for 30 minutes. The acrylic specimens were retrieved by deflasking following the bench cooling for about 30 minutes at room temperature. The excess material from the specimens was trimmed, and finishing and polishing were done.

2.1.2 Pressure-pot polymerization method

After the bench curing for about 30 minutes/1 hour, the dental flask was placed in a water-filled pressure pot and the lid was closed with weight in place. The flame was turned on till the first pressure ejection and permitted to cool to room temperature. The lid was opened and deflasked, the specimens were verified, and excess material was trimmed and wet polished.

2.2 Flexural strength evaluation

A total of 10 specimens (n=10), which comprises 5 specimens from each group were subjected to a 3-point bending test using the universal testing machine (UTES-40-HGFL, Fuel Instruments and Engineers Pvt Ltd., India) at a crosshead speed of 5 mm/min until the specimen fractured. The load at fracture was computed automatically from the universal testing machine.

2.3 Water sorption evaluation

A total of 10 specimens (n=10), which comprises 5 specimens from each group, were used for the evalua-

tion of water sorption. The specimens were weighed by digital analytical weighing balance (Shimadzu ATX 224, India) instantly after preparation (W1). The specimens were stored in distal water for one week at 37^0C in an oven. After week, they were removed, and the excess water was shaken off. The specimens were weighed (W2). Then, the specimens were desiccated for 24 hours and the weight (W3) of the specimens were recorded. The percentage of water sorption was calculated using the following formula.

$$(W2-W3)/W1 \times 100.$$

Where,

W1 is the original weight of the specimen.

W2 is the weight of the specimens after 7days of immersion.

W3 is the weight of the specimens after desiccation.

2.4 Residual monomer evaluation

The A total of 10 specimens (n=10), which comprises five specimens from each group, were stored in distilled water for two days at 37^0C. The storing medium of each specimen was collected through a pipette and placed over Nano-drop advanced version of UV spectrophotometer (NanoDrop™ 2000/2000c Spectrophotometers, ThermoFisher Scientific, USA). The detection was performed under the wavelength of 400nm, the pipette volume was 0.5µl. The values and graphs of both groups were generated digitally.

The obtained data were subjected to statistical analysis using Statistical Package for Social Sciences (SPSS), version 20.0, USA.

3. Results

In the present study, an independent t-test was employed to find the significance of flexural strength and percentage of water absorption rate of the acrylic specimens from the groups. The acrylic specimens processed with the pot-pressure method showed a slightly more flexural strength compared to the conventional curing method with a mean flexural strength of 66.23±9.27 MPa (Table 1). However, statistically, no significant differences (p=0.131) were observed between the two groups (Table 1).

The percentage of water sorption of acrylic specimens cured with different processing methods is given in table 2. The acrylic specimens processed with the pot-pressure method showed the least water sorption (0.81%) compared to the specimens processed with the conventional curing method. Statistically, a significant difference (p=0.047) was observed between the two groups (Table 2).

The residual monomer content of both the groups was plotted in figure 1. The values had fallen close to each other from both groups. A slightly more amount of residual monomer is observed from the specimens processed with the conventional curing method.

4. Discussion

The polymerization of PMMA requires activation of an initiator (benzoyl peroxide), to commence the additive reaction from a first free radical to start the polymerization chain reaction by opening the double bonds of the methyl-methacrylate. The threshold temperature for the generation of free radicals requires more than 60° C. As the temperature increases, there is a chance for increasing the exothermal polymerization. The methyl-methacrylate monomer boils at 100.8° C, and at this temperature, the residual monomer evaporates and create porosities in the resin and weakens the mass. To avoid this, the polymerization requires initial processing at a low temperature for a long time to prevent boiling of the monomer. To balance this thermal gradient, the complete polymerization of the denture base at least requires 8 hours at a much slower rate. Therefore, the longer time for the processing is a major disadvantage of the water bath polymerization technique [5].

Although microwave polymerization; which was introduced by Nishii *et al.* in 1968 [3], takes less than 10 minutes, which claimed as a major advantage and reported with better dimensional stability, transverse strength, less residual monomer content, and porosities. However, microwave polymerization has inherent disadvantages including the usage of special non-metallic flasks, conventional resins that cannot be used, and expensive [9]. Numerous researchers suggested the usage of a pressure-pot for processing acrylic dentures at a different time and pressure intervals as an alternative [10]. However, adequate research was not focused on the effect of pressure pot processing on the properties of denture base resin materials. Hence, this study was designed to compare the effect of conventional and pressure-pot processing on the flexural strength, water absorption and residual monomer content of commonly used denture base material.

Table 1: Comparison of flexural strength (MPa) between conventional and pressure-pot polymerization methods (one-way ANOVA).

Polymerization methods	n	Mean ± Standard deviation	t-value	Significance (*p*-value)
Conventional water bath	5	66.23 ± 9.27	1.677	0.131*
Pressure polymerization	5	78.92 ± 14.13		

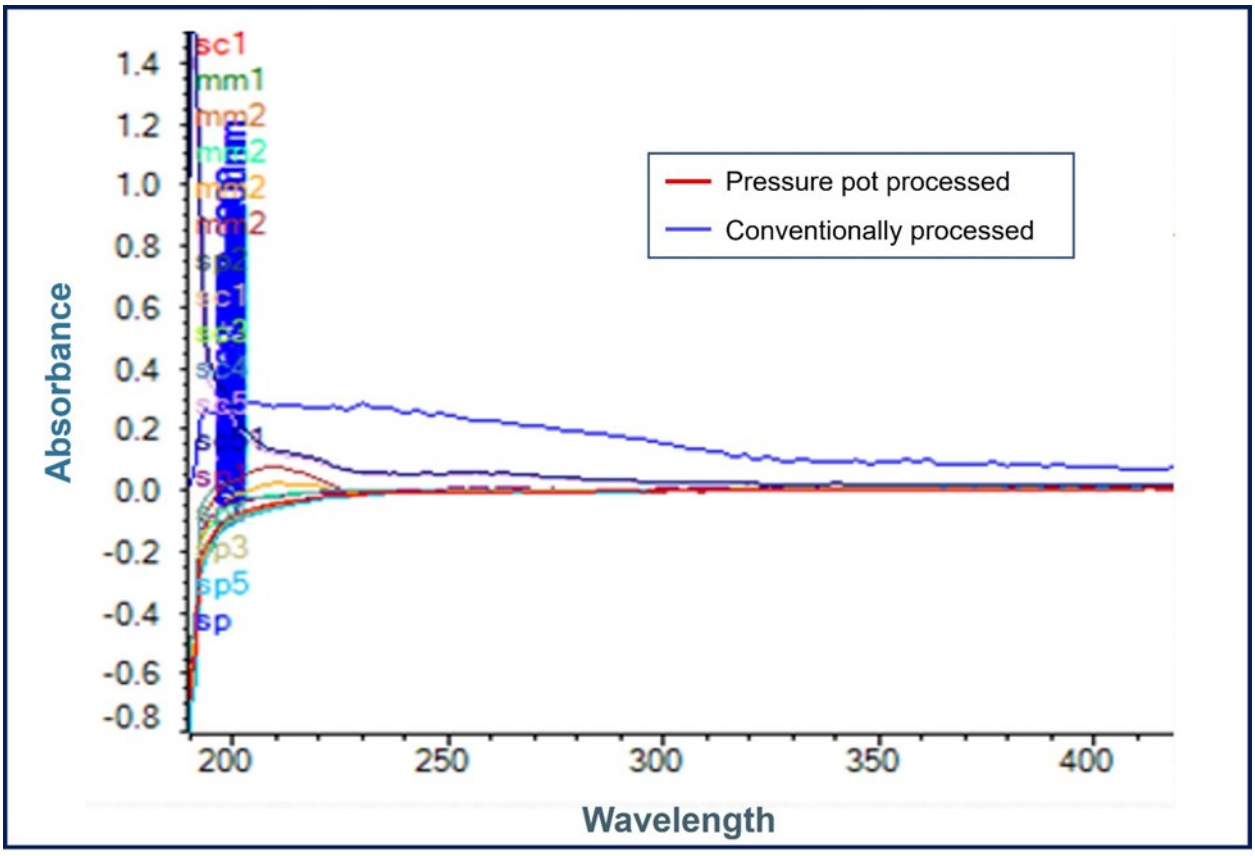
*statistically no significant difference was observed.

Table 2. Comparison of water sorption (%) between conventional and pressure-pot polymerization methods (one-way ANOVA).

Polymerization methods	n	Water sorption (%)	t-value	Significance (*p*-value)
Conventional water bath	5	1.63	0.063	0.047*
Pressure polymerization	5	0.81		

*statistically significant difference was observed

Figure 1. Residual monomer content of acrylic specimens processed with different techniques.



In the present study, the flexural strength was assessed as it reflects the complex stresses applied to the denture during mastication. The pressure-pot processed acrylic specimens exhibited a slightly greater mean flexural strength compared to the conventionally processed acrylic specimens. This slight increase in flexural strength can be attributed to the greater degree of polymerization under higher pressure (1/15psi) in the pressure pot, thereby the boiling point of water rises from 100^0-121^0C. The hotter steam can transmit its thermal energy around four times the rate of conventional boiling, and pressure can be maintained up to a certain period. An important role played by rising steam pressure is that it is instantly transmitted to the resin dough, possibly accelerating the initial polymerization and reducing the boiling of the monomer and thus preventing the residual monomer and the porosities. Earlier it was thought that the boiling point of monomer at 1520mm/Hg could be much higher than 120^0C. However, Maron and Prutton determined a formula for the boiling point of monomer at this pressure [9-11].

$$\text{Log}10 = \frac{P2}{P1} = \frac{HV}{2.30R} = \frac{(T2\text{-}T1)}{T2 \cdot T1}$$

P2 = pressure under consideration
P1 = atmospheric pressure
HV = heat of evaporation (8974.9 in case of methyl methacrylate)
R = 1.987 (gas constant in case of methyl methacrylate)
T2 = boiling point at P2
T1 = boiling point at P1

Using this formula, the boiling point of methyl methacrylate resin was calculated to be 128°C at 1520 mm Hg in the pressure cooker. This fact supports the hypothesis that pressure plays a significant role in accelerating the initial polymerization.

Acrylic polymers have the ability to absorb water. Further, the presence of porosities in the acrylic mass increases the water sorption capability. The absorbed water pushes the polymer chains apart and weakens the mass [12]. This study demonstrated less amount of water sorption by the acrylic specimens processed with pressure-pot. This is due to the smaller number of porosities in the pressure-pot processed specimens as there must be a greater degree of polymerization. The water sorption results of this study are in accordance with S.V. Bhide *et al.* [10]. From this study, it is evident that the lesser the water sorption more would be the flexural strength for acrylic dentures.

Inadequate or improper usage of the polymerization cycle leads to a more amount of residual monomer. This residual monomer may be leached into the oral cavity from the denture prosthesis during its service and transported to several parts of the body and exhibits several systemic toxic effects [13]. Therefore, it is necessary to follow an appropriate curing mechanism to enhance the degree of polymerization. Hence, this study also focused on evaluating the residual monomer content of acrylic resin specimens processed with different curing methods. From this study, it was observed that the pressure-pot curing facilitated the maximum conversion of monomer molecules to the polymer by maintaining the temperature under pressure.

This study was focused on evaluating the flexural strength, water absorption and the residual monomer content of the acrylic specimens processed with conventional and pressure-pot curing methods. Further studies may be conducted on evaluating the other physical and mechanical properties of denture base materials processed with the pressure-pot curing method.

5. Conclusion

From the results of this study, the following conclusions can be drawn.

1. Both the processing methods do not have a significant effect on the flexural strength of the acrylic resin specimens.
2. The percentage of water sorption was less in the acrylic specimens processed with the pressure-pot technique compared to the specimens processed with conventional methods.
3. From this study, it was observed that the pressure-pot processing method had an advantage in terms of decreased processing time and utilization of less energy.

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Effect of zirconium oxide and cellulose nanoparticles addition on the flexural strength, impact strength and translucency of heat polymerized acrylic resin: an *in vitro* study

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ABSTRACT

Background: Polymethyl methacrylate denture base material is considered the most popular denture base material to date. The advantages of the PMMA include low cost, biocompatibility, ease of processing, stability in the oral environment, and acceptable aesthetics. To improve the acrylic polymer's properties for removable acrylic appliances, the significant issues to be addressed are its low mechanical properties such as impact, bending, and fatigue.

Aim: This study was aimed to evaluate the effect of incorporating different concentrations of zirconium oxide and cellulose nanoparticles on flexural strength, and impact strength and translucency of heat polymerized acrylic resin.

Materials and methods: A total of 180 acrylic specimens were made and divided into two groups, which comprises 90 specimens in each. Group I and Group II were reinforced with ZrO_2 and cellulose nanoparticles, respectively. Each group was divided into three subgroups depending on the properties to be evaluated i.e., flexural strength, Impact strength, and Translucency, respectively. Each subgroup was further divided into three based on the concentrations (1.5 wt%, 2.5 wt% and 5.0 wt%) of the nanoparticles. The flexural strength was determined using a universal testing machine. The Izod impact tester was used to evaluate the impact strength. Translucency measured by UV visible spectrophotometer. The obtained data were analysed using one way ANOVA within the group followed by posthoc comparison by TUKEY'S method for the comparison between groups.

Results: Acrylic specimens incorporated with 2.5 wt% ZrO_2 exhibited more mean flexural strength, and the specimens with 2.5 wt% and 5.0 wt% cellulose nanoparticles showed the highest impact strength and translucency, respectively. One-way ANOVA showed significant differences (p=0.000) between the groups.

Conclusion: PMMA incorporated with 2.5 wt% of ZrO_2 NPs, 2.5 wt% and 5.0 wt% of cellulose NPs showed superior flexural strength, impact strength, and translucency, respectively.

1. Introduction

An ideal denture base material should have adequate mechanical and physical properties, besides biocompatibility and aesthetics[1]. In 1937, Dr Walter Wright

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introduced Poly Methyl Methacrylate (PMMA) denture base material, which is considered the most popular denture base material to date [2]. The advantages of the PMMA include low cost, biocompatibility, ease of processing, stability in the oral environment, and acceptable aesthetics [3]. In order to improve the acrylic polymer's properties for removable acrylic appliances and dentures, the important issues to be addressed are its low mechanical properties against impact, bending, and fatigue [4]. Hence, PMMA cannot be considered an ideal material because of its inferior physical and mechanical properties.

To improve mechanical and physical properties, various nanoparticles (NP) have been added to different dental materials like Zirconium oxide (ZrO_2), copper oxide (CuO), silver (Ag), silicon dioxide (SiO_2), zinc oxide (ZnO), titanium dioxide (TiO_2), etc. Among these, Zirconium nanoparticles received great attention because of their superior mechanical and esthetic properties [5]. Nano cellulose is a natural renewable polymer derived from plants and wood pulp, used to increase the strength and hardness of the material [6]. Another important parameter that governs the success of a complete denture is its translucency. Translucency is one of the major parameters when esthetics is considered and several nanoparticles have been added to improve the translucency of PMMA.

Previous studies suggested that the addition of Zirconium oxide and Cellulose nanofillers to PMMA improved mechanical properties such as flexural strength, fracture toughness, and hardness [7]. However, the translucency denture prosthesis was adversely affected and reduced as the nanoZrO_2 concentration was increased [8].

Though several studies have evaluated the effects of nanoZrO_2 and nanocellulose inclusion on the properties of PMMA denture base material, there is limited literature on comparing the effects of nanoZrO_2 and nanocellulose incorporation on the properties of PMMA. The purpose of this study was to assess and compare the effects of zirconium oxide and cellulose nanoparticles added in concentrations of 1.5wt%, 2.5wt%, and 5wt% on the flexural strength, impact strength, and translucency, respectively of heat polymerized acrylic resin.

2. Materials and methods

2.1 Incorporation of ZrO_2 and cellulose nanoparticles into PMMA heat cure resin

ZrO_2 nanoparticles (Nanoshel, India; Purity – 99.9%, Average particle size – 20 nm) were incorporated into the polymer of heat cure acrylic resin (DPI Heat Cure, the Bombay Burmah trading corporation ltd, India) at three different concentrations, viz. 1.5% and 2.5% and 5.0% by weight. The appropriate amount of ZrO_2 and acrylic resin were weighed using a digital weighing balance and were mixed using a mortar and pestle. To ensure uniform distribution of ZrO_2 in the polymer of heat cure acrylic resin "geometric dilution" method was employed for trituration. The insertion of cellulose nanoparticles (Nanoshel, India; purity – 99.9%, average particle size – 20 nm) followed a similar approach.

2.2 Fabrication of test specimens

Rectangular specimens were fabricated for measuring the flexural strength, impact strength and translucency. The dimensions of the rectangular specimens were 65x10x3 mm for flexural strength, 80x4x10 mm for impact strength, and 15x12x2 mm. Plexiglass moulds of the above-mentioned dimensions were fabricated with high precision laser cutting machine. Wax patterns were prepared from plexiglass moulds and were invested. The monomer and polymer of the heat polymerized acrylic resin were proportioned, mixed, packed, and pressed into the mould following the manufacturer's instructions. After closing the lid of the flask, it was subjected to 200 pascal loads using a hydraulic bench press. The flasks were bench cured for 30 minutes and processed at 74°C for 2 hours and then at 100°C and for 1 hour. After completion of the curing cycle, the flasks were removed from the water bath and allowed to cool slowly to room temperature. All the specimens were stored in distilled water at 37±1°C for 7 days, before testing.

2.3 Flexural strength evaluation

The flexural strength of the specimens was evaluated according to the ISO 1567, 1999 for denture base resins by a three-point bending test using a Universal testing machine (Instron, Maeon laboratories, Chennai, India). The rectangular specimens were inserted in relative points on the testing machine such that the span length was 50 mm. The samples were stressed at a crosshead speed of 5 mm/min until fracture occurred.

Flexural strength was calculated using the following equation.

$$S = 3 FL / 2bd^2$$

Where,

S: Flexural strength

F: Force of wedge to the middle of specimen

L: Distance between supporting wedges

b: Width of specimen

d: Thickness of specimen

2.4 Impact strength evaluation

The IZOD impact tester (Maeon laboratories, Chennai, India) was used to evaluate the impact strength of each specimen. IZOD is a pendulum impact machine consisting of a base, a pendulum and a striker rod. The rectangular specimens were inserted in the anvil or support to receive the blow of moving mass.

For plastic-type material like the acrylics, the pendulum apparatus imparting the load was a half-disc shape. The energy of the pendulum alone was 2.7J. Initially, the machine was calibrated to reduce the error, the test specimen was held tightly in the anvil, and the pendulum is then released from its latch. Pendulum swings down gaining energy from gravitational force and the height from which it is released. It hits onto the specimen, and the specimen breaks, and the pendulum swings to the other side. The energy required to fracture the specimen was measured in KJ/m^2.

2.5 Translucency evaluation

Light transmittance was measured using UV Visible Spectrophotometer (Varian, CARY 100 BIO, LabX, Canada). Light transmittance has been used as a translucency measure because it is a property of a substance that allows light to pass through it partially. UV/VIS spectroscopy is based on the absorption of light by a sample. Valuable information can be obtained based on the amount of light absorbed by the sample and its wavelength.

A spectrophotometer with a double prism monochromator to create the light of any desired wavelength, a photometer with a silicon photodetector to measure light intensity, and a sample holder made up the spectrophotometer. The equipment was set up such that specimens could be positioned between the spectrometer beam and the photometer at the integrating sphere's entrance port to measure the total amount of light transmitted and dispersed through it.

3. Results

The data were analysed using Statistical Package for Social Sciences (SPSS) version 16.0 software. Data obtained was expressed in its mean and standard deviation. Analysis of Variance (One Way ANOVA) was performed as a parametric test to compare different groups. In order to facilitate multiple comparisons between groups, Tukey's method was employed as a post hoc test along with ANOVA. For all statistical evaluations, a two-tailed probability of value less than 0.05 was considered significant.

The mean and standard deviations of flexural strength, impact strength and translucency of acrylic specimens incorporated with various concentrations of Zirconia and Cellulose NPs are presented in table 1. The maximum mean flexural strength was exhibited by the specimens incorporated with 2.5% ZrO_2 and 5.0% cellulose NPs. Maximum mean impact strength was observed in the acrylic specimens modified with 1.5% ZrO_2 and 2.5% cellulose NPs. The denture base acrylic specimens modified with 1.5 wt% of ZrO_2 and 5.0 wt % of Cellulose NPs showed more translucency (Table 1). One-way ANOVA showed statistically significant differences (p=0.000) among the various concentrations of nanoparticles incorporated acrylic specimens in all the tested properties (Table 1).

Multiple comparisons with post hoc by Tukey's method revealed that the acrylic specimens incorporated with 5.0wt % of Cellulose NPs exhibited significant differences with 1.5 wt% (p=0.001) and 2.5 wt% (p=0.0001) of Cellulose NPs in the flexural strength. A significant difference (p=0.032) was observed in impact strength between 1.5 wt% and 5.0 wt% of ZrO_2 NPs incorporated specimens. In translucency, acrylic specimens modified with 5.0 wt% Cellulose NPs showed significant differences with 1.5 wt% (p=0.0073) and 2.5 wt% (p=0.0406) of Cellulose NPs. Significant differences (p=0.000) were observed between the acrylic specimens incorporated with ZrO_2 NPs at all concentrations (Table 2).

Multiple comparisons with post hoc analysis between the two different nanoparticles at different concentrations showed significant differences in flexural strength between all the concentrations except 5.0

Table 1. Mean and standard deviation of flexural strength, impact strength and translucency of acrylic specimens incorporated with various concentrations of nanoparticles (One-way ANOVA).

Properties	Nanoparticles	N	1.5wt%	2.5wt%	5wt%	p value
Flexural Strength (MPa)	Zirconia	10	72.02+2.40	76.37+5.06	72.42+4.50	0.00*
	Cellulose	10	64.42+2.84	60.97+2.01	71.47+3.64	0.00*
Impact Strength (KJ/m^2)	Zirconia	10	1.34±0.11	0.83±0.26	1.03±0.27	0.00*
	Cellulose	10	0.95±0.34	1.37±0.52	1.32±0.48	0.00*
Translucency	Zirconia	10	45.91±1.49	32.97±1.73	24.22±2.66	0.00*
	Cellulose	10	51.79±3.12	52.39±1.60	55.31±1.68	0.00*

*statistically significant difference was observed.

Table 2. Multiple group comparison of flexural strength, and translucency of acrylic specimens modified with various concentrations of Cellulose and Zirconia NPs using Tukey's post hoc test

Nanoparticles	Concentrations		Flexural Strength		Translucency	
			MD* ± SE!	Significance (*p*-value)	MD* ± SE!	Significance (*p*-value)
Cellulose	1.5wt%	2.5wt%	3.45 ± 1.601	0.276	0.597 ± 0.962	0.989
		5.0wt%	7.051 ± 1.601	0.001	3.518 ± 0.962	0.0073
	2.5wt%	5.0wt%	10.5 ± 1.601	0.0001	12.94 ± 0.962	0.0406
Zirconia	1.5wt%	2.5wt%	4.349 ± 1.601	0.089	21.69 ± 0.962	0.000
		5.0wt%	0.398 ± 1.601	1.000	8.751 ± 0.962	0.000
	2.5wt%	5.0wt%	3.951 ± 1.601	0.152	0.597 ± 0.962	0.000

* Mean difference, ! Standard error

Table 2. Multiple group comparison of flexural strength, and translucency of acrylic specimens modified with various concentrations of Cellulose and Zirconia NPs using Tukey's post hoc test

Nanoparticles		Flexural Strength		Impact Strength		Translucency	
Cellulose	Zirconia	MD* ± SE!	Significance (p-value)	MD* ± SE!	Significance (p-value)	MD* ± SE!	Significance (p-value)
1.5 wt%	1.5wt%	7.606 ± 1.601	0.000	0.387 ± 1.601	0.171	5.876 ± 0.962	0.000
	2.5wt%	11.96 ± 1.601	0.000	0.116 ± 1.601	0.978	18.82 ± 0.962	0.000
	5.0wt%	8.004 ± 1.601	0.000	0.083 ± 1.601	0.995	27.57 ± 0.962	0.000
2.5 wt%	1.5wt%	11.06 ± 1.601	0.000	0.031 ± 1.601	0.99	6.473 ± 0.962	0.000
	2.5wt%	15.41 ± 1.601	0.000	0.534 ± 1.601	0.019	19.42 ± 0.962	0.000
	5.0wt%	11.45 ± 1.601	0.000	0.335 ± 1.601	0.310	28.17 ± 0.962	0.000
5.0 wt%	1.5wt%	0.555 ± 1.601	0.999	0.015 ± 1.601	0.99	9.394 ± 0.962	0.000
	2.5wt%	4.904 ± 1.601	0.038	0.488 ± 1.601	0.040	22.34 ± 0.962	0.000
	5.0wt%	0.953 ± 1.601	0.991	0.289 ± 1.601	0.474	31.09 ± 0.962	0.000

* Mean difference, ! Standard error

wt% of Cellulose NPs with 1.5 wt% and 5.0 wt% of ZrO_2 NPs. Incorporation of 2.5 wt% of ZrO_2 NPs exhibited significant differences with acrylic resin specimens modified by 2.5 wt% and 5.0 wt% Cellulose NPs in impact strength. In translucency, significant differences were observed between both the NPs at all concentrations (Table 3).

4. Discussion

The Polymethyl methacrylate (PMMA) is used to fabricate denture bases due to its various advantages, including low cost, biocompatibility, ease of processing, stability in the oral environment, and acceptable aesthetics [3]. As discussed in the literature, one of the major shortcomings of PMMA is its inadequate mechanical and physical properties such as low flexural strength (FS), impact strength (IS) and surface hardness that leads to the reduced clinical performance of the denture. This ultimately leads to reduced clinical life of the prostheses [4]. The translucency of the denture base of a removable prosthesis determines its esthetic outcome [7]. The addition of various nanoparticles has been shown to increase the translucency of PMMA.

Various nanoparticles (NP) have been added to different dental materials to improve their properties. Among these NPs, nano-ZrO_2 received great attention due to its excellent toughness and mechanical strength, enabling it to withstand crack propagation. In addition, they have improved abrasion and corrosion resistance, and are highly biocompatible. They are also less likely to alter the aesthetics compared to other metal oxides because of their white colour [5]. Nano cellulose is a natural renewable polymer derived from plants and wood pulp, the most abundant, biocompatible, cost-effective, easily available option to increase the strength and hardness of the material [6]. Several studies have been done earlier to evaluate the effect of zirconia and cellulose nanoparticles on PMMA. However, their effect on the properties of PMMA has not been compared to date. This study was conducted to evaluate and compare the flexural strength, impact strength and translucency of heat polymerized acrylic resin incorporated with 1.5wt%, 2.5wt% and 5.0wt% of zirconium oxide and cellulose nanoparticles.

In this study, the acrylic resin incorporated with 2.5 wt.% ZrO_2 showed the highest mean flexural strength among all the concentrations of both the NPs. At 5.0 wt% of ZrO_2 NPs showed a decrease in flexural strength. This can be attributed to the proper dispersion of NPs in the acrylic resin mass at lower concentrations and as the concentration of NPs is increased, they tend to agglomerate resulting in a decrease in the flexural strength. In addition, the presence of Zirconia NPs improves the strength with the transformation toughening mechanism. Under stresses, the Zirconia transforms from the tetragonal to monoclinic phase resulting in absorbing the energy of crack propagation, which causes an increase in strength. Also, expansion of ZrO_2 crystals occurs under stress and places the crack under a state of compressive stress and arresting the crack propagation.

Mohamed *et al.* (2014) [7] concluded that incorporation of Zirconium oxide (ZrO_2) nanofiller powder with different concentrations (1.5%, 3.0%, 5.0% and 7.0%) increased the flexural strength of PMMA. They demonstrated the best mechanical properties with the addition of 7.0% wt ZrO_2 concentration. Zhang *et al.* (2014) [8] and Mohammed *et al.* (2012) [9] also proved that the addition of modified nano-zirconium oxide improved the mechanical properties of heat-cured acrylic denture base material. in the present study, contrary to the results found in previous studies, desirable flexural strength was achieved by adding 2.5 wt % nano ZrO_2 concentration, which is a lower concentration when compared to earlier literature.

This study also compared the flexural strength of PMMA reinforced with different concentrations of nano-cellulose. PMMA reinforced with 5.0wt.% nano cellulose showed the highest mean flexural strength (71.47 MPa). Talari *et al.* (2016) [10] proved that the addition of nano cellulose Particles (1.0, 2.5, 5.0 wt%.) into the auto-polymerized temporary fixed restoration resin resulted in an increase of flexural strength in all weight percentages, where the most notable increase was observed with the 2.5 wt%. Contrary to the results found in the above study, desirable flexural strength was achieved by adding 5.0wt.% nano cellulose in the present study.

In the present study, intergroup comparison between the PMMA+nanoZrO_2 and PMMA+nanocellulose showed that 2.5% ZrO_2 has the highest flexural strength compared to 5.0% cellulose. The results were statistically significant (0.038). One of the reasons for improved mechanical properties is due to the addition of nanoparticles is due to high interfacial shear

strength and good bonding between the resin matrix and nanofillers which prevents crack propagation, enhancing the mechanical properties [11-13].

When impact strength was compared, PMMA reinforced with 1.5 wt% ZrO_2 showed the highest mean impact strength (1.34) KJ/m^2. Ihab *et al.* (2011) [14] proved that impact strength of PMMA modified with Zirconium oxide (ZrO_2) nanofillers in different percentages improves the impact strength; the maximum was observed with 5.0wt% of nanoZrO_2. Sajida Begum *et al.* (2019) [15] concluded that PMMA reinforced with ZrO_2 nanoparticles decreases the impact strength with increased concentration of ZrO_2 and impact strength was found to be least at 7.0 wt% concentration. Contrary to the earlier literature, the present study showed that PMMA reinforced with 1.5 wt.% ZrO_2 showed the highest mean impact strength (1.34 KJ/m^2).

Among the nanocellulose reinforced group, the specimens with 2.5wt % nanocellulose showed the highest mean impact strength. Shenggui Chen *et al.* (2018) [16] concluded that the addition of 2.5wt.% nanocellulose improve the impact resistance PMMA composite resins. Intergroup comparison between the PMMA + nanoZrO_2 and PMMA + nanocellulose showed that 2.5% cellulose had the highest impact strength compared to 1.5 wt.% ZrO_2.

The present study also compared the translucency of PMMA + nanoZrO_2 and PMMA + nanocellulose at different concentrations. The translucency of the denture base of a removable prosthesis determines its esthetic outcome. This desired level of translucency imparts the chameleon effect, which is created due to the harmonious optical properties between the underlying mucosa and the denture base of the removable prosthesis [17]. Translucency is defined as the ability of a material to permit some light to pass through its structure, thus allowing the background underneath to show through [5]. Light transmittance was considered as a translucency parameter. Light transmittance in percentage was measured using UV Visible Spectrophotometer.

Among the PMMA + nanoZrO_2 group, PMMA reinforced with 1.5 wt.% nanoZrO_2 showed the highest mean translucency. The translucency parameter was reduced as the nanoZrO_2 concentration increased. These results were in agreement with the study conducted by Mohammed M Gad (2018) [5] concluded that the addition of nanoZrO_2 reduced the translucency of the PMMA as the concentration of nanoZrO_2 increased. Similar results were quoted by Aszrin *et al.* in (2016) [18]. This decrease in translucency could be attributed to the crystalline form of nanoZrO_2 (high opacity), which prevented absorbed light from passing through, lowering translucency. This change is inversely proportional to the concentration of nanoZrO_2 [5].

Among the PMMA + nanocellulose group, PMMA reinforced with 5.0wt.% nano cellulose showed the highest mean translucency. Gibril *et al.* (2019) [19] concluded that the transmittance of Nanocomposite films (PMMA/CNC–TiO_2) was decreased with increasing cellulose nanofiber content. This is probably due to the agglomeration of the nanofiller at higher concentrations. The optical transmittance of PMMA nanocomposites decreased with increasing CNC-TiO_2 content, especially with the high content of nanofiller.

Contrary to the results found in previous studies, the present study showed PMMA reinforced with 5.0wt.% nano cellulose showed the highest mean translucency. Since the refractive index of PMMA (1.4813) is closer to that of cellulose (1.54) translucency is increased. In this study intergroup comparison between the PMMA + nanoZrO_2 and PMMA + nanocellulose showed that 5.0% cellulose has the highest translucency compared to 1.5% ZrO_2. The results were statistically significant (p= 0.0073).

The difference between the refractive indices of the fillers and matrix affects the refraction and reflection of light at the filler/matrix interface, which affects the translucency of the nanocomposite. It was found that the refractive index (RI) of the nanoZrO_2 (2.1750) is higher than that of the PMMA (1.4813) [5]. Since this nanocomposite (PMMA + nanozirconia) was composed of resin and inorganic nanoparticles, the higher the difference in refractive index between the two phases, the greater is the opacity of the nanocomposite [5]. The increased translucency in the PMMA + nanocelulose specimens can be attributed to their lower RI compared to nanoZrO_2. Further, nano cellulose RI is almost the same as that of PMMA.

However, this study evaluated the effect of ZrO_2 and cellulose nanoparticles incorporation on the properties of denture base resins with only three concentra-

tions. Further studies may be focused on by incorporating a few more concentrations of these NPS and evaluating their effect on the physical and mechanical properties of denture base acrylic resins. Studies must also be concentrated on optimising a precise concentration of nano zirconia and nanocellulose particles so that superior mechanical and aesthetic qualities may be achieved.

5. Conclusion

Within the limits of the study, the following conclusions were drawn:

1. PMMA + nanoZrO_2 has the highest flexural strength compared to PMMA + nanocellulose, especially at a concentration of 2.5% nanoZrO_2.
2. PMMA + nano cellulose at a concentration of 2.5% has the highest impact strength compared to PMMA + nanoZrO_2.
3. PMMA + 5.0wt.% nanocellulose has the highest translucency compared to PMMA + nano ZrO_2.

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An overview of composition, properties, and applications of Biodentine

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ABSTRACT

A series of events leads to loss of tooth structure by dental caries, tooth wear and trauma, which is often replaced by inert dental materials that replace the bulk of the tooth. If pulp health is affected, a series of interventions need to be undertaken. Initially, the pulp vitality needs to be maintained. Later, elimination of infection and filling of the pulp space is necessary. When pulpal involvement occurs the choice of material has to change, and materials that interact with the pulp are indicated. Interactive materials used for dental procedures include calcium hydroxide in its various presentations and hydraulic calcium silicate cement. Biodentine is a promising dentine substitute that has been recently introduced in dentistry. Although many other materials like Glass Ionomer Cement (GIC), composite and Mineral Trioxide Aggregate (MTA) are available for repair of dentin loss in tooth structure, none of them possesses ideal properties. Despite many advantages, MTA has been replaced by Biodentine, which is a new calcium silicate -based material, due to its limitations. It has good handling properties, short setting time, and improved mechanical properties. Biodentine was designed explicitly as a "dentine replacement," with applications ranging from endodontic repair to pulp capping.

1. Introduction

Glass-Ionomer cement has been used extensively in deep carious lesions and dentine loss in the coronal part. However, its inherent limitation of not stimulating any reparative dentin formation led to the evolution of many other materials [1-3]. When pulpal involvement occurs, the material choice must change, and materials that interact with the pulp or the dentine are indicated. Calcium hydroxide, in various forms, and, more recently, hydraulic calcium silicate cement, are interactive materials used in dental procedures. They can even be used on moistened tooth surfaces. In endodontic therapy, the practitioner employs endodontic repair materials that are insoluble in oral fluids, maintain an adequate seal, are dimensionally stable, non-resorbable, radioopaque, and biocompatible. Amalgam, zinc-oxide eugenol cement, composite resin, and glass-ionomer cement have all been utilised in the past for retrograde filling and perforation repair. Unfortunately, none of these materials has been able to meet all of the ideal material's requirements.

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In the early 1990s, mineral trioxide aggregate (MTA), a biomaterial, was investigated for its potential in restorative dentistry. Its multiple applications include direct & indirect pulp clapping, the formation of the apical plug, root-end filling, perforation repair, furcation repair, repair of resorptive defects, and the management of immature apices (Apexogenesis/ Apexification) etc. [4-9]. However, this material has a few inherent limitations, including difficulty in manipulation, a prolonged setting time, and is expensive [10].

Septodont's research group recently developed Biodentine™, a novel dental material class that combines high mechanical qualities with exceptional biocompatibility and bioactive behavior. Biodentine is the first -in-one biocompatible dentine substitute, based on Active Biosilicate Technology™, that is used to restore and endodontically treat damaged dentine [2]. In 2009, it was made commercially available.

2. Composition of Biodentine

Biodentine is available in powder and liquid forms. The powder primarily consists of Tricalcium silicate ($3CaO.SiO_2$) and Di-calcium silicate ($2CaO.SiO_2$). They regulate the setting reaction and act as core materials. Calcium carbonate ($CaCO_3$) acts as a filler and is responsible for improving mechanical properties. A radiopacifier may also be present such as Zirconium dioxide (ZrO_2).

The liquid contains Calcium chloride ($CaCl_2.2H_2O$), which acts as an accelerator and regulates the setting reaction. Water reducing agent (Super-plasticizer) such as a hydro-soluble polymer is added to reduce the amount of water required for the mix (water/ cement), decreases viscosity and improve cement handling characteristics [11].

3. Setting reaction

Initially, the reaction starts with the hydration of the tricalcium silicate, leading to hydrated calcium silicate gel (CSH gel) and calcium-hydroxide [12]. The cement located in inter-grain areas contains a high level of calcite (CaCO3) content. The tricalcium silicate is hydrated by the dissolution and precipitation of calcium silicate hydrate. In general, it is represented by chemists as C-S-H; where 'C' is CaO, 'S' is SiO2, and 'H' is H2O. The calcium hydroxide takes origin from the liquid phase. C-S-H gel layer formation occurs after the nucleation and growth on the tricalcium silicate surface. The remaining unreacted tricalcium silicate grains are surrounded by layers of calcium silicate hydrated gel, which are relatively impervious to water, thereby slowing the further reactions. The C-S-H gel formation is due to tricalcium silicate's permanent hydration, which gradually fills in the spaces between the tricalcium silicate grains. The following chemical equation summarises the complete hydration reaction [12].

$$2(3CaO.SiO_2) + 6H_2O \rightarrow \underset{\text{C-S-H gel}}{3CaO.2SiO_2.3H_2O} + 3Ca(OH)_2$$

3.1 Structure of cement

The set cement consists of calcite rich ($CaCo_3$) structures of variable sizes. The crystals of $CaCO_3$ are diamond-shaped (or rhombohedra form) and observed at the surface. Taylor (1997) observed that calcium- hydroxide crystallizes in the form of a hexagonal plate [13]. The surface of the $CaCO_3$ crystals is rough and irregular. Therefore, CSH gel is considered the cement matrix, and the crystals of CaCO3 fill the spaces between grains of cement. Calcite ($CaCO_3$) has two distinct functions including Calcite acts as an active agent, is implicated in the process of hydration, and as a filler that improves the mechanical properties of the cement [14]. The hardening process results from the formation of crystals that are deposited in a supersaturated solution. Setting reaction of $3CaO.SiO_2$ includes four elements such as the unreacted particles, surface products (CSH gel), the content of the pores ($Ca(OH)_2$) and porous capillary space [15].

4. Properties of Biodentine

4.1 Setting time

Compared to MTA, Biodentine has a shorter setting time and is in the range of 9-12 minutes. The main reason for the shorter setting time is the presence of Calcium chloride, which acts as an accelerator. Further, this material also contains a Hydro-soluble polymer, which acts as a water-reducing agent [16]. The initial and final setting times of Biodentine and MTA are given in table 1.

Table 1: Setting time of MTA and Biodentine

Materials	Initial setting time (Minutes)	Final setting time (Minutes)
Biodentine	6	10.1
MTA	70	175

4. 2 Adhesion

The Biodentine adheres to the dental surfaces with the help of physical bonding by ion exchange. The Physical process of crystal growth within dentine tubules leads to a micromechanical tag that gives a long-lasting seal. Compared to the MTA and Dycal, Biodentine exhibits a greater bond strength with the dental surfaces [14].

4.3 Density and porosity

The use of hydro-soluble polymer in Biodentine composition reduce the amount of water that exhibits a positive influence on the density and porosity of Biodentine. The lower porosity of Biodentine leads to higher mechanical strength. Also, it exhibits a lower porosity compared to Dycal and MTA [16].

4.4 Radiopacity

Biodentine is a radiopaque material as it contains zirconium oxide, which allows easy identification on the radiographs. According to the ISO standard 6876, Biodentine shows a radiopacity equivalent to 3.5 mm of aluminium. This value obtained is over the minimum requirement of ISO standard (3mm aluminium) and makes BiodentineTM particularly suitable in the endodontic indications of canal repair [16,17].

4.5 Compressive strength

The cement must have the capacity to withstand masticatory forces; in other words, sufficient compressive strength to resist external forces [18]. Biodentine has the unique property of demonstrating its ability to improve compressive strength over time until it reaches a level comparable to natural dentine [19]. In a study, Grech *et al.* (2013) [20] reported that the highest compressive strength with the Biodentine compared to Bioaggregate, Tricalcium-Silicate cement and Intermediate Restorative Materials (IRM). This increase in compressive strength can be attributed to the requirement of lower water: powder ratio of the Biodentine as it contains a water-soluble polymer in the liquid. Kayahan *et al.* (2013) [18] evaluated the compressive strength from another perspective and attained conclusions specifically on clinical usage. Acid etching was done for mechanical adhesion of Biodentine to the tooth structure. Numerous studies aimed to assess whether there will be any alteration in the compressive strength due to the etching process. They concluded that the acid etching process after seven days did not reduce the compressive strength of ProRoot MTA and Biodentine [18]. In a study by Koubi *et al.* [19], Biodentine was used as a posterior restoration and revealed favourable surface properties such as good marginal adaptation until six months. The compressive strength of Biodentine will be 100 MPa in the first hour, which will be increased to a value of 300 MPa after one month. This value becomes relatively stable and is in the compressive strength of natural dentine (297MPa).

4.6 Flexural strength

High flexural strength is a compulsory prerequisite for any restorative material for its long-term efficiency in the oral cavity. The three-point bending test was used to measure the flexural strength and is of high clinical significance. The bending value obtained after 2 hours was 34 MPa compared with other materials such as 5-25 MPa for the Conventional Glass Ionomer Cement; 17-54 MPa for Resin modified GIC; and 61-182 MPa for Composite resin [21]. Therefore, it has been inferred from the test that the bending resistance of Biodentine™ is superior to conventional GIC but much lower than the composite resin.

4.7 Microhardness

There is an increase in microhardness of Biodentine with time. After one month, the hardness of Biodentine reaches the same range as natural dentine [14].

4.8 Biodentine interfaces

Biodentine's interface with adjacent phosphate-rich hard tissue substances is improved by the deposition of calcium phosphate crystals on the surface. As a result, Biodentine is more resistant to acid erosion and microleakage. Biodendine appeared to have more resistance to decay and microleakage than MTA, Dycal and GIC [22].

4.9 Discoloration

Biodentine exhibits colour stability over five days and can serve as an alternative for use under light cure restorative materials in highly esthetic areas [23].

4.10 Antibacterial activity

Biodentine exhibits a significant amount of antibacterial activity as well. Calcium hydroxide ions released

from cement during the setting phase of Biodentine increases pH to 12.5, which inhibits the growth of microorganisms and can disinfect the dentin.

4.11 Biocompatibility

According to Laurent *et al.* [24], Biodentine is non-toxic and has no adverse effects on cell differentiation and specific cell function. They reported that Biodentine increases TGF-B1 (growth factor) secretion from pulp cells which causes angiogenesis, recruitment of progenitor cells, cell differentiation and mineralization. The material is inorganic and non-metallic and can be used in direct and indirect pulp capping procedures as a single application dentin substitute without any cavity conditioning treatment [2].

4.12 Stability in the oral environment

Biodentine is not that stable as a composite material so that it is not suitable as permanent enamel replacement material. When compared to other Portland cement-based materials, Biodentine is stable enough to use as a temporary filling in the load-bearing areas [22].

4.13 Washout resistance

Washout of a material can be defined as the tendency of freshly prepared cement paste to disintegrate upon early contact with the fluids such as blood or other liquids. The available study results on these characteristics of Biodentine does not reveal favourable results as it demonstrated a high washout with every sample used in the methodology [11].

The advantages of Biodentine include reduced setting time, better handling and ease of manipulation, improved mechanical properties, biocompatibility, preserves pulp vitality, which promotes pulp healing and helps in remineralisation of dentine [1,2]. However, this material possesses a few disadvantages, such as poor radio-opacity and lower washout resistance [13,25].

5. Clinical applications of Biodentine

In restorative dentistry, Biodentine is used as a direct pulp capping material, which helps for reactionary dentine stimulation in indirect pulp capping. In endodontics, it is used for pulpotomy, endodontic repairs, and root-end filling material.

5.1 Pulp capping agent

Biodentine is used as a indirect pulp capping agent. Biodentine™ can stimulate reactionary dentine, which is a natural barrier against bacterial invasions. The reactionary dentine formation stabilizes at three months, indicating that the stimulation process is stopped when a sufficient dentine barrier is formed [26]. It causes early mineralization by releasing TGF-β1 from pulpal cells to encourage pulp healing and by odontoblast stimulation for dentine bridge formation to protect the pulp. In contrast to Dycal, which is associated with tissue necrosis and inflammation during the initial time of installation, Biodentine has a well-localized pattern (full dentinal bridge development) and no inflammatory reaction histologically. A clinical trial conducted by Septodont suggested that the Biodentine™ could be used in direct pulp capping indications with a reasonable success rate. Perard *et al.* [27] assessed the biological effects of Biodentine for use in pulp-capping treatment on pseudo-odontoblastic and pulp cells. They found that MTA and Biodentine modify the proliferation of pulp cell lines. Nowicka *et al.* [28] concluded that Biodentine had similar efficacy to MTA in the clinical setting and can be considered an alternative to MTA in pulp capping treatment because it preserves pulp vitality and promotes its healing.

5.2. Dentine substitute

Due to its dentine like mechanical properties, Biodentine is used as a permanent dentine substitute under a composite, especially in deep carious teeth. The absence of aluminates results in less brittleness and is thus used as an ideal base under restorations. A study conducted by Septodont to compare the Biodentine with Filtek™ Z100 as posterior restorative material showed that Biodentine™ has easy handling, excellent anatomic form, perfect marginal adaption, and establishes a very good interproximal contact [1].

5.3 In vital pulpotomy

Biodentine is also utilised in a pulpotomy, which is a vital pulp therapy. It is commonly employed in pediatric dentistry and involves amputation of the pulp chamber and material placement to preserve the radicular pulp tissue vitality. It is preferred when the coro-

nal pulp tissue is inflamed, and direct pulp capping is not suitable. The success rate of vital pulpotomy with Biodentine is higher than that of MTA and Pulpotec [29 -31].

5.4 Endodontic repair material for perforations

The endodontic indications of Biodentine™ are similar to the normal calcium silicate-based materials, like the Portland cements and MTA. Biodentine is recommended for perforation repair, the formation of apical plug and furcation repair.

5.5 Root-end filling material

To evaluate this application, Soundappan *et al.* [32] compared MTA, IRM and Biodentine as a retrograde filling material and found that at 1mm level, there was no difference among tested materials. Still, at 2mm level MTA was superior to both IRM and Biodentine. The results reveal that further research is required before Biodentine can be advocated as root-end filling material. Biodentine as root-end filling material has also been advised because of its better consistency, better handling, safety and faster setting time.

6. Advantages of Biodentine Over MTA [5,33-35]

- BiodentineTM consistency is better suited to clinical use than MTA.
- BiodentineTM presentation ensures better handling and safety than MTA.
- BiodentineTM exhibits better mechanical properties than MTA.
- BiodentineTM does not require a two-step restoration procedure as in the case of MTA.
- As the setting is faster, there is a lower risk of bacterial contamination than with MTA.

Despite a few contradicting reports, numerous studies support this substance in terms of physical and therapeutic characteristics [19, 36, 37].

7. Conclusion

Biodentine, a popular tricalcium silicate-based dentine replacement and repair material, has been evaluated in several aspects since its launching in 2009. Despite a few inconsistent results, various investigations have demonstrated that the Biodentine is superior in terms of physical and clinical features. Biodentine holds promise for clinical dental procedures as a biocompatible and easily handled product with a short setting time. As more research is performed regarding this exciting alternative to MTA, we will be provided with more reliable data and confidently implement Biodentine into routine clinical applications.

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Materials used to maintain integrity of enamel in Orthodontics: an update

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ABSTRACT

After Orthodontic treatment, it's just as crucial to restore a healthy and normal tooth structure as it is to achieve the aims of Orthodontics. Orthodontic treatment has the potential to cause some damage to dental enamel. Orthodontists should make every effort to minimize damage to dental tooth enamel. These enamel lesions, such as white spot lesions, are managed first by developing appropriate dental hygiene habits and prophylaxis with topical fluorides, high-fluoride toothpaste, fluoride mouthwashes, gels, varnishes, fluoride-containing bonding materials, fluoride-containing luting cement, and fluorides in elastomers. Other materials and treatments include casein phosphopeptides-amorphous calcium phosphate, probiotics, carbamide peroxide, polyols, sealants, microabrasion, resin infiltration, antiseptics, and lasers, have recently been recommended. This article reviews the current information regarding the various materials used to manage enamel demineralization and promote remineralization during and after orthodontic treatment.

1. Introduction

Restoring a healthy and normal tooth structure after the end of Orthodontic treatment is as important as accomplishing the goals of Orthodontics. If orthodontic therapy is beneficial to the patient, the treatment advantages should significantly outweigh any adverse sequelae that the treatment might cause [1]. The clinician should be aware of the problems during the treatment procedures to prevent, minimize, and manage the possible adverse effects of orthodontic treatment.

Orthodontic procedures such as conditioning and etching of enamel, debonding of brackets, removal of resin debris and resin cement from the enamel surface, and enamel reduction or stripping are a few of the many causes of enamel damage related to iatrogenicity [1]. The presence of fixed orthodontic appliances causes an increasing number of retention sites due to brackets, bands, wires, and other applications making cleaning teeth more difficult [2]. White spot lesions (WSLs) result from prolonged plaque accumulation on the affected surface of the teeth.

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Enamel damage can be considered an inevitable sequela to orthodontic treatment, with various procedures producing varied effects. Every orthodontic practitioner should aim to minimize injuries to enamel, helping improve the longevity of teeth and dentition as a whole. It necessitates fundamental knowledge of preventive dentistry principles and the clinical skill to apply them properly [2].

Post orthodontic lesion's best course is to wait and watch since most lesions tend to improve their appearance over the first couple of years after debonding [2]. These are managed first by beginning and building on good oral habits and topical fluorides, including high-fluoride toothpaste, fluoride mouthwashes, gels, varnishes, fluoride-containing materials, and elastic ligatures [3].

Recently, other materials and methods, including the use of casein phosphopeptides-amorphous calcium phosphate, antiseptics, polyols, probiotics, sealants, laser, tooth bleaching agents, resin infiltration, and microabrasion [2].

This review intends to compile the most relevant materials and methods that may be useful for healing and maintaining the integrity of the enamel during Orthodontic treatment and post orthodontic treatment.

2. Remineralization

One of the essential biological elements determining the intraoral neutralizing effects of acid exposure is saliva. Saliva provides a steady source of calcium and phosphate, which aids in the maintenance of supersaturation with respect to tooth minerals, preventing tooth demineralization during low pH periods and promoting tooth remineralization when the pH recovers to neutral [4]. Saliva delivers fluoride to the tooth surface constantly; salivary fluoride is an important factor in avoiding tooth demineralization and promoting remineralization [5]. Visible WSL present after orthodontic treatment tends to decrease in area and improve their appearance over the first couple of years after debonding. The status of the lesions determines the potential for enhancement, with active lesions having an improved prognosis than arrested lesions. Active lesions are more porous and allow for easier penetration of calcium and phosphorous into the enamel during the remineralization process. In contrast, arrested lesions often appear shiny white. They may even have a brown surface appearance due to the formation of a remineralized layer in the outer part of the enamel. Most WSL that are present after orthodontic treatment have already undergone a demineralization and remineralization cycle. Some of the active lesions at the end of treatment have already been some remineralization as well [6].

3. Promotion of Remineralization

3.1 Fluoride Toothpaste

Conventional Flouride toothpaste's efficacy (1,000 ppm) is contemplated these days; toothpaste with higher fluoride concentrations (1,500–5,000 ppm) have shown a more remarkable ability to inhibit demineralization and promote remineralization. A modified fluoride toothpaste technique involving twice-daily brushing for 2 minutes followed by swishing vigorously with toothpaste slurry for half a minute without rinsing with water, and avoiding eating or drinking for two hours, has also been shown to reduce the incidence of new caries in orthodontic patients [7].

3.2 Fluoride Rinses

Daily 0.5% sodium fluoride rinse and fluoridated dentifrice are perhaps the most common fluoride regimens recommended by orthodontists. For fluoride rinses to be successful in the prevention of WSL, orthodontic patients must use them consistently. Daily mouth rinses with sodium fluoride (NaF) (0.05% or 0.2%) and/or weekly with acidulated phosphate fluoride (1.2%) rinse have reduced the prevalence of enamel demineralization during active fixed orthodontic treatment [8].

Benson recommended that the best approach to prevent enamel demineralization during fixed orthodontic treatment is the daily usage of 0.05% NaF mouth rinse [9]. Geiger *et al.* reported a 25% reduction in the number of WSL using a fluoride rinse. Using NaF mouth rinse for two weeks, with one rinse per day, had reported a significant increase in fluoride concentration in the saliva [10].

3.3 Fluoride gel

Many researchers have tried Stannous fluoride gels (0.4%) during orthodontic treatment and reported decreased enamel decalcification. Currently, Boyd compared an 1100 ppm fluoride toothpaste with a daily 0.05 percent NaF rinse, or a 0.4 percent stannous fluoride gel applied twice daily by a toothbrush to an 1100 ppm fluoride toothpaste alone. [11]. He also

found that both the gel and rinse provide increased protection against decalcification compared to toothpaste alone, but neither was superior.

3.4 Fluoride varnish

Fluoride varnish applied around orthodontic brackets during treatment helps to reduce the extent and prevalence of WSL. Floor protector (1% difluorosilane and 0.1% F),Duraphat (5% NaF), duraflor (5% NaF) are the commonly used Fluoride varnishes. Azarpazhooh concluded that over the 3-year follow-up period, the application of fluoride varnishes every six months was the most cost-effective method for the high- and medium-risk groups [12]. Demito *et al.* found an increase of 32% in demineralization in areas where the varnish was not applied compared to a 30-50% reduction in WSL's in areas where duraphat was applied twice annually [13]. The use of Fluor Protector (polyurethane varnish) decreased WSL formation under molar bands. Recently, chlorhexidine varnishes contemplated reducing plaque accumulation and enamel decalcification.

3.5 Fluoride-releasing bonding materials

In the late 1980s, Glass Ionomer cement was replaced as an alternative to the more commonly used composite material for bracket bonding. The proposed benefits of using glass ionomer cement included the lack of need for pretreating the enamel with phosphoric acid to create conditions for mechanical bonding, the release of fluoride over several months, and the possible development of a modified, less cariogenic microflora [14]. The cariostatic effect is mainly attributed to the fluoride release of both glass ionomer and resin-modified glass ionomer cement [15]. It occurred for more extended periods and with greater fluoride release levels than with fluoride-containing composites or compomer cement [15]. Glass Ionomers showed an initial burst of fluoride discharge that rapidly declined to levels that are unlikely to have a clinically significant effect on caries inhibition.

3.6 Fluoride in luting cements

It is best to use cement containing fluoride like GIC for banding because fluoride-releasing types of cement such as zinc polycarboxylate and resin-modified GIC shown less enamel demineralization than zinc phosphate cement [16].

3.7 Fluoride in bonding agents

Bonding agents, which contain fluoride have the potential for reducing enamel decalcification [17]. Bonding with GIC showed less WSL in 12-year follow-up in comparison to the conventional composite material. However, traditional fluoride-releasing cement, glass-ionomer cement, and resin-modified GIC have bond strengths that are substantially lower than those of conventional resins. Recently, Bioactive glass (BAG) materials entered the field of dentistry. They are surface-active materials known to successfully release ions (calcium, phosphate, and fluoride ions) in simulated body fluid. Manfred *et al.* and Brown *et al.* found that BAG-Bond adhesives outperformed traditional composites to help preserve the superficial enamel hardness around orthodontic brackets and released reservoir ions that decreased the chances of WSL around brackets. As a result, these adhesives could be used as biomimetic bonding agents [18].

3.8 Fluorides in elastomers

Fluoride-releasing elastomeric modules have also been shown to effectively minimise plaque accumulation and enamel decalcification around brackets in numerous studies [19]. However, some authors concluded that fluoridated elastomers did not affect the quantity of disclosed plaque around orthodontic brackets. Even the fluoride release from the fluoride-containing elastic chain was high for the 1st week and decreased significantly. Thus, it is good to prescribe Fluoridated toothpaste and mouth rinses so that fluoridated elastomers may imbibe fluoride from their environment [20].

3.9 Antibacterial adhesives

The antibacterial activity of 12-methacryloyl-oxydodecyl-pyridinium bromide incorporated in the antibacterial adhesive systems demonstrated inhibition of caries formation, especially along the enamel margins [21]. Among the various metals, silver, since ages, has been known for its antimicrobial activity against various microorganisms. Traditional orthodontic adhesives and appliances have been infused with silver nanoparticles (AgNPs). The antibacterial effects of the silver coating were demonstrated by the decreased adherence of S. mutans and S. sobrinus to the orthodontic brackets. The use of silver nanoparticles on the surface of orthodontic brackets can help to prevent the formation of tooth plaque and cavities during orthodontic therapy [22]. In a study conducted by Wang X, a

novel RMGIC was developed with NAg for the prevention of white spot lesions. The results of the study showed that RMGIC containing NAg had much stronger antibacterial effects, and the incorporation of NAg into RMGIC could combat white spot lesions both beneath and away from the orthodontic brackets. These advantages were achieved without compromising the enamel shear bond strength and did not require any patient compliance. So, the NAg-containing RMGIC might be more effective in preventing white spot lesions[23].

3.10 Casein Phosphopeptide-Amorphous Calcium Phosphate

The role of casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) has helped decrease the incidence of dental caries [24]. The topical anti-cariogenic effect of dairy products in animal and human in situ caries models has led to the production of casein phospho-peptides (CPP) and their accepted ability to stabilize calcium and phosphate in an amorphous state [25]. The CPP molecules contain a cluster of phosphoryl residues which markedly increase the apparent solubility of calcium phosphate by stabilizing amorphous calcium phosphate (ACP) under neutral and alkaline conditions. The localized CPP-ACP nano-complexes subsequently act to buffer free calcium and phosphate ions in the plaque fluid to maintain a state of supersaturation of ACP concerning enamel mineral, thereby limiting enamel demineralization and enhancing remineralization [24].

MI Paste (GC America, Alsip, IL, USA) is a product that contains casein phosphopeptide ACP. This milk-derived protein helps to promote high rates of enamel remineralization. MI Paste Plus is the same product as casein phosphopeptide ACP but also has 900 ppm of fluoride. A recent randomized controlled trial demonstrated that patients undergoing orthodontic treatment who used MI Paste Plus nightly along with a fluoride delivery tray for 3 to 5 minutes following brushing showed fewer and less severe WSL than controls [26]. Hence, CPP-ACP might be incorporated into chewing gums, lozenges, or creams. GC marketed it as a cream for application on tooth surfaces twice a day after brushing the teeth and refraining from drinking or eating for 30 min after the application (Tooth Mousse, Tooth Mousse Plus) (Fluor 900 ppm) [27]. For remineralization post-orthodontic treatment WSLs, CPP-ACP application may be more effective than fluoride rinse. So, the CPP-ACP's ability to prevent the formation of orthodontic WSLs in the long-term needs elucidation [28].

3.11 Probiotics

The use of probiotics has been recently introduced to dentistry. Still, the concept involves populating the oral environment with noncariogenic microorganisms that compete with cariogenic bacteria and periodontal pathogens and reducing their numbers. Although data are scarce on this topic and none specific to WSL prevention, preliminary reports show potential for materials such as ProBiora 3 (Oragenics, Tampa, FL, USA) to positively influence the oral environment reducing S. *mutans* and specific periodontal pathogens [29]. It is hypothesized that probiotic strains interfere with or inhibit other microorganisms, especially pathogens. Probiotic bacteria might enhance the effect of fluoride in preventing dental caries [30]. The treatment strategies conferred by probiotics are mainly anticipated to be either by inhibition of specific pathogen adhesion, colonization and biofilm formation or by altering the host immune response by inhibition of collagenases, reduction of inflammation-associated molecules [31].

3.12 Carbamide Peroxide

Carbamide peroxide, also known as urea-hydrogen peroxide, is a water-soluble, white crystalline solid compound consisting of hydrogen peroxide and urea. There is evidence that urea increases salivary and plaque pH. This increase in pH, together with the antimicrobial effect of hydrogen peroxide, may reduce plaque formation [7]. It enhances patients' compliance with frequent use of carbamide peroxide whitening agents during orthodontic treatment because of the patient's perceived added benefits of tooth whitening.

3.13 Xylitol

Polyols are sweeteners that are weakly metabolized (sorbitol) or not metabolized (xylitol) by cariogenic bacteria. Evidence supports that xylitol is noncariogenic, exhibits a dose- and frequency-dependent effect on dental plaque and streptococci mutans, and is safe. Thus, chewing xylitol (2 g of xylitol/socket) or polyols after each meal (three times daily) for 10-20 min increases the production of stimulated saliva, which has higher phosphate and calcium concentrations than

non-stimulated saliva [7]. Sengun reported that xylitol lozenges significantly decreased the acidity of dental plaque in fixed orthodontic appliance patients. It helped neutralize the acidity of dental plaque after sucrose consumption in patients undergoing fixed orthodontic treatment [32].

3.14 Pit and fissure sealants

There is evidence to support that bonded resin barriers such as pit and fissure sealants may protect against the development of WSL. Filled resin sealants such as Pro Seal (Reliance Orthodontic Products, Itasca, IL, USA) may have the potential to provide even more excellent protection as a physical barrier because of their increased wear resistance compared with unfilled resin sealants. Still, their removal after orthodontic treatment can be tedious and requires the use of a high-speed rotary instrument [33]. Ultraseal XT Plus sealant showed a significant reduction in enamel demineralization during fixed orthodontic treatment and should be considered for use to reduce white spot lesions. This highly filled light-cured sealant effectively sealed the enamel surfaces adjacent to orthodontic brackets, resisted mechanical abrasion, and remained well-attached. The DIAGNOdent may be useful for evaluating the severity, progression, and depth of white spot lesions during orthodontic treatment [34].

3.15 Microabrasion

Microabrasion consists of chemical and mechanical processing of the enamel surface by applying an abrasive slurry of 6.6% (Opalustre) or 6% (Whiteness RM) hydrochloric acid with a brush. Microabrasion is a helpful method for the treatment of post-orthodontic WSLs [35].

3.16 Resin Infiltration

Resin infiltration of incipient carious lesions is a relatively new approach that shows the possible ability to improve the appearance of WSL. The idea behind resin infiltration is that the porous nature of active WSL allows a low-viscosity resin to permeate into the previously demineralized enamel matrix and fill in many of the voids with resin rather than air or water. Resin infiltration creates a refractory index that is more similar to healthy enamel. The result is an improvement in the appearance of the lesion [36]. Icon (DMG America, Englewood, NJ, USA) is currently the only product on the market that uses this approach. The clinical protocol involves etching of WSL with 15% hydrochloric acid for 2 minutes under rubber dam isolation, followed by thorough rinsing, desiccation of the enamel lesion with an ethanol drying agent, and then the application of the very low-viscosity resin, removal of gross excess, and light-curing for 40 seconds. This approach seems more successful in partially arrested lesions [36]. A comparative study by Annapurna Kannan showed that Clinpro™ XT varnish showed significantly better improvement than Icon® resin infiltration in restoring the colour and lightness of the WSLs at 3 and 6 months. The fluorescence loss significantly recovered with both the methods between immediate application and at six months [37].

3.17 Antiseptics

Chlorhexidine is the most used antiseptic in dentistry. It has proved very effective in controlling and managing biofilms in gingivitis. It is usually available as mouthwashes, gels, or varnishes [7]. It affects cariogenic flora and reduces streptococci mutans counts. Chlorhexidine varnishes are more effective than gels and mouthwashes. Various studies have shown the efficacy of chlorhexidine varnishes in reducing the prevalence of caries during orthodontic treatment, while others have not demonstrated the effectiveness of a varnish of 40% chlorhexidine [36].

3.18 Lasers

The application of Lasers increases enamel microhardness and resistance to acid attack. The principal laser usually used in preventive dentistry includes argon lasers, CO2, Nd-YAG, and erbium YAG [38]. Irradiation of enamel with argon laser beams decreases the amount of demineralization up to 30%–50%. Kim *et al.* reported that, apart from reducing enamel demineralization, laser beams lowered the dissolution threshold pH value [39]. Laser beams resulted in changes in surface morphology by improvement in enamel crystallinity but maintained an intact enamel surface. The application of argon laser beams (488 nm) significantly decreased the mean lesion depth compared to visible light controls, supporting that irradiation with argon laser beams might prevent the development of WSLs during treatment [40].

3.19 Bleaching

Khoroushi *et al.* showed in an *in vitro* study that a

gentle, non-invasive bleaching procedure by incorporating three different biomaterials, including nano-BAG, nano-hydroxyapatite, and nano-amorphous calcium phosphate, into bleaching agents might mitigate the adverse effects of tooth bleaching and prevent the irreversible changes in the enamel surface [41]. This treatment modality should be reserved for patients with good oral hygiene to mask inactive lesions when natural remineralization is not complete [42].

4. Conclusion

Damage to dental enamel is one of the common complications of fixed orthodontic treatment. The responsibility of an orthodontist is to minimize the risk of the patient having decalcification as a consequence of orthodontic treatment by educating and motivating the patients for excellent oral hygiene practice.

During and after orthodontic treatment, prophylaxis with topical fluoride application should be used, high-fluoride toothpaste, fluoride mouthwashes, gels, and varnishes, especially for individuals at high risk of caries. Ultimately, although scientists and/or clinicians may discover new understanding, develop new technologies and products, but it's the responsibility of patients and orthodontists to promote and use new materials which help in maintaining enamel surface integrity.

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