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Effect of silver nanoparticles incorporation on microhardness of Heat-cure denture base resins

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ABSTRACT

Background: Poly (Methyl methacrylic acid) based materials are widely used for the fabrication of removable complete and partial denture prosthesis. Regular cleansing of these dentures may abrade the surface due to an inherent lack of adequate surface hardness. This roughness may adhere food to the denture surface, making it dirty and further cause stomatitis. Numerous studies reported the antimicrobial activity of denture base materials incorporated with silver nanoparticles, which may logically prevent microbial growth on the denture. However, the effect of these nanoparticles on the mechanical properties, which provide longevity to the prosthesis, was not substantiated.

Aim: This study was designed to evaluate the effect of incorporating various concentrations of silver nanoparticles into heat-cure denture base resin materials, on their surface hardness. .

Materials and methods: A Silver nanoparticles were incorporated at various concentrations (0.5, 1.0, 2.0 and 5.0 wt%) into three different heat-cure denture base materials. A total of 150 rectangular-shaped specimens (62 x 10 x 2.5), which comprises 50 samples from each of the three heat-cure acrylic resins were made using the compression moulding technique. Ten specimens (n=10) were allocated for each concentration such as control, 0.5wt%, 1.0wt%, 2.0wt% and 5.0wt% concentrations of silver nanoparticles. The microhardness was evaluated using the Vickers microhardness tester. The data were subjected to One way ANOVA and Tukey HSD tests for statistical analyses.

Results: Significant differences (p=0.000) were observed in the surface hardness between the unmodified and modified denture base materials. .

Conclusion: Silver nanoparticles can be considered as the favourable additives to increase the surface hardness of denture base materials.

1. Introduction

Dentures remain the most popular choice of prosthetic devices with a high success rate for the treatment of edentulous conditions. Complete dentures are usually made with polymers, precious metal alloys and base metal alloys [1,2].

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Among these, polymer-based materials, especially Poly (methyl methacrylate) resins are widely used for the fabrication of complete and partial dentures [3,4]. The reasons for using PMMA resin as the most common materials are due to its favourable working characteristics, accurate fit, and stability in the oral environment, superior aesthetics, and ease of processing with inexpensive equipment. However, it has few shortcomings such as the frequent fracture of dentures due to mechanical fatigue and chemical degradation of the base material, low thermal conductivity [1-4] and ease of microbial adherence to the intaglio surface [5,6]. Numerous researchers have studied the effect of incorporation of various fillers like metallic particles, fibres, nanoparticles, etc., on the mechanical properties of PMMA materials with varying success [4]. Further, attempts have been made to copolymerize PMMA with rubber materials to improve the impact strength [4]. Though these attempts were successful to a certain extent, the problem of microbial adhesion remained as a critical feature of PMMA based denture base materials leading to Denture stomatitis.

Various studies reported the application of antifungal agents orally in the form of drops, lozenges, cream, pastille, lacquer, gel or mouthwashes [5-7]. However, these attempts reported the loss of the drug rapidly into saliva, inhomogeneous distribution of the drug, and the development of resistance to the antifungal therapy [6].

Recently, numerous studies have uncovered the effect of nanoparticle incorporation on the antimicrobial activity of the polymers. Among the various nanoparticles, silver nanoparticles (AgNPs) received a particular interest by the researchers as they show a broad spectrum of antimicrobial activity. Alla RK *et al.* [8] studied the antimicrobial activities against different microorganisms, and flexural strength [9] of heat-cure denture base materials incorporated with various concentrations of silver nanoparticles. Studies reported that the denture base materials incorporated with AgNPs exhibited antimicrobial activity against C.*Albicans*, and S. *Mutans*, especially at lower concentrations [8].

However, the effect of incorporation of AgNPs on the mechanical properties of denture base materials has not been validated. The surface hardness along with the strength is an essential mechanical property as denture prosthesis should exhibit maximum resistance to abrasion under masticatory forces and while cleaning dentures. Due to lack of adequate wear resistance, the surface of the dentures becomes rough during regular denture cleaning procedures. The food and debris may stick to these rough surfaces resulting in an unhygienic denture and thereby cause stomatitis [10]. Therefore, to prevent this adversity, it is necessary to increase the hardness of acrylic resins. Hence, this study aimed to evaluate and compare the surface hardness of heat-cure denture base resins modified with the incorporation of different concentrations of AgNPs.

2. Materials and methods

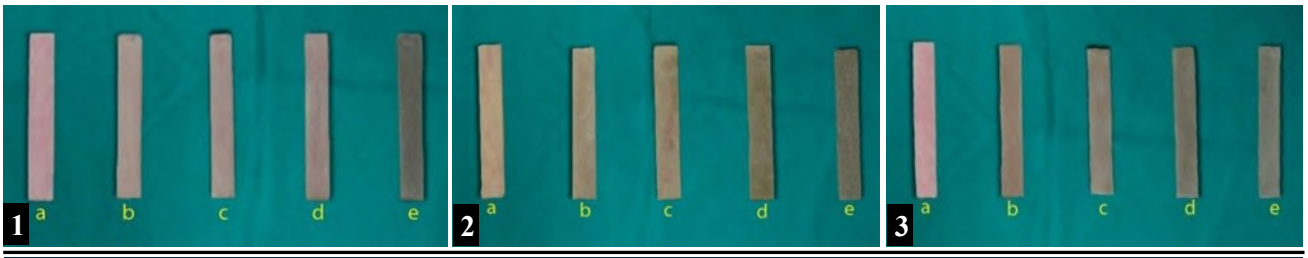
The materials used in the present study are detailed in Table 1.

2.1 Preparation of Acrylic Specimen

A total of 150 specimens were fabricated using the compression moulding technique. Acrylic specimens were made by investing rectangular metal strips of 62x10x2.5 mm. Metal strips were carefully removed after the investment material was set. A thin layer of separating medium was applied in the mould space and allowed to dry. Denture base acrylic powder with or without silver nanoparticles and monomer liquid was mixed as per the manufacturer recommendations and packed into the mould when the mix reached the dough consistency. Then the flask was closed, and a pressure of 4 lbs was applied and bench cured for 30 minutes in a hydraulic press (Silfradent, India). Then the flask was tightly secured in a clamp and transferred into a thermostatically controlled water bath (Acrylizer, Confident A-73, India) and cured as per the manufacturer's recommendations. The temperature of the water bath was increased to 73±1°C within 30 minutes and maintained at the same temperature for 90 minutes. Then the temperature of the water bath was increased to 100°C and maintained for 60 minutes. The flask was allowed to cool in the water

Table 1. Materials used in the study

Materials	Manufacturer's details
Trevlon	Dentsply India Pvt Ltd., India.
Lucitone 199	Dentsply International Inc., USA.
TriplexHot	IvoclarVivadent, USA.
Silver nanoparticles (80 – 100 nm)	Nanolabs Pvt Ltd., India.



Figures 1-3. Acrylic specimens made with Trevlon, Lucitone199 and TriplexHot denture base materials incorporated with Silver nanoparticles, respectively for evaluation of microhardness. Where a. Control (without nanoparticles), b. 0.5wt%, c. 1.0wt%, d. 2.0wt% and e. 5.0wt% of Silver nanoparticles .

bath to room temperature after completing the polymerization cycle. The acrylic resin specimens were retrieved after deflasking. The specimens obtained were finished and polished in a conventional manner [2]. Fifty specimens from each denture base material (Figures 1 – 3) were made totalling to 150 specimens. These 50 specimens from each denture base material were divided into five groups based on their concentration of silver nanoparticles (AgNPs), with ten specimens (n=10) in each group. These five groups included a control group (with no modification of denture base materials) and four modified groups with 0.5wt%, 1.0wt%, 2.0wt%, and 5.0wt%of AgNPs respectively. The specimens were stored in distilled water at 37^0C for seven days. .

2.2 Evaluation of Microhardness

Hardness was measured using Vicker's microhardness test apparatus, which has a diamond pyramid as indenter (Daksh Quality Systems Pvt Ltd., India). The test specimen was held firmly in position and lens were arranged to get the image clearly at its focal length. Subsequently, the indentation was made by applying the load of 25 gms for 25 seconds. A total of five indentations were made at different points for each specimen, and the mean values of individual specimens were averaged.

2.3 Scanning electron microscopy

The specimens were vacuum dried in a desiccator containing silica gel until a constant weight was obtained. The dried specimens were gold-sputtered and were subjected to scanning electron microscopy at 10 kV.

The data were subjected to One-way ANOVA and TukeyHSD tests for statistical analyses using SPSS for Windows, Version 12.0., SPSS Inc., USA.

3. Results

The concentration of the AgNPs was in direct proportion to the Vicker's hardness (HV) of three denture base materials used in the present study (Figure 4). Incorporation of 5.0 wt% of AgNPs showed maximum surface hardness. Among the three denture base materials, TriplexHot exhibited superior hardness at all the concentrations with the maximum mean hardness of 22.068 ± 0.321. Trevlon denture base material displayed less surface hardness at all concentrations compared to Lucitone 199 and TriplexHot materials. The control group of Lucitone199 specimens showed the least mean surface hardness (10.902 ± 0.390) among the materials tested. One-way ANOVA showed a significant difference (p = 0.000) in the surface hardness among the three groups.

PostHoc (Tukey's HSD) test showed significant differences (p=0.000) between unmodified and modified groups except with the Trevlon and TriplexHot groups modified by 0.5wt% of AgNPs (Table 2). Among the modified groups, significant differences were observed except between 2.0 wt% and 5.0 wt% of AgNPs in Lucitone199 denture base materials (Table 2).

PostHoc (Tukey's HSD) analysis showed significant differences (p = 0.000) among the three denture base materials incorporated with AgNPs, except Lucitone199 with Trevlon material at 0.5 wt%, and 1.0 wt% and also with TriplexHot material at 5.0 wt% (Table 3).

Scanning electron microscopic analysis (SEM) showed agglomeration of nanoparticles, and this agglomeration was found directly proportion to the concentration of nanoparticles in acrylic specimens (Figure 5).

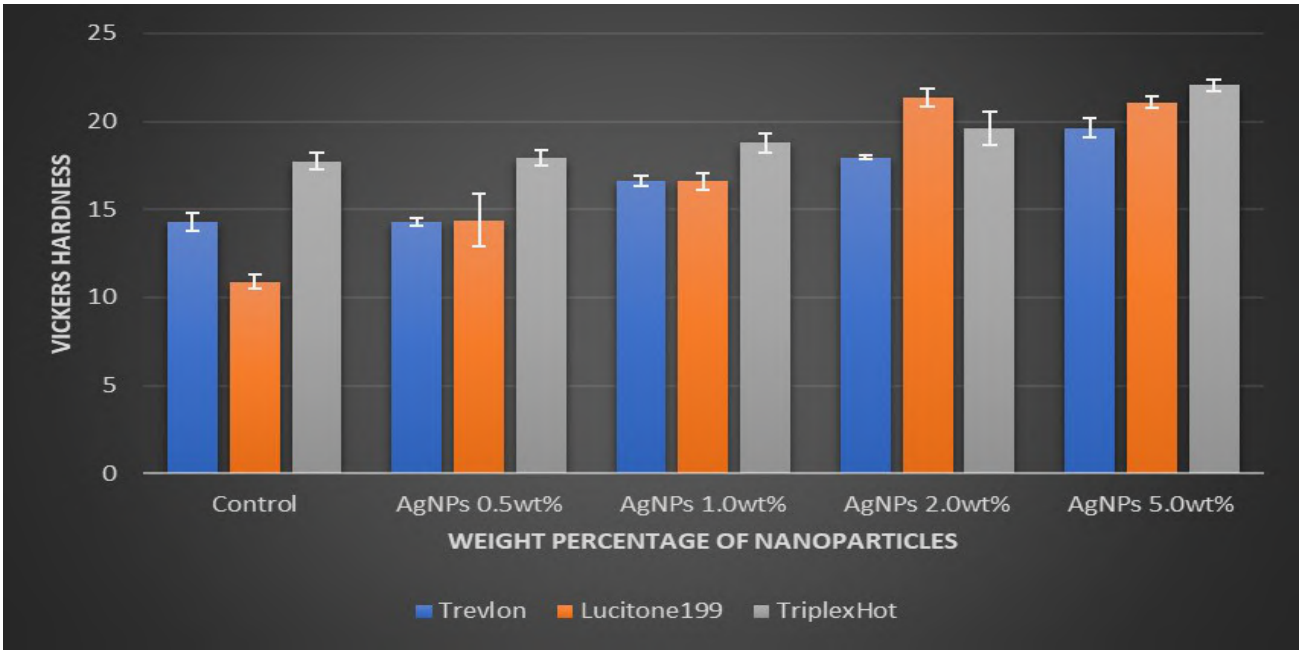


Figure 4. Vickers' hardness (HV) of denture base materials incorporated with various concentrations of Silver nanoparticles.

Table 2. Post-Hoc analysis (TukeyHSD) of Vickers' hardness (HV) of three denture base materials incorporated with various concentrations of Silver nanoparticles .

Groups		Trevlon		Lucitone 199		TriplexHot	
		Mean Diffeence ± Standard Error	Signifi-cance	Mean Diffeence ± Standard Error	Signifi-cance	Mean Diffeence ± Standard Error	Signifi-cance
Control	0.5 wt%	0.010 ± 0.165	1.000	3.493± 0.518	0.000	0.188± 0.258	0.949
	1.0 wt%	2.330±0.165	0.000	5.684± 0.518	0.000	1.053± 0.258	0.002
	2.0 wt%	7.078±0.165	0.000	10.463±0.518	0.000	1.868± 0.258	0.000
	5.0 wt%	11.082±0.165	0.000	10.789±0.518	0.000	4.340± 0.258	0.000
0.5 wt%	1.0 wt%	2.340±0.165	0.000	2.191± 0.518	0.001	0.865± 0.258	0.014
	2.0 wt%	3.683±0.165	0.000	6.970± 0.518	0.000	1.680± 0.258	0.000
	5.0 wt%	5.346±0.165	0.000	7.296± 0.518	0.000	4.152± 0.258	0.000
1.0 wt%	2.0 wt%	1.343±0.165	0.000	4.779± 0.518	0.000	0.815± 0.258	0.023
	5.0 wt%	3.006±0.165	0.000	5.105± 0.518	0.000	3.287± 0.258	0.000
2.0 wt%	5.0 wt%	1.663±0.165	0.000	0.326± 0.518	0.970	2.472± 0.258	0.000

Table 3. Post-Hoc analysis (TukeyHSD) of microhardness (HV) of denture base materials incorporated with various concentrations of AgNPs.

Groups			Significance (p-value)
Control	Lucitone199	Trevlon	0.000
		TriplexHot	0.000
	Trevlon	TriplexHot	0.000
0.5%	Lucitone199	Trevlon	0.954
		Triplex	0.000
	Trevlon	TriplexHot	0.000
1.0%	Lucitone199	Trevlon	0.987
		Triplex	0.000
	Trevlon	TriplexHot	0.000
2.0%	Lucitone199	Trevlon	0.000
		TriplexHot	0.000
	Trevlon	TriplexHot	0.000
5.0%	Lucitone199	Trevlon	0.002
		TriplexHot	0.761
	Trevlon	TriplexHot	0.000

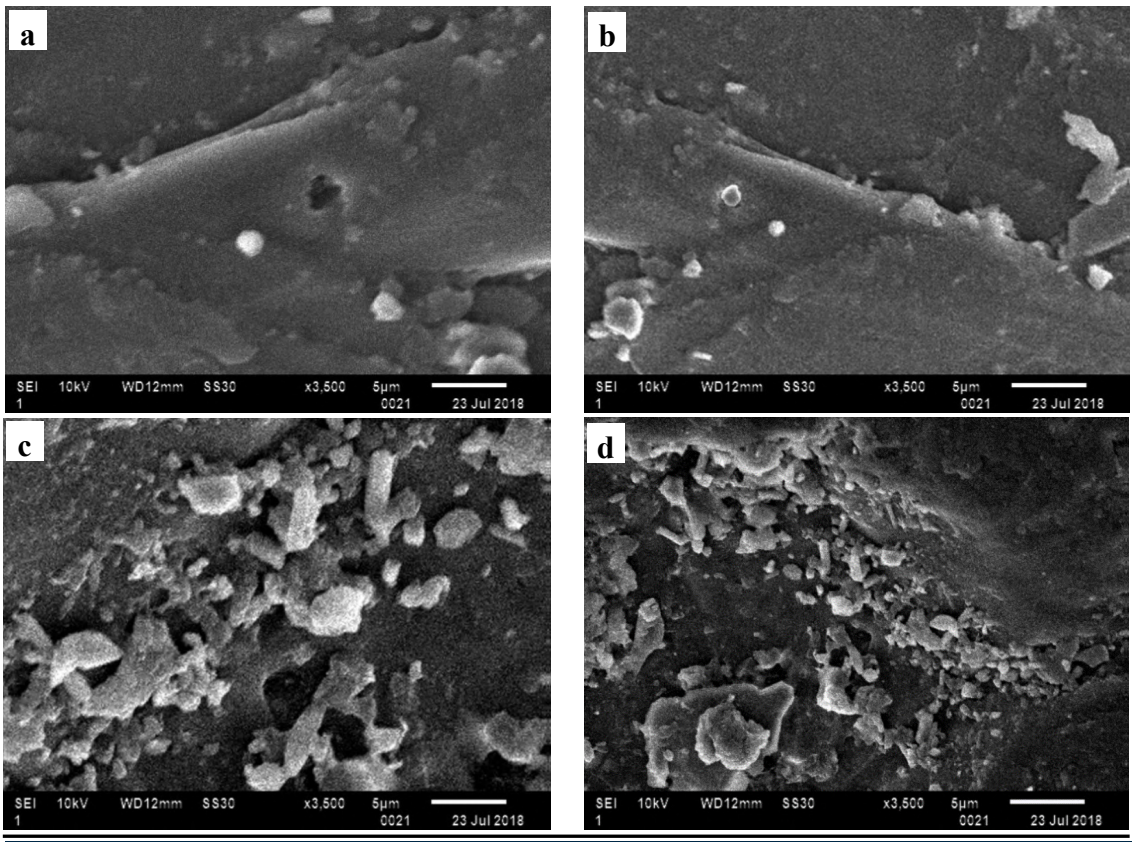


Figure 5. Dispersion of Silver nanoparticles in acrylic resin denture base material. Where a, b, c and d are denture base resin specimens incorporated with 0.5wt%, 1.0wt%, 2.0wt% and 5.0wt% of Silver nanoparticles respectively.

4. Discussion

An ideal denture base prosthesis must have maximum resistance to abrasion under a variety of loads. Conventional cleansing agents may soften the denture base materials leading to fracture [11-13]. Unfortunately, PMMA-based denture base materials are weak at resisting abrasion, which may create surface irregularities on the prosthesis. These irregularities can become the areas of debris accumulation and cause stomatitis [10]; hence, it is necessary to enhance the hardness of an acrylic resin. Numerous researchers have suggested that incorporation of AgNPs serves as good antimicrobial agents in denture base materials and denture lining materials, and may be considered as alternatives to the regularly used antibacterial and antifungal drugs [8,14-16]. This study evaluated the effect of AgNPs incorporation on surface hardness of denture base materials using the Vickers hardness test. The hardness was tested using the ability of the material to resist the indentation of a specific load [1,17].

The degree of conversion of heat-cured acrylic resin may be evaluated indirectly by measuring the surface hardness[18]. There are many factors; the matrix composition, filler content, filler shape, size distribution, and proportion having a maximum effect on the mechanical and physical properties of reinforced resin [19,20].

In the present study, it was observed that the hardness was directly proportional to the concentration of nanoparticles incorporated. Both unmodified and modified groups of TriplexHot denture base material exhibited more Vickers hardness among the materials tested. A gradual increase in hardness was observed in all the modified groups with an increase in the weight percentage of nanoparticles. One-way ANOVA showed a significant difference ($p = 0.000$) in hardness among the three denture base materials. The hardness value was increased by increasing the concentration of nanoparticles (Figure 1). It is because of the nanoparticles' surface area to make suitable adhesive with the polymer. Therefore, the size of the nanoparticles used in this study may be considered as hard fillers in the resin matrix. The larger particles may form larger voids in the resin matrix, and these act as stress concentrators. In the present study, the average particle size used was in the range of 80–100 nm. However, it was also evident from the literature that nanoparticles agglomerate at higher concentrations and attaches physically with the PMMA polymer chains. These physically bonded nanoparticles may be separated easily during indentation and facilitate the easy crack propagation through the resin matrix and results in a fracture. The SEM evaluation (Figure 5) showed the agglomeration of the nanoparticles in this study but had not shown any effect on the hardness. Numerous SEM studies indicated similar findings during microhardness testing though agglomerates were formed [21]. Besides, these nanoparticle agglomerates form a thick immobilized PMMA layer, which resists indentation. This phenomenon is evident from this study that the Vicker's hardness was more at 5.0 wt% of AgNPs incorporation in all the denture base materials.

The results of this study are in agreement with Vojdani *et al.* (2012) [22] and Masouras *et al.* (2008) [23]. According to them, the surface hardness improves with increasing the concentration of filler particles; thus, the filler amount contributes to the material performance. These results are also similar to Sodagar *et al.* (2013) [24], who showed that the effect of silver filler particle size on the internal structure of polymerized PMMA. Similarly, Sokolowski J *et al.* (2014) [25] also reported an increase in Vicker's hardness of resin adhesives by the increase in silver nanoparticle concentration. They also suggested that the incorporation of silver nanoparticles may not have any adverse effect on mechanical properties of composite adhesives containing silica nanofillers and silver nanoparticles if proper amounts of silver nanoparticles are used.

The other factor which influences the hardness is the aging of the specimens. Several studies reported that aging results in an increase in hardness of denture base materials modified with various nanoparticles [26], as it facilitates more degree of polymerization. In this study, the specimens were also soaked in distilled water for seven days before the hardness test was carried out. Fan *et al.* (2011) [27] demonstrated that in terms of Rockwell hardness measurements, the degree of cure was lowered as the concentration of silver benzoate was increased in light-cure composite resins. The authors suggested that Ag^{+} ion reduction and the generation of clusters of atoms and nanoparticles while curing causes competition with the free radical polymerization process. However, the resin materials used in this study were heat-cured resins in which free -radical addition polymerization was unaffected though the nanoparticles agglomerated. Also, aging the

specimens caused an increase in microhardness [28].

On the contrary, Alhareb *et al.* (2017) [29] reported less Vickers hardness with the incorporation of the nanoparticles and nitrobutyl rubber. The reason for the decrease in hardness can be attributed to nitrobutyl rubber that provided more ductility to the resin matrix and had a detrimental effect on hardness. Similarly, Asopa V *et al.* (2015) [30] also reported a decrease in hardness by the incorporation of nanoparticles attributing it to a lack of bonding between the resin matrix and the nanofillers. Chladek *et al.* (2013) [31] reported that the hardness is increased as the nanoparticles concentration increased to a certain level beyond which a decrease in hardness was found. So, it can be attributed that more the concentration of nanoparticles there is a possibility for more agglomeration and creates more or large voids at the filler–resin interface which results in a decrease in hardness and strength. However, the present study reports an increase in the hardness with a maximum concentration of nanoparticles (5.0 wt%) that was used for the three denture base materials.

The variation in the hardness of three denture base materials with and without the addition of nanoparticles can also be attributed to the chemical composition of the denture base resins, mostly the amount of the crosslinking agent and plasticizer [32] that were present in the individual denture base materials. However, incorporation of 5.0wt% of NPs significantly improved the Vickers hardness among all the denture base materials tested.

5. Conclusion

From this study, it can be concluded that the incorporation of AgNPs increases the surface hardness of denture base materials used in the study. Since the silver nanoparticles already proved their antimicrobial characteristics, their incorporation into denture base materials may also be considered to enhance the surface hardness. However, incorporation of AgNPs in higher concentrations impart black colour to the denture bases, which is undesirable. Further studies are required to address the biocompatibility issues and the colour stability of denture base materials incorporated with the silver nanoparticles.

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Comparative evaluation of gingival displacement using retraction cord impregnated with Astringedent®, Magic foam and Expasyl: an *in vivo* study

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ABSTRACT

Background: Gingival retraction helps in achieving good quality impressions. These are needed for a precision fit and long-term success with fixed prosthodontic restorations.

Aim: This study aimed to evaluate the clinical efficiency of gingival displacement obtained using Expasyl, Magic foam cord and Medicated retraction cord.

Materials and methods: One hundred twenty patients with the requirement of full veneer crowns were selected. They were divided into three groups, forty subjects in each group (twenty subjects by each operator) namely Expasyl, Magic foam cord and Medicated retraction cord. The impressions obtained before and after placing the retraction system were poured with type IV die stone. The casts obtained before and after placing the retraction system were coded in a blind fashion to avoid the influence of the operator. The casts were viewed under tool maker microscope "10X" magnification for the amount of both depth and width of gingival displacement.

Results: Mesial, distal, mid-buccal, mid-lingual were taken as reference points and for Medicated retraction cord, Expasyl and Magic foam cord the mean values are 0.50mm, 0.49mm and 0.29mm respectively in horizontal displacement and 0.56mm, 0.47mm and 0.31mm respectively in vertical displacement. One way ANOVA was used to calculate the p-value and multiple range test by the Tukey-HSD analysis to identify significant groups at 5% level. The level of significance for all tests was set as $p < 0.05$.

Conclusion: Within the limitations of this study, Magic foam cord showed the ease of placement followed by Expasyl retraction system and Medicated retraction cord.

Clinical significance: Gingival retraction helps in achieving good quality impressions. These are needed for a precision fit and long-term success with fixed prosthodontic restorations. Selecting techniques and materials that produce transient retraction and dry field without irreversible damages to the tissues is of utmost importance.

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1. Introduction

Tissue management is one of the critical factors in achieving a successful fixed prosthodontic restoration. The success of the restoration is not only evaluated in terms of fit, function and esthetics but also a restoration must have a suitable emergence profile with well-adapted and smooth gingival margins. Gingival and periodontal factors also play a significant role in a restoration's longevity and aesthetics. The health of gingiva and periodontium must be considered while planning restorative procedures that are in close proximity with soft tissues. In such restorations, isolation for subgingival placement becomes an important step [1,2].

The increasing use of cast restorations makes effective gingival retraction essential. With open, dry and clean gingival sulcus, accurate impressions can be made without systemic complications and with minimal tissue trauma. In order to record subgingivally placed margins, the adjacent soft tissue needs to be retracted and displaced adequately for the impression material to penetrate and capture fine details that are necessary for a successful outcome of the restoration [3].

For a precision fit and long-term success with fixed prosthodontic restorations, the quality of impressions made is a key element. Gingival displacement is one of the procedures, which helps in achieving this. The goal of any method of gingival retraction should be to achieve effective gingival fluid free sulcus that is predictable and repeatable, without tissue damage. Therefore, the dentist must select techniques and materials that produce transient retraction and dry field without irreversible damages to the tissues [1].

A number of gingival retraction systems presently available in the market which include retraction cords, pastes and foam. Newer cordless retraction systems like Expasyl and Magic foam cord are easy to handle and comfortable to the patient [4]. These systems displace gingiva and are supportive to the periodontal tissue [5]. Choice of appropriate gingival retraction system is still a dilemma in the mind of the operator [4].

Gingival displacement approaches include mechanical, chemical and surgical methods. Mechanical methods are fast, simple and inexpensive. They achieve hemostasis and control crevicular seepage but are tough and exhausting to use. They are painful procedures and need anaesthesia to be administered. They may cause an injury to the epithelial attachment. Chemical agents exhibit hemostatic effects under physiological condition through protein precipitation. They inhibit plasma proteins inter-capillary immigration, decrease cell permeability, control the moisture in the peripheral tissues through protein precipitation on the superficial layer, and increase the mechanical strength of the mucosa. The disadvantage of this method is that denatured proteins can be involved in topical tissue destruction. The present study has been compelled to evaluate the clinical efficiency of gingival displacement obtained using Expasyl, Magic foam cord and Medicated retraction cord [5].

2. Materials and methods

Prior to the start of the study, ethical clearance was taken from the Institutional Ethics Committee, Sri Sai College of Dental Surgery, Vikarabad. One twenty patients with the requirement of full veneer crown on tooth were selected.

First and second molar teeth were included with thick gingival biotype. A periodontal probe was used to evaluate gingival biotype. Patients having healthy gingiva and periodontal status were selected. Criteria for assessing healthy gingival and periodontal status was kept as probing depth of 1-3mm; no bleeding on probing/mobility/furcation involvement; 0mm clinical attachment loss/bone loss and no visible inflammation. Only molars were used for establishing standardization and also considering that the effect of gingival retraction is better evaluated in larger sized teeth. This requirement was set as the inclusion criteria for the study.

Exclusion criteria were set as patients having attachment loss or signs of periodontal disease, cardiovascular disorders, hypertension, tilted or tipped tooth. Hypertensive patients were excluded from the study as one of the retraction systems used (Astringedent®- 15% ferric sulphate) is an agent that causes tissues to vasoconstriction and reduces capillary flow which may compromise the health of a hypertensive patient. The retraction systems used for this study were:

Group A: Expasyl (ACTEON France) (figure 1), a unique paste system that is injected into sulcus using the applicator. It takes between 15-20 seconds to apply the paste. This has a highly viscous organic binder,

KAOLIN-especially clay (responsible for rigidity) which is mixed with small amount of aluminum chloride (15%) to act as a haemostatic agent and also to keep the working field dry.

Mechanical action- Compressive action of paste into the sulcus.

Chemical action- Aluminum chloride, which is astringent, leads to protein coagulation on the surface of the tissue.

Group B: Medicated retraction cord (figure 2.a and 2.b), by soaking plain knitted retraction cord (Ultrapak; Ultradent South Jordan, Utah) of size #0 or #1 in 15% ferric sulphate (Astringedent®; Ultradent South Jordan Utah). Astringedent® (15% ferric sulphate) is an agent that causes tissues to vasoconstriction by precipitating proteins associated with limiting cell membrane permeability; by reduction of mucous and various secretions and reduction of capillary blood flow.

Group C: Magic foam cord (Coltene Switzerland) (figure 3), is a low consistency addition silicone elastomer (Poly vinyl siloxane). It is directly applied to sulcus without pressure or packing. Provides effortless removal, thus is comfortable for the patient. This contains no haemostatic chemicals that may contaminate the impression. The magic foam cord has inbuilt cotton rolls which show resistance to pressure. While applying, patients were asked to stop biting once they reach the resistance from cotton rolls.

The instrument used was a Toolmaker microscope (METLAB India) (figure 4). These are special type of microscopes that are used to create precision tools and measure small distances between two points of a specimen. It works on principles of optics. In contrast to a conventional light microscope, a toolmaker microscope is typically used as a measuring device. Fundamentally, it can be used to measure up to 1/100th of a millimetre. Die focused under Toolmaker microscope measuring the depth and width of gingival displacement after placing retraction system (figure 5).

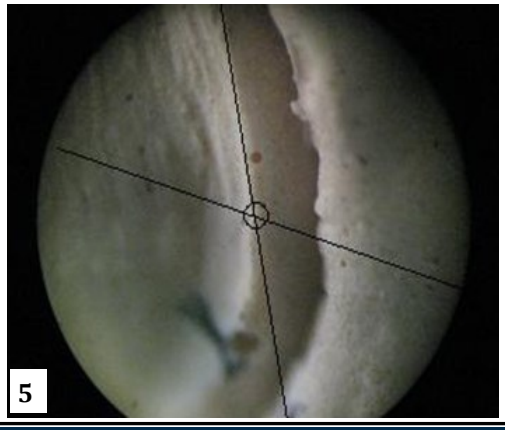
The impressions obtained before and after placing the retraction system were poured with type IV die stone (Ultrarock, India). The casts obtained before and after placing the retraction system were coded to constant identity being influenced by the operator. Hence, this study was conducted in blind fashion.

Figures 1 - 3: Materials used in the study. Where 1. Expasyl; 2. Medicated retraction cords, a. Ultrapak, b. Astringedent®; and 3. Magic Foam Cord - Low consistency Polyvinyl siloxane material.

Mesial, distal, mid-buccal and lingual were taken as reference points because of the difference in closure patterns in mid-buccal, lingual and interproximal areas and due to anatomic and microstructural differences [5]. The casts are viewed under Toolmaker microscope for the amount of both vertical and horizontal gingival displacement. The difference was evaluated as the amount of retraction obtained by the retraction systems. The differences were measured and subjected to statistical analysis.

3. Results

The present clinical study was carried out to evaluate the efficacy of Expasyl retraction system, medicated retraction cord and magic foam cord. The mean gingival retraction width at the mesio-buccal area for Group A



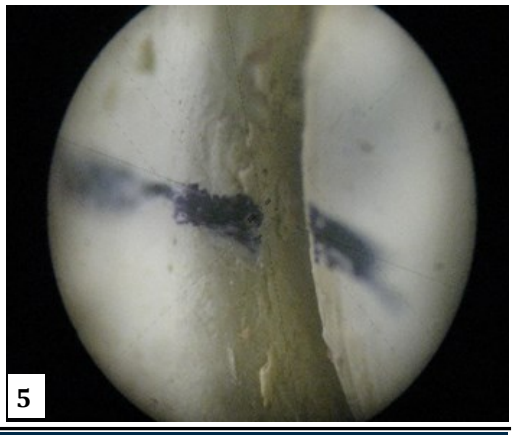


Figure 4. Tool maker microscope.
Figure 5. Microscopic images of the depth and width of gingival displacement after placing retraction system.

was 0.36mm, Group B was 0.46mm, and Group C was 0.33mm. The mean gingival retraction width at the disto-buccal area for Group A was 0.38mm, Group B was 0.42mm and Group C was 0.37mm. The mean gingival retraction width at the mid-buccal area in Group A was 0.41mm; 0.54mm in Group B, and 0.22mm in Group C with a 5% level of significance and p-value of <0.001. The mean gingival retraction width at the mid-lingual area in Group A was 0.47mm; 0.58mm in Group B, and 0.23mm in Group C. One-way ANOVA test and tukey-HSD procedure was applied to identify significant groups at 5% level. The mean gingival retraction depth at the mesio-buccal area for Group A was 0.37mm; 0.50mm in Group B, and Group C was 0.33mm. The mean gingival retraction depth at the disto-buccal area for Group A was 0.40mm; Group B was 0.40mm, and Group C was 0.35mm. Group A and B showed similar results. The mean gingival retraction depth at the mid-buccal area in Group A was 0.59mm; 0.68mm in Group B, and 0.27mm in Group C with a 5% level of significance and p-value of <0.001. The mean gingival retraction depth at the mid-lingual area in Group A was 0.5mm; 0.67mm in Group A, and 0.29mm in Group C.

The mean gingival retraction width in each retraction technique Group A 0.41mm, Group B 0.50mm and Group C 0.29mm (Figure 6). The mean gingival retraction depth in each retraction technique Group A 0.47mm, Group B 0.56mm and Group C 0.31mm. The results indicate that Medicated retraction cords (Group B) have effective retraction but are skill dependent and may cause gingival inflammation. Expasyl has produced retraction and was the least time consuming while magic foam cord has the ease of manipulation and has been maximum tissue supportive.

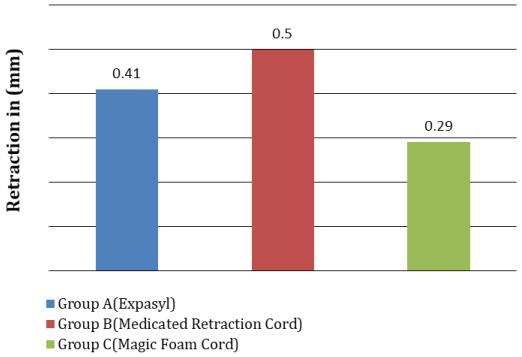


Figure 6. Mean gingival retraction width in each retraction technique

4. Discussion

The goal of any retraction system is to reversibly displace the gingival tissues in a lateral direction so that a bulk of low-viscosity impression material can be introduced into the widened sulcus and capture the marginal details [8].

The critical sulcular width in this regard seems to be approximately 0.2mm. A width of less than 0.2mm results in impressions that have a higher incidence of voids in a marginal area, an increase in tearing of material and reduction in marginal accuracy. Hence, it is imperative that a small amount of impression material flows beyond the prepared margin, and this permits accurate trimming of required die [9].

The results of the present study showed that Expasyl and Medicated Retraction Cord had greater values in the mid-buccal and the mid-lingual when compared to the mesio-buccal and the disto-buccal areas in both vertical and horizontal displacement of the gingiva.

This could be due to anatomic and microstructural differences in collagen fiber relation. As the gingiva at the proximal area is not only thicker than the buccal and lingual area but is also richer in collagen fibers with the intersection of the dentogingival, semicircular fibers and the transgingival fibers that originate from the adjacent tooth [10]. The forces applied in both the systems are uniform all through the gingival crevice.

Whereas in Magic Foam Cord mesio-buccal and disto-buccal areas showed greater values than mid-buccal and mid-lingual areas. This could be best explained as the magnitude and direction of force is not equal throughout gingival as contour and size of comp recap will exert more pressure interproximally than the mid-buccal and the mid-lingual which explains the difference in mean values between the locations.

In Magic foam cord and Expasyl, the disto-buccal area showed higher value compared to mesio-buccal. The mean values for Expasyl are 0.38mm, 0.36mm and 0.37mm and 0.33mm for magic foam cord. The reason could be when occlusal forces are applied, distal surfaces of teeth come in contact taking arc of closure into consideration.

All three groups showed a sulcular width greater than 0.2mm. However, Group C showed results matching with critical sulcular width in relation to mid-buccal and mid-lingual, which may need improvement in the design for better results.

Standard deviation which is high in vertical displacement (0.14) for Medicated retraction cord, shows it is extremely technique sensitive and multiple factors which makes it less predictable than other two retraction systems which have low standard deviation (Expasyl showing 0.06 and Magic foam showing 0.05).

Thimmappa *et al.* (2018) compared the efficiency of three non-invasive gingival displacement systems; Merocel strip, Ultrapak cord and Magic foam cord. The study showed that the Merocel strip provided the maximum amount of vertical and lateral tissue displacement, followed by Ultrapak cord and least with magic foam cord [11]. Singh *et al.* (2019) compared the efficiency of foam cord and retraction cord, and stated that the retraction cord provided 0.8% more gingival displacement when compared to the magic foam cord [12].

Gingival retraction methods provide ample vision and ideal working environment along with maintaining hemostasis to a certain extent. Thorough knowledge of gingival retraction agents and techniques available is necessary to procure superior bonding and minimal contamination from numerous factors of the oral cavity. Also, to be able to apply the appropriate one for specific purposes. Moreover, a particular clinical situation may indicate a specific technique. Selecting techniques and materials that produce transient retraction and dry field without irreversible damages to the tissues is of utmost importance.

5. Conclusion

Expasyl showed superior result when compared to Magic foam and less when compared to Medicated retraction cord taking both the parameters into consideration because of the presence of kaolin-clay which endures atraumatic mechanical retraction and aluminium chloride, causing chemical retraction. This synergistic effect leads to a maximum amount of gingival displacement.

Within the limitations of the study, Magic foam cord showed the ease of placement followed by Expasyl retraction system and Medicated retraction cord. However, the amount of vertical and horizontal displacement observed with Medicated retraction cord was significantly higher when compared to Expasyl and Magic foam cord.

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Evaluation of translucency of two types of glass ceramics with different thickness: An *in vitro* study

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Translucency

Thickness

ABSTRACT

Background: Veneered all-ceramic restorations are associated with a high incidence of chipping and veneer delamination from the inner core. Monolithic all-ceramic crowns facilitate the fabrication process and minimize residual stresses between core and veneer. A new material, zirconia-reinforced lithium silicate (ZRL), Celtra Duo was recently introduced for the fabrication of monolithic anterior crowns to overcome the aesthetic drawbacks of traditional zirconia and also to improve the strength of the lithium disilicate.

Aim: This study aimed to evaluate and compare the translucency of CAD/CAM zirconia reinforced lithium disilicate ceramic and Lithium silicate glass-ceramic at a different thickness .

Materials and methods: A CAD/CAM Lithium Silicate glass-ceramic (e.max CAD) and CAD/CAM ZLS Celtra Duo ceramic materials were used in the study. A total of forty Disc-shaped ceramic specimens (n=40), which comprises 20 from each ceramic material (n=20) were fabricated. The twenty specimens from each material group were divided into four subgroups with five specimens each (n=5) with a thickness of 1.0 mm, 1.2 mm, 1.5 mm and 2.0 mm, respectively. All the specimens were thermo-cycled to simulate one-year clinical service followed by analyzing the degree of translucency using spectrophotometer. The obtained data were subjected to statistical analysis using the student t-test and post-hoc pair-wise comparisons .

Results: A decrease in translucency with an increase in the thickness of the ceramic specimens was observed. Significant differences were observed between the ceramic materials except at 1.5 mm thickness (p=0.621) .

Conclusion: Both the ceramic materials displayed decreased in their translucency with the increase in the thickness. The glazed Celtra Duo has demonstrated relatively more translucency than e.max CAD ceramic at all thicknesses.

1. Introduction

The Patients' demand for natural-looking restorations, such as laminates, inlays, onlays and full coverage crowns, that mimic tooth structure has led to the development of new all-ceramic systems. Esthetically pleasing restoration should be an exact replica of shape, size, translucency and surface texture of the natural tooth. Despite the clinical success that was offered by porcelain fused to metal

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restoration, unpleasant esthetic light reflection from the opaque metal substructure can compromise the natural appearance and affect the overall esthetic result of the restoration [1]. All-ceramic restorations play one of the most critical roles in today's dentistry. Literature indicates the effectiveness of all-ceramic restorations for numerous clinical applications [2,3].

The interest of dentists, dental technicians and patients in all-ceramic materials is rapidly increasing as stronger and tougher materials are being developed and commercialized along with novel processing technologies [4-6]. The optical properties of the restorative materials, the hard tissues, and the interaction between them influence the aesthetics of the restorations and the natural tooth. Therefore, the translucency of a material is an essential factor for the clinical selection of restorative materials. From the aesthetic aspect, it is crucial to select a material that closely matches the natural translucency and grey -scale of the tooth. Therefore, clinicians must have adequate knowledge about the translucency of various restorative materials in order to match the esthetics of the artificial restorations with the natural teeth in individual clinical situations [2,4].

Recently, the progress in the development of CAD-CAM technology and the materials science led to the development of promising materials such as Zirconia reinforced-lithium Silicate (ZLS). This material claimed to have enhanced translucency as its' glassy matrix contains a homogeneous crystalline structure made of lithium silicate crystals, is reinforced with about 10% of tetragonal zirconia fillers. These fillers provide enhanced strength than the Lithium di Silicate ceramics [7]. ZLS possesses higher translucency, along with adequate biaxial flexural strength. These characteristics make this material a better choice for minimally invasive, single tooth esthetic restorations [7-9]. Numerous studies reported that the thickness of the ceramic materials influences the translucency parameter [10]. Studies also considered the ceramic thickness of 1.5-2.0 mm is adequate to achieve appropriate chromatic masking [10]. However, limited research is available regarding the effect of thickness on the translucency of ZLS ceramics. Hence, this study was designed to evaluate the effect of the thickness on the translucency of ZLS ceramic materials. Also, this study compared the translucency of ZLS ceramics with Lithium di Silicate ceramics at different thicknesses.

2. Materials and methods

2.1 Materials

Two all-ceramic materials such as Lithium disilicate (IPS e.max CAD, Ivoclar Vivadent, USA), and Lithium disilicate reinforced by zirconia (Celtra Duo, Dentsply Sirona, GmbH) were used in the study.

2.2 Methods

A total of 40 disc-shaped ceramic specimens with different thickness were milled using CAD/CAM technology. The forty specimens comprise 20 from each ceramic material. The thickness of the specimens was 1.0mm, 1.2 mm, 1.5 mm, and 2.0 mm, and a diameter of 10 mm. Five samples were allocated for each thickness from each ceramic material.

2.3 Preparation of specimen

Lithium Disilicate glass-ceramic (IPS e.max CAD) blocks were milled, and the specimens were crystallized and glazed at 840ºC (1544°F) in a ceramic furnace (Programat® CS, Ivoclar Vivadent) following the manufacturer's instructions.

Lithium disilicate reinforced by zirconia (Celtra Duo) ceramics were milled, polished and glazed the specimens at after 820°C as per the manufacturers' recommendations.

2.4 Evaluation of translucency [11]

All the specimens were ultrasonically cleaned in distilled water for 10 minutes and dried with compressed air before subjecting them to the translucency evaluation. The translucency of the ceramic samples was evaluated with translucency parameter (TP), using a clinical spectrophotometer (UV-3101 PC).

Specimens were placed over white (L* = 96.3, a* = 0.1, b* = 1.9) and black (L* = 8.9, a*=-0.7, b*= 1.2) tiles and "tooth single" mode were selected.

Measurements for each specimen were repeated two times on each background, and the mean CIE L*a*b* values were recorded for both backgrounds. TPs were obtained by calculating the colour difference between the value while the specimen over the white background and that over the black background using the following formula:

$$TP = [(L^*B - L^*W)^2 + (a^*B - a^*W)^2 + (b^*B - b^*W)^2]^{½}$$

Where, B corresponds to the colour coordinates over the black background, and W corresponds to those over the white background.

If the material is opaque, the TP value was assigned as zero; and if the material is transparent, the TP value was considered as 100. The greater the TP value, the higher the translucency of the material.

2.5 Statistical analysis

The obtained data were analyzed using Statistical Package for Social Sciences, version 20.0. (SPSS, IBM Corp., NY). The Kolmogorov-Smirnov test was used to verify the normality of distribution. Quantitative data were described using mean and standard deviation. The unpaired t-test was used to compare mean translucency scores between two groups at a different thickness. The p-value <0.05 was considered statistically significant for all the comparisons.

3. Results

The obtained mean and standard deviations of translucency of the ceramic materials with different thickness are given in table 1. Among the ceramic materials tested, both the Celtra Duo and the e.max CAD materials showed more translucency at 1.0 mm thickness (Table 1). Celtra Duo ceramic materials exhibited more translucency at all the thickness compared to e.max CAD except at 1.5 mm thickness. However, no statistical significance (p=0.6221) was observed between the ceramic samples at 1.5 mm thickness. The decrease in translucency was observed as the thickness of the ceramic specimens was increased. At 2.0 mm thickness, both the ceramic materials demonstrated the least translucency. Among both the ceramic materials, e.max displayed the least translucency at 2.0 mm thickness (Table 1). Significant differences were observed between the ceramic materials at all the thickness except at 1.5 thickness (p=0.621).

4. Discussion

Spectrophotometry is a method used to measure colour and translucency in dentistry [12,13] quantitatively. Different parameters are used to describe the translucency, such as the translucency parameter, making it difficult for clinicians to compare studies. Moreover, these parameters are not applicable to the direct measurement of translucency and cannot be used below 50% transmission [14,15]. Therefore, in the present study, the absolute translucency was determined to obtain meaningful and comparable values. Ceramic was one of the primary materials used as an esthetic restorative material. Due to optical properties and colour, which looks like natural teeth, with good resistance against wear and more stable in colour. The manufactures lately claim that newly Introduced all ceramics in dentistry have translucency properties comparable to feldspathic porcelains along with improved mechanical resistance. Therefore, a correct selection, esthetics and longevity have to be considered from the main parameters.

Lithium disilicate ceramic material which has durability and superior esthetics is considered one of the important ceramic material available nowadays. The light diffusion and translucency of IPS e.max ceramics were reached to replicate natural tooth appearance and structure [16]. New additions to the category to the glass-ceramics are zirconia reinforced lithium

Table 1: Comparison of translucency of ceramic materials at different thicknesses.

Thickness	Materials	N	Mean±SD[$]	t-Value	Significance (p - value)
1.0 mm	e.max CAD	5	12.40±0.55	3.464	0.009*
	Celtra Duo	5	13.60±0.55		
1.2 mm	e.max CAD	5	10.40±0.55	2.558	0.034*
	Celtra Duo	5	11.60±0.89		
1.5 mm	e.max CAD	5	9.20±0.84	0.535	0.621
	Celtra Duo	5	9.00±0.00		
2.0 mm	e.max CAD	5	6.00±0.00	4.00	0.016*
	Celtra Duo	5	6.80±0.45		

* Significant differences were observed. [$]Standard Deviation.

disilicate in vitro testing of the ZLS showed a favourable combination of the material characteristics of zirconia and glass-ceramics. This study aimed to assess the effect of zirconia addition to lithium disilicate ceramic on translucency.

Celtra Duo is a new class of ceramic, which is called zirconia-reinforced lithium silicate. In these ceramics, 10% of zirconia is dissolved into the lithium silicate glass matrix that results in approximately four times smaller silicate crystals with a high glass content. These smaller crystals with a high glass content exhibit higher translucency compared to conventional lithium disilicate ceramics (Celtra Duo; DeguDent GmbH). Celtra Duo presents higher T% values than IPS e.max CAD.

The present study reported the highest translucency parameter (TP) with the zirconia-reinforced lithium silicate glass-ceramic compared to Lithium disilicate glass-ceramic. The results of this study are in accordance with the previous studies [17-20]. Zirconia-reinforced lithium silicate glass-ceramic demonstrated a higher mean of translucency than Lithium disilicate glass-ceramic. This increase in the translucency can be attributed to the addition of zirconia and the ensuing nucleation process, resulting in more homogenous crystalline structure and finer crystal size (0.5 μm) compared to the needle-shaped coarser crystalline structure (1.5 μm) of Lithium disilicate glass-ceramic [21]. Also, the thickness influenced the final colour of the ceramic, partially due to the translucency, as the thicker ceramic disks were less translucent [20].

The results of this study were in accordance with the study by Heffernan *et al.* (2002) [22,23], who stated that the amount of light absorbed, reflected and transmitted is dependent on several factors including the particles size compared to the incident light's wavelength. They also stated that the porcelain translucency depends on the composition of ceramic and an increase in particle size is inversely proportional to the translucency. The other factors include irregularities in the distribution of the phases and optical anisotropy of the grains.

Similarly, Bachhav VC *et al.* (2011) [20] also reported that the translucency of ceramics decreased with an increase in the thickness. Therefore, thickness of the ceramic restorations must be considered as one of the factors during shade selection and fabrication.

Giordano RA [24], and Denry IL [25] reviewed various ceramic materials and reported that the amount of glass content also influences the translucency. The decrease in glass content in ceramics results in greater opacity.

The limitations of this study include the *in vitro* use of a spectrophotometer to evaluate the translucency of all ceramic materials. In addition, the samples used in this study were disc shaped rather than crown shaped. Further studies may be required to evaluate the clinical implications of the color and translucency of all ceramic restorations with different layers including core and veneer ceramics. Also, the effect of repeated firings and the influence of the type of luting cements may be studied.

5. Conclusion

From this study, it can be concluded that the translucency of the ceramic material is inversely proportion to the thickness. Compared to e.max CAD, Celtra Duo ceramic materials exhibited more translucency at all thicknesses except at 1.5 mm.

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Fiber-reinforced composites in endodontic practice: a review

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ABSTRACT

Fiber-reinforced composites (FRCs) are a group of non-metallic biomaterials characterized by good mechanical properties, such as high fatigue resistance and fracture toughness growing in popularity in several dental applications. FRCs are a combination of two materials: the reinforcing phase in the form of fibers, which are embedded in to the other material, called the matrix phase. Factors influencing the properties of FRCs include fibre properties versus polymer matrix properties, impregnation of fibres in the resin, adhesion of fibres to the polymer matrix, quantity and direction of fibres, and location of the fibre-rich phase in construction. The most commonly used applications of FRCs are in removable dentures, minimally invasive fixed dental prostheses, periodontal splints, root canal posts, and orthodontic retainers. This article discusses in detail the applications of FRCs in endodontics, including root canal posts, reinforcement of restorative composites in restorations and core build-ups and splinting of teeth in dental trauma.

KEYWORDS

Composites

Fiber-reinforced composites

Fibers

Glass fibers

Carbon fibers

Polyethylene fibers

Aramid fibers

Kevlar fibers

Endodontic Posts

1. Introduction

Fiber-reinforced composites (FRCs) are lightweight metal-free materials characterized by good mechanical properties, such as high fatigue resistance and fracture toughness [1]. Fiber-reinforced composite is a synthetic material combination of a polymeric (resinous) matrix and reinforcing fillers of high aspect ratio, i.e., the fibers [2]. Modern fiber-reinforced composites are used in applications where high static and dynamic strength and fracture toughness, especially in relation to weight, are required [1]. The areas of application of FRC include construction industries, decking, window and door frames, sports equipment, electronics, and medical field [3].

The use of fiber-reinforced technology in dentistry dates back to the 1960s, when fiber reinforcements were incorporated into polymethyl methacrylate (PMMA) denture base resin to reduce the incidence of fracture [4]. Their reinforcing effect was found to be superior to that of conventional metal wire strengtheners [5].

FRCs could have been developed as tough tooth-coloured materials at the time of the introduction of Bowen's resin in 1962. However, because there were some problems associated with combining resin systems with reinforcing fibres and with the technical and clinical handling of FRC, these materials have not been

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widely accepted until recently [6]. When reinforcing fibers were successfully combined with dimethacrylate resins and particulate filler composites, they became applicable in fixed prosthodontics and other fields of dentistry. As reported in the literature, FRC have been used as fixed partial dentures, implant supra-structure, periodontal splints, orthodontic retainers, root canal posts, and in repairing fractured porcelain veneers and reinforcement of composites [1].

FRCs are durable materials with a lower elastic modulus than metals [7]. The mechanical strength and modulus of elasticity of unidirectional FRC (20–40 GPa) are close to that of dentin and natural bone [8]. FRCs have highly favorable mechanical properties, and their strength to weight ratios are superior even to those of most alloys. When compared to metal alloys, the advantages of FRCs include non-corrosiveness, translucency, good bonding properties, and repair facility. Additionally, FRCs can be used both for chairside and laboratory fabrication [9].

The use of an adhesive technique, together with the possibility to tailor the physical properties of the restorations through individual fiber orientation and positioning, makes FRC restoration a minimally invasive, tooth-conserving procedure. Other benefits promoting the use of FRC materials are their cost-effectiveness and, good cosmetic properties (in the case of glass and silica fibers) due to the translucency of the fibers [1]. A critical evaluation of the FRC materials available and the proper case selection are highly essential to ensure the successful use of these materials [6].

2. Clinical applications of FRCs in dentistry

Fiber Reinforced Composite materials have many applications in dental practice. These materials were originally developed as part of a reinforcing system for denture bases in the early 1960s. The development of FRCs with a new type of resin system, combined with a better understanding of the design principles governing device construction, has led to the use of FRCs in a variety of disciplines and applications: removable prosthodontics, fixed prosthodontics, restorative dentistry, periodontology, orthodontics, and in repairs of fractured porcelain veneers [6]. The various applications of FRCs are described in table 1.

Applications of FRCs in endodontics include root canal posts [10-12], and reinforcement of restorative composites in restorations and core build-ups [13,14] and splinting of teeth in dental trauma [15-17]. The properties such as elastic modulus close to that of natural dentin, high tensile strength, and the suitability for cost-effective chairside techniques make fiber-reinforced composites well suited in the restoration of root canal-treated teeth [1].

3. Structure of fiber-reinforced composites

FRCs are a combination of two materials, one of which is a reinforcing phase in the form of fibers, which is embedded in the other material called the matrix phase [18]. The role of the fibers in a composite material is primarily to increase the strength and stiffness of the simple resin system, while the matrix polymer binds the fibers together, forming a continuous phase around the reinforcement. This phase transfers the loads to the fibers and protects the fibers from the moisture of the oral environment [1].

3.1 The matrix

Two types of resins can be used in FRCs, resulting in

Table 1. Clinical Applications of FRCs

- Reinforced direct composite restoration
- Root canal posts
- Single indirect restorations
    - Inlay
    - Onlay
    - Partial/full veneer crowns
- Teeth splinting
    - Periodontal splinting
    - Post trauma splints
- Fixed dental prostheses (anterior and posterior)
    - Simple cantilever
    - Fixed-fixed
    - Implant supported
- Immediate replacement transitional and long-term provisional bridges
- Reinforced or repairing dentures
- Fixed orthodontic retainers

either a crosslinked (thermoset) polymer matrix, or a linear (thermoplastic) polymer matrix. The cross-linked matrix is formed from multifunctional or dimethacrylate resins, (bis-GMA, TEGDMA, UDMA) whereas monofunctional methacrylates (MMA) form a linear polymer matrix [3,19,20]. Some impregnation methods have also been developed based on a combination of thermoset and thermoplastic resins. In that case, the polymer matrix is multiphase in nature and it is by definition a semi-interpenetrating polymer network (semi-IPN) in which one or more polymers are crosslinked and one or more polymers are linear or branched [21,22]. The semi-IPN polymer matrix of FRC offers advantages in terms of its handling properties and the bonding of indirectly made restorations and root canal posts to resin luting cements and veneering composites [23-25].

3.2 Fibers

Fibers of the composite are the reinforcing phases when a load is applied to the composite. The load is transferred to be carried by the stronger fibers through the interface between the fiber and polymer matrix. In contrast to particulate fillers, typically used in dental restorative composites, FRCs are reinforced with high-aspect ratio fillers (length being much greater than their cross-sectional dimensions)[26].

The higher the fiber concentration, i.e., the fiber volume fraction, the higher is the tensile strength of the composite. A relatively small quantity of fibers may be sufficient, given that it is positioned on the tension side of the composite structure. This concept of partial fiber reinforcement is often more applicable than a total fiber reinforcement in dental applications [27-29]. The reinforcement is used in a high stress-bearing area and covered with a second material to fulfill the esthetic and hygienic needs [1].

The type, positioning, and orientation of reinforcement largely determine the mechanical properties of the composite[2]. FRCs can be classified based on the type, length and orientation of fibers. Based on the type of reinforcing fibers, they are classified as glass fiber-reinforced FRC, Carbon fiber reinforced FRC, Polyethylene fiber reinforced FRC, and Aramid fiber reinforced FRC. Based on the length of reinforcing fibers, they are divided as Short discontinuous FRC, and Long continuous FRC. Based on the orientation of reinforcing fibers, they are classified as Unidirectional FRC, Bidirectional FRC, and Multidirectional FRC.

3.2.1 Fiber length and orientation

FRCs can be described as short discontinuous FRCs or long continuous FRCs, according to the aspect ratio of the fibers used [1]. A root canal post is a typical application of a long continuous FRC. Short discontinuous fibers can be used to reinforce dental filling composites [6].

Depending on the design of the composite, the reinforcing fibers can be either unidirectional, running all parallel to each other, or multidirectional, oriented in two or more directions as shown in figure 1. The mechanical properties of FRCs depend on the direction of the long axis of the fibers. When reinforcing fibers are oriented in the direction of stress, they provide the highest reinforcing efficiency. However, when stress is applied perpendicular to the long axis of the fibers, the fibers do not reinforce the polymer at all. This property is known as anisotropicity [1].

The efficiency of fiber reinforcement and its dependency on fiber length and orientation is described by Krenchel's factor [1]. Continuous unidirectional fibers give the highest reinforcing effect but only anisotropically in the direction of fibers. Randomly oriented discontinuous fibers give the reinforcing effect three dimensionally, i.e., isotropically [26].

The reinforcing efficiency (Krenchel's factor) of unidirectional fibers is theoretically 100% which means that reinforcing properties can be obtained in one direction. Continuous bidirectional (woven) fibers have reinforcing fibers in two directions, so they have a reinforcing effect equally in two directions. The theoretical reinforcing efficiency of such fibers is 50% or 25% [30].

If the fibers are oriented randomly as in chopped short FRC, the mechanical properties are the same in all directions. Composites that have randomly oriented fibers are isotropic in their mechanical and thermal properties; i.e the strength of the FRC is not related to the direction of the fracture force. The theoretical reinforcing efficiency of such fibers is 20% in three dimensions, whereas in two dimensions orientation gives 38% reinforcing efficiency [30].

Failure types of continuous and discontinuous FRCs differ from each other, as the high tensile strength of unidirectional FRCs cannot be obtained with discontinuous FRCs [1]. Failure types of discontinuous short

FRCs include cracking of the polymer matrix, debonding of the fiber, and fracture of the fiber, whereas axial tensile failure, transverse tensile failure, and shear failure are the most common failure types of unidirectional continuous FRCs [3].

3.2.2 Reinforcing fibers used in FRC

Several types of fibers have been tested and found to be applicable as reinforcements of dental polymers, most commonly glass, carbon/graphite, and polyethylene fibers.

Currently, g**lass fibers** are the most suitable fibers for clinical dentistry. The benefits of glass fibers include high tensile strength, low extensibility, excellent compression and impact properties, and low cost. Their transparent appearance is also well suited for dental applications with high cosmetic demands, such as root canal posts in the anterior teeth. The reason behind the success of glass fibers is the surface chemistry, which allows for their adhesion to dental polymers via silane coupling agents [1]. Glass fibers stretch uniformly under stress to their breaking point, and on the removal of the tensile load short of breaking point, the fiber will return to its original length. This property, together with their high mechanical strength, enables glass fibers to store and release large amounts of energy [2]. Based on the chemical composition of the glass mass, the glass fibers are classified into A (alkali), C (chemically resistant), D (dielectric), E (electrical), R (resistant), and S (high strength) glass types. They differ in mechanical and chemical resistance properties. The most commonly used glass fiber in reinforced composites is E glass (99% of all glass fibers manufactured) [31], which has a calcium-alumino-borosilicate composition.

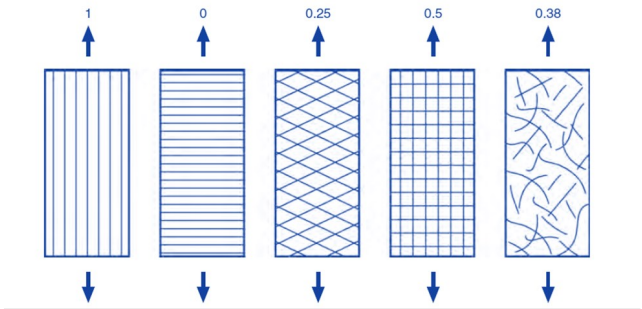

Figure 1: Reinforcing efficiency, Krenchel's factor, of fibers according to their orientation. From left to right: Reinforcing efficiency of unidirectional fibers oriented in the direction of the load, 90angle to the load, bidirectional fibers in 45/45 angle to the load, 0/90 to the load and short random fibers. Arrows indicate the load direction of the load.

Carbon fibers (CF) or carbon/graphite fibers are the most common high strength and high modulus of elasticity reinforcing fibers. They possess high strength in both tension and compression. In contrast, their impact strength is lower than that of glass or aramid FRC [2]. Carbon fiber reinforcements have not met wide clinical acceptance because of their difficult handling characteristics and black color resulting in poor esthetics [31]. The prefabricated root canal post has been the most widespread application of carbon/graphite fibers in dentistry [33-36].

Ultrahigh molecular weight (UHMW) polyethylene fibers are among the strongest reinforcing fibers available. They consist of aligned polymer chains with low elastic modulus and density and offer good impact resistance [2]. Their color is white and they are thus suited for dental applications. Despite excellent flexural properties of UHMW-polyethylene fibers, their clinical use is limited, mainly because of the problems involved in bonding the fibers to dental resins and potential problems related to increased adhesion of oral microbes to FRC [37].

Aramid fibers (AF) are created from aromatic polyamide fibers, more commonly known as Kevlar® fibers. These fibers have high strength and low density, with anisotropic tensile strength as fibers. They are resistant to chemicals and thermally stable and have high mechanical stability and high glass transition temperature. Aramid fibers have been used to reinforce the denture base polymers with and without silane treatment [38]. However, the yellow color of the fibers, lack of bonding between fibers and resin, and poor polishing surface limit their use in dental applications.

3.3 Adhesion between fiber and matrix

The performance of FRCs is controlled by the properties of the fiber–matrix interface. A good adhesion between the fibers and the matrix is a primary requirement for effective use of reinforcement properties. This interfacial bonding (or adhesion) results in efficient stress transfer from the continuous matrix to the dispersed fiber reinforcement and can increase its ability to absorb energy [39].

Treatment of the fibers is beneficial in order to improve the water resistance of fibers, enhance the wettability of fiber surface by resin, and promote interfacial adhesion. A coupling agent is a chemical that

functions at the interface to create a chemical bond between the reinforcement and matrix. Silanes are recognized as efficient coupling agents extensively used in composites and adhesive formulations [40,41]. Silanation refers to the surface treatment aiming at promotion of bonding dissimilar matrices together [42,43]. Effective wetting of fibers by resin matrix, also called resin impregnation, is a prerequisite for their effective use before further steps in the fabrication of the final restoration in dentistry [43]. One current fiber reinforcement system based on pre-impregnation utilizes highly porous linear polymers to preimpregnate the fibers. As a concept, an IPN is a combination of two or more polymers in network form that are synthesized in juxtaposition [21].

4. Advantages of the use of FRCs

- The main advantages of the use of FRCs over conventional materials are mainly due to their easy manipulation and high mechanical properties especially in dynamic loading conditions [44].
- The mechanical advantages provided by FRCs are their flexural strength, fatigue strength, elastic modulus, and bond strength (of fiber substructure to veneering composites and resin luting cements) [45].
- The mechanical strength and elastic modulus of FRC are close to that of dentin and natural bone [8].
- Metal free restorations - The absence of metallic parts in the FRC structure allows their use also in patients allergic to nickel or other metals [44].
- The other positive characteristic is the high aesthetics achieved with these materials over metal reinforced alternatives [46].
- FRCs allow a minimally invasive treatment technique even with direct treatment technique.
- Cost effective
- For many FRC applications, no or minimal laboratory work is needed, and often frameworks can be prepared at chairside, directly in the oral cavity [47].
- Simple production in laboratory without the need for waxing, casting and investing.
- Easily repairable.

5. Limitations of the use of FRCs

- The main limitations of FRC clinical use are that, even though many *in vitro* studies have been conducted, research is still lacking regarding long-term clinical performance [44].
- The most important weakness of FRC is the interface between the fiber and the organic matrix. Intraoral hydrolysis and degradation weaken this interface and may result in failure [44].
- Principal failure reasons of FRC devices are fracture and delamination, but they could be easily repaired with resin composite materials [48].

6. Applications of FRCs in endodontics

6.1 Restorations and core build-ups

Contemporary restorative dentistry uses direct, semi-direct as well as indirect restorations to restore lost tooth tissue, with biomimetics as the new driving force. Biomimetic restorative approach involves replacing lost tooth tissue by biomaterials with similar physical properties, especially with reference to elastic modulus, strength, and thermal expansion coefficient [49]. A well accepted biomimetic restorative approach advocates replacing enamel with feldspathic porcelain or glass ceramic, and dentine by hybrid composites [49,50]. Although it seems to be effective, fracture toughness of hybrid Particulate filler composites (PFC) is still lower than that of dentine [51]. Furthermore, the microstructure of the hybrid composite does not resemble that of dentine.

Research has been conducted to improve the reinforcing phase of restorative PFC in order to increase their safety for use in high stress-bearing areas [52]. Earlier attempts have been failed mainly due to sub-optimal reinforcement of the polymer matrix by short fibers. Fiber fillers should have a minimal length, the so-called critical fiber length, in order to optimally reinforce the polymer matrix. The critical fiber length of the reinforcing fibers are of paramount importance regarding the overall mechanical properties and fracture toughness of short fiber reinforced composite [53].

A new type of short fiber-reinforced composite (SFRC) everX Posterior (GC Corporation, Tokyo, Japan) was introduced in 2013. It consists of a combination of a resin matrix, randomly orientated E-glass fibers, and inorganic particulate fillers [14,54,55]. The resin matrix contains BisGMA, TEGDMA, and PMMA forming a semi-IPN which provides good bonding properties and improves the toughness of the polymer matrix.

In vitro studies showed improvements in the load-bearing capacity and fracture toughness of short FRC resin in comparison with conventional PFC resin [55,56]. The short FRC resin showed significantly higher fracture toughness (2.4 MPa.m0.5), flexural strength (124 MPa), and flexural modulus (12.6 GPa) than all other comparative composite materials [55,56]. The reinforcing effect of the fibers is based on transfer of stress from the polymer matrix to fibers and the behavior of individual short fibers as crack stoppers. Random fiber orientation and decreased cross-linking density of the polymer matrix by the semi-IPN structure had a significant role in mechanical properties.

Curing depth was found to be 4.6 mm, which was similar to other bulk fill composites and higher than conventional hybrid PFC [55]. They also showed a lower percentage of shrinkage strain (0.17%) compared to other tested composites [56]. The short FRC resin has also exhibited control of the polymerization shrinkage stress by fiber orientation, and thus marginal microleakage was reduced compared with conventional PFC resins [57,58]. On the basis of the available data, it is suggested that short FRC resin could be used to fulfill the requirements for ideal posterior composite restorations. It is intended to be used as bulk substructure material which will be covered by a layer of PFC resin (1–2 mm).

Bilayered composite structure of SFRC as substructure and PFC as top surface layer has been evaluated in several in vitro investigations and with different applications [59-61]. Studies have shown that SFRC substructure supports the PFC layer and serves as a crack prevention layer [62-64]. Some fibers that are protruding from the surface after application of the SFRC layer can be embedded in the veneering PFC layer and form an interface similar to that found at the dentine enamel junction (DEJ) which act as a natural crack arrest barrier. The significant advantage of this bilayered or biomimetic restoration is its ability to mimic the natural behavior of enamel and dentine. It is difficult to predict long term clinical performance from only laboratory experiments. One-year clinical report showed good clinical performance of this novel material combination of bulk short FRC substructure and surface layer of PFC in high stress-bearing areas [65].

SFRC is intended as dentine replacing material (base filling material) in high stress-bearing areas, especially in large cavities of vital and nonvital teeth. SFRC can therefore be used for direct and indirect biomimetic composite restorations, which are indicated for [26];

1. Restoration of endodontically treated teeth, including core build-ups, post-and-core restorations, and endocrowns
2. Medium to large Class I and II restorations
3. Cusp-protecting and cusp-replacing restorations
4. Crown build-ups

6.1.1 Direct biomimetic composite restoration

Restoration of an endodontically treated tooth with a direct bilayered or biomimetic composite restoration [26].

The cavity and the endodontic access opening are cleaned with prophylaxis spray, 1-2 mm of gutta-percha is removed at the canal orifices with a round carbide bur. A Flowable bulk fill composite is used to seal the endodontic access cavity. Then the Pulp chamber filled with the first increment of SFRC and each cusp is built up separately with 2 mm thick increments of SFRC followed by 1-1.5mm of a final layer of hybrid PFC [26].

6.1.2 Indirect biomimetic composite restoration

Restoration of an endodontically treated tooth, in which the structural integrity is compromised due to extensive loss of tooth tissue, with an indirect biomimetic composite restoration [26]. The indirect procedure requires two appointments. In the first appointment, the missing dentin of the endodontically treated tooth is replaced with SFRC, and then the tooth preparation is done to receive an overlay. The amount of occlusal reduction depends on the selected overlay material: it is recommended to have at least 1-1.5 mm for resin composite. Then immediate dentine sealing (IDS) adhesive - sealing of the entire dentine surface is done and light-cured. Subsequently, impressions are taken, and a provisional restoration is fabricated and luted [26]. In the second appointment conditioning of the preparation is done by etching the enamel with phosphoric acid for 15 sec and an adhesive system is applied. The composite resin overlay received from the dental laboratory is conditioned with organosilane and bonding agent is applied, and a flowable core build-up composite is used to lute the overlay onto the tooth [26].

6.1.3 Biomimetic post-and-core restorations

Endodontically treated tooth restored with a biomimetic post and core [26]. Post space preparation is

done, and a prefabricated fiber post is luted with a flowable core build-up composite. Core build-up is done with SFRC replacing the dentin part. This is veneered with micro-hybrid PFC in order to create a direct biomimetic post-and-core restoration [26].

6.1.4 Biomimetic endocrown

Endodontically treated tooth restored with a biomimetic endocrown [26]. In the first appointment, tooth preparation is done, and the endodontic access opening is sealed with a flowable composite. An impression is made and poured in gypsum. A biomimetic restorative approach is adopted for the fabrication of an endocrown. Dentine is replaced by a SFRC, and this is veneered with a final layer of at least 1 mm PFC serving as enamel replacement. In the second appointment, the restoration was luted with a dual-cure core build-up composite [26].

6.2 FRCs as root canal posts

A root canal post is a common application of unidirectional fiber-reinforced composites in dentistry [1]. The use of FRC root canal posts to anchor cores and crowns to the root has rapidly increased during the last decades [12,66]. Unidirectional FRC can be used both as prefabricated fully polymerized solid posts and individually formed in situ polymerized posts [1].

6.2.1 Prefabricated FRC Posts

Prefabricated FRC posts consist of a high-volume percentage of continuous unidirectional reinforcing fibers in a finally polymerized polymer matrix, thus forming a solid post with a predetermined diameter [1]. The fibers used in prefabricated FRC posts are carbon/graphite or glass (E-glass, S-glass, quartz/ silica) fibers, and the matrix is usually an epoxy polymer or a mixture of epoxy and dimethacrylate resins with a high degree of conversion and a highly cross-linked structure [1]. The fibers contribute stiffness and strength to the usually elastic matrix. The fiber quantity in prefabricated FRC posts varies from 40 to 65 vol% [67, 68] according to the manufacturer.

6.2.1.1 Advantages of Pre fabricated FRC posts

- The most important advantage of glass FRC is the suitable elastic modulus, which results in fewer root fractures and fewer unfavourable failures [69].
- The other advantages of prefabricated FRC posts are good esthetics and the ease of build-up and removal in situ.

6.2.1.2 Disadvantages of Pre fabricated FRC posts

- 1.The predetermined shape of a prefabricated FRC post seldom follows the anatomy of the root canal. Therefore, when placing a prefabricated FRC post, a large space will be filled with resin cement coronally, and an unnecessary amount of dentin have to be removed apically. To minimize unnecessary preparation, a post with a smaller diameter is often chosen, resulting in a postcore structure with an inadequate stiffness and load-bearing capacity [26].
- Additionally, the coronal part of the prefabricated FRC post-core system may not be stiff enough, to resist the high stresses produced by occlusal loads at the coronal and cervical areas [70]. The result is a post-core system with insufficient load-bearing capacity and a restored tooth which will not be able to resist the high stresses cervically at the restoration margins. This leads to marginal break-down by means of adhesive failure on the tension side of the restoration and in the end, secondary caries [71]. This problem arises particularly when the restoration lacks a ferrule effect [72].
- Prefabricated FRC posts are attached to the root canal dentin using adhesives and composite resin luting cements. However, their highly cross-linked polymer matrix with a high degree of conversion is nonreactive and therefore difficult to bond to resin luting cement and core materials [73]. The bond between epoxy-based matrix of certain FRC posts and composite resin luting cements and composite core material is mainly mechanical. To overcome the problem with adhesion, surface features, e.g., serrations, [74,75] have been added to the prefabricated FRC post to increase mechanical retention of resin cements and core material. However, this has been shown to be nonbeneficial or even harmful with regard to adhesion and flexural strength of an FRC post with an anisotropic nature [76]. Efforts have been made to improve the bond of the prefabricated FRC post surface with different surface treatments, both mechanical and chemical [77-79]. These include air-particle abrasion, silanization, and resin impregnation.

6.2.2 Individually Formed Customised FRC Posts

Attempts to eliminate the disadvantages of prefabricated FRC posts have given rise to the concept of individually formed posts. Greater resistance under loading and more favorable fractures were reported

with individual customized FRC posts compared to prefabricated FRC posts [80]. Significantly higher bond strength and fatigue resistance has been reported with individually formed glass FRC posts compared to prefabricated posts [81-84].

An individually formed FRC post with a semi-interpenetrating polymer network (IPN) polymer matrix is made from nonpolymerized fiber-resin prepregs, consisting of glass fibers and light-curing resin matrix. The purpose of the individual or custom-made FRC post is to fill the entire space of the root canal in cross-section with the FRC material, following the anatomical form and using minimally invasive preparation.

6.2.2.1 Advantages of Individually formed customised posts

By this method, more reinforcing fibers may be placed in the cervical parts of the canal where high tensile stresses occur, resulting in increased resistance [85,86].The increased fiber quantity in the coronal portion of the root canal increases the load-bearing capacity of the post system. FRC post formed with this technique resembles the design of a traditional cast post and core. With a gradual apico-coronal increase in thickness, following the anatomy of a modern flared canal preparation, more dentin can be saved in a structurally compromised tooth [26].

With the individually formed FRC post, which consists of a semi-IPN polymer matrix between the fibers, problems concerning the adhesion between post and resin luting cements as well as composite core materials are minimized. The bond between individually formed FRC posts and resin cements has been reported to be good [82-87].

When post dimensions closely follow the dimensions of the canal orifice, the cement thickness can be reduced. This lowers the polymerization contraction stress in the adhesive layers between the post and the surrounding dentin.

The biomechanics of the tooth is better simulated by placing the fibers closer to the dentinal wall, where the highest stresses occur [88-90]. When the outer ferrule of the restoration is lacking, adhesive failure and marginal leakage, especially on the tension side of the tooth, is a common failure type seen in teeth restored with prefabricated FRC posts [71]. The individual FRC post approach aims to diminish the adhesive failures of the restoration by providing increased structural stiffness and resistance in the critical cervical area. Moreover, a tooth restored with a short and thick individual FRC post has been reported to withstand higher loads than a tooth restored with a thin and long individual FRC post [90]. This technique offers benefits also from an operative perspective. A shorter root canal preparation is less time-consuming, and unnecessary hard-tissue removal can be avoided.

The fundamental requirement of an adequate degree of conversion of the polymer matrix of the in situ polymerized FRC post is achieved with the individually formed FRC post material [91]. In addition, it seems that the direct method of polymerizing the individually formed FRC post simultaneously with the resin cement in situ in the root canal may be superior to pre-polymerizing when looking at fracture load and microleakage [90,92].

6.2.2.2 A Step-by-Step Clinical Protocol of making an individually formed root canal post (Semi-IPN Post Material: EverStick Post, Stick Tech-GC)

- Isolate the area with rubber-dam.
- Remove old fillings when necessary.
- Remove root canal obturation material with a rotating instrument using a slow speed handpiece (e.g., gates glidden bur).
- The length of the root canal preparation should equal the height of future clinical crown.
- Rinse with NaOCl followed by distilled water and dry with air.
- Measure canal depth and add coronal dentin height=length of fiber needed.
- Cut the measured amount of the fiber post material with sharp scissors.
- Use two sets of tweezers to flare the coronal end of fiber bundle and make an oblique cut at the apical tip of fiber bundle thus easing the placement into the canal.
- Pretreat the root canal and coronal dentin according to the cement you are using.
- Apply a small amount of cement into the canal (use a flowable, dual cured resin cement).
- Place the fiber bundle into the root canal, control seating depth .
- Use a hand instrument (e.g., carver) to make room for the second, lateral fiber bundle.
- Cut a second, shorter piece of the fiber and place it into the canal.

- When needed, use more fibers to fill the entire coronal opening of the root canal, repeating the previous steps.
- Remove excess cement and light cure for 40 seconds.
- Continue with core build-up or composite resin restoration.

6.3 FRC splints in dental trauma

Dental trauma is a common injury, especially in children. Trauma displaces a tooth from its original position that needs to be repositioned for optimal healing and good outcomes. Dental splinting is frequently needed following traumatic injuries to stabilize subluxated, luxated, avulsed, and root fractured teeth.

The term splint has been defined by the American Association of Endodontics (AAE) as a 'rigid or flexible device or compound used to support, protect or immobilize teeth that have been loosened, replanted, fractured or subjected to certain endodontic surgical procedures. It allows periodontal healing and regeneration of the attachment apparatus [93].

The most common use for fiber reinforcement that has been described in the dental literature has been the splinting of teeth [94-96]. Fibre splints use polyethylene or Kevlar fibre mesh which are attached either with an unfilled resin such as Optibond FL (Kerr, USA) and/or with composite resin. Materials such as Fiber-Splint (Polydentia SA Mezzovico-Vira, Switzerland), Ribbond (Ribbond Inc., Seattle, USA) or EverStick (Stick Tech Ltd, Turku, Finland), which is a silinated E-type Glass fibre, are commercially available [15]. In a study conducted by Andreasen *et al.* on 400 root-fractured teeth fibre splints were associated with the highest frequency of favourable healing outcomes [97].

6.3.1 Ribbond splint

This type of splint is based on the use of special polyethylene fibers (Ribbond fibers) and composite materials. In dental traumatology, Ribbond fiber splints are a type of fixed and extra-coronary splints [16].

Ribbond fibers are popular as a form of immobilization due to their properties:

- They are exceptionally strong, owing to the special way they are woven.
- The surface of the fiber is treated using an electro-chemical plasma procedure, so that the mechanical properties of the fibers are improved, as well as bonding to the composite resin.
- Their permeability to light makes work possible with any form of composite material.
- They have excellent properties relating to manipulation [16].

6.3.1.1 The technique for the placement of a Ribbond splint:

- Gently reposition the avulsed or luxated tooth.
- Measure the length of the Ribbond needed with a dental floss. The Ribbond should extend ¾ of the distance across the abutments at the level of interproximal contacts.
- Cut the Ribbond using special scissors.
- Wet the Ribbond with an unfilled bonding adhesive or pit and fissure sealant.
- Clean and etch the injured and neighbouring teeth at the level of interproximal contacts. Apply bonding resin and cure.
- Apply the filled composite material to the tooth and press the Ribbond through the composite against the tooth and cure.
- Using a drill, remove the excess composite material and polish the surface of the composite [16].

6.3.2 Kevlar fiber

Kevlar fiber, is a synthetic, organic fiber of exceptional strength. It is used to make bulletproof vests and in the aero-industry. It is used in dental traumatology as a means of immobilizing teeth. It has the similar features, therapeutic effect, and manner of application as Ribbond splints [16].

6.3.3 Advantages of fiber splints

- The main advantage of the fibre splint is that it does not require any laboratory assistance and can be bonded directly on to the teeth.
- Procedures can often be completed in a single appointment.
- It has an acceptable strength because of the good integration of fibers with the composite resin which leads to clinical longevity.
- Due to the use of a thinner composite resin, the volume of the retention appliance can be minimized.
- In addition, the appliance can be repaired easily in case of fracture due to wear-and-tear.
- There is no need for removal of any significant

tooth structure, making the technique reversible and conservative. Moreover, it meets patients esthetic expectations [98].

7. Conclusion

Fiber-reinforced composites are growing in popularity in several dental applications. Applications of FRCs in endodontics include root canal posts, reinforcement of restorative composites in restorations and core build-ups and splinting of teeth in dental trauma. The advantages of using FRCs in endodontics are their elastic modulus is close to that of natural dentin, the high tensile strength, and the suitability for cost-effective chairside techniques. For optimal clinical performance, it is important to understand the factors influencing the behavior of these composite materials.

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Occupational risk factors and preventive measures for COVID-19 in prosthodontics

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ABSTRACT

Today, novel coronavirus infection has become pandemic worldwide. It is the primary cause of sickness from the common cold to severe acute respiratory syndrome in individuals. In a dental operatory, infections can be expedited through several routes like aerosol generation, contaminated surfaces, droplet splatter, oral fluids, and direct contact. Keeping in mind about the routes of transmission of COVID-19 (Coronavirus disease-19), dental practitioners are at higher risk of exposure and disease spread. Hence, this review article emphasizes the routes of transmission, risk factors, prophylactic and preventive measures. It also sights on alternative approaches to prosthodontic procedures to reduce the burden of COVID-19 infection in their community. Data acquisition was made using the keywords, COVID-19, infection control, prosthodontic risk factors in electronic databases like PubMed, Medline, ProQuest, etc. A manual search of several journals and books was also carried out, and only highly relevant articles were considered for the present review.

KEYWORDS

COVID-19

Infection control

Prosthodontic risk factors

1. Introduction

The novel coronavirus (2019-nCoV) is rapidly spreading into public health crisis from its origin in Wuhan city of Hubei province of China, and its outbreak has gripped the whole world [1]. The World Health Organisation (WHO) on 11th February 2020, has declared a new name for the pandemic disease caused by 2019-nCoV as coronavirus disease (COVID-19). As for the virus alone, the International Committee on Virus Taxonomy has renamed the previously provisionally named 2019-CoV as Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) [2,3]. They belong to a family of single-stranded RNA viruses known as Coronaviridae and are large in dimension varying from 60nm to 140nm [4].

These are primarily zoonotic, transmitting infection from animals to humans and humans to humans [5]. According to the China modelling study, the COVID-19 has a mean serial value of 5.8days between onset symptoms. The infectiousness has begun 2-3 days prior to the onset of symptoms and declined within seven days [6]. The transmission of SARS-CoV-2 has also been reported within the incubation period [7].

Dental care setups are always at high risk of COVID-19 infection. Its spread as

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clinical procedures involves face to face communication with the patients and frequent exposure to saliva, blood, aerosols generation and oral cavity and respiratory system. The viable transmission of infection can be through the respiratory droplets, produced while coughing or sneezing, speaking as well as the spread can occur through contaminated surfaces (Figure-1).

So, the dental surgeons have to change protocols for protecting the patients, prevent the spread of COVID-19 and defend themselves by disinfecting and sterilizing dental operatory and postoperative disinfection and waste management [8].

2. Clinical features (Table-1)

Coronavirus causes sickness ranging from the common cold to more severe disease such as Middle East Respiratory Syndrome (MERS-CoV) and Severe Acute Respiratory Syndrome (SARS-CoV).

Risk factors: Aged people with additional medical co-morbidities like hypertension, diabetes mellitus, asthma, chronic obstructive pulmonary disease, and other cardiovascular conditions are more prone to develop a severe form of the disease [9].

2.1 Preparation of operatory

Dental surgery is a surgical procedure, and infection prevention has always been required for a healthy and effective dental practise [10,11]. Disinfection of dental operatory before and after treating the patients is required and numerous protocols including;

2.1.1Common ventilation for six minutes, air changes for each hour (ACH) of 60 minutes.

2.1.2 HEPA (High-efficiency particulate air) 13/14 air filters with minutes 12 ACH.

2.1.3 Disinfecting or defogging for 30-45 minutes:
Ultraviolet germicidal irradiation (UVGI) plus two minutes to six hours of ventilation depending upon UV light position, wattage of the light source, and room size. UV-C disinfection is most effective against microbes and viruses in the present scenario.

2.1.3.1 Fumigation:
This method can be performed by electric boiler fumigation and potassium permanganate method. Formaldehyde, phosphine, 1,3-dichloropropane, hydrogen cyanide, chloropicrin, methyl isocyanate are the different agents used for Fumigation.

2.1.3.2 Fogging
Foggers generate a fog or mist formed by Ultra-low Volume (ULV) uniform sub-micron size liquid particles (Dry Fog) Glutaraldehyde, Glucoprotamine, Hydrogen Peroxide+ Silver Nitrate are different chemicals used for fogging procedure. Fogging is done using equipment called Fogger.

2.1.3.3 Ultraviolet (UV) light:

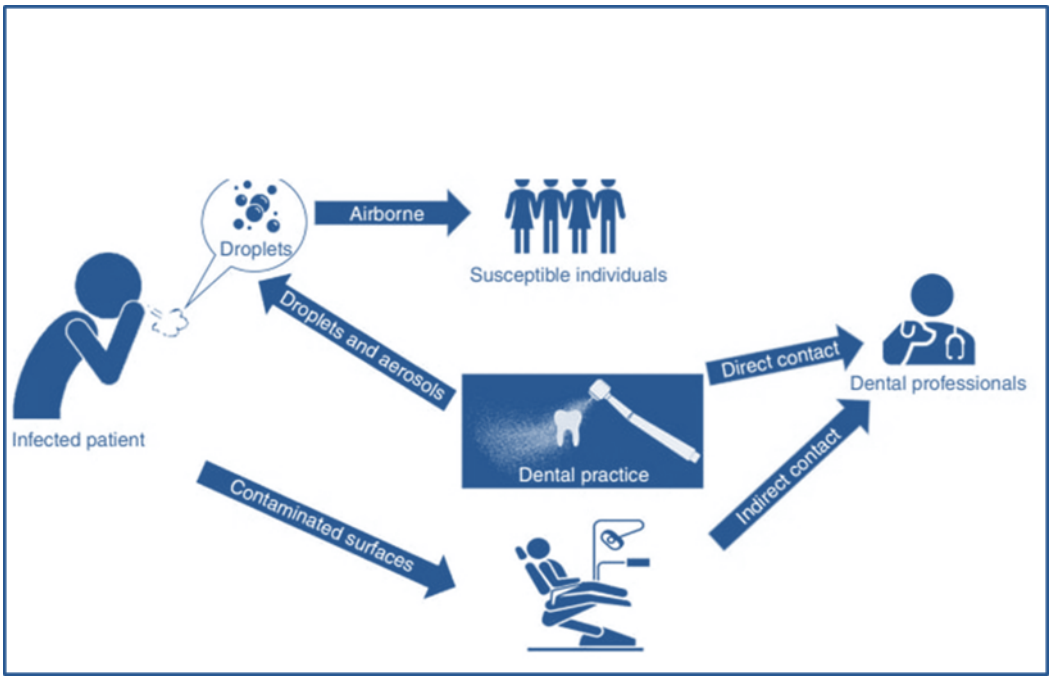

Figure 1. Transmission routes of 2019-nCoV in dental clinics and hospitals

Table-1: Symptoms of COVID-19 [8]

Common symptoms	Less common symptoms	Rare symptoms
Fever	Myalgia/arthralgia	Nausea, vomiting
Cough	Headache	Nausea, congestion
Fatigue	Sore throat	Diarrhoea
Shortness of breath	Chills	Palpitations and chest tightness

Ultraviolet (UV) is the part of electromagnetic light constrained by the lower wavelength extreme of the visible spectrum and the X-ray radiation band.

Using the Commission of Illumination classification, the UV spectrum is subdivided into three bands:

- UVA (long-wave) from 315 to 400 nm
- UVB (medium-wave) from 280 to 315 nm
- UVC (short-wave) from 100 to 280 nm

UVC disinfection has attained more favour among these types because of its efficacy against a wide range of microbial and viral agents in various environments. The cellular RNA and DNA absorb high energy from the short-wavelength UVC light, damaging nucleic acids and preventing microorganisms from infecting and reproducing [12].

2.1.3.4 Surface disinfection:

Human coronavirus may live up to nine days at room temperature on an inert surface with a higher preference for humid circumstances. Sanitize inert surfaces using chemicals confirmed against COVID-19 and keep a dry atmosphere to reduce the increase of 2019-nCoV. Such surface sanitizers include 62–71% ethanol, 0.5% hydrogen peroxide, and 0.1% (1 g/L) sodium hypochlorite.

2.2 Sterilization of instruments

All instruments are to be immersed in Sodium Hypchlorite+Detergent Solution 24 hours and then transferred to Ultrasonic cleaner the next day. Instruments must be wrapped in a sterilization pouch, and packaging should be done in a clean and low contamination area [13].

2.3 Patient Evaluation

The waiting room in the dental practice/center should be adequately ventilated. Prior to the patient's entry to the dental chair-side, patients should be provided with a surgical or face mask and disinfectant gel. The patient's temperature must be measured using a sterile or contact-free forehead thermometer. A pulse oximeter should be used for pre-screening to rule out reduced blood oxygen saturation levels, respectively. A detailed medical history should be taken from the patients, and a designated screening form must be precisely completed and signed by the patient (Figure-2).

If a patient is suspected to be positive, such patient should be immediately identified, quarantined and referred to the department of infection control in a hospital/center or the local health department.

In case of emergency dental complications, patients can undergo required treatments even if they are in the acute phase of the disease. According to WHO, the doubtful and healthy patients must be moved with negative pressure ventilation to precautionary rooms (12 air changes/hour "ACH" or 160 L /s/patient).
Patients who do not report any symptoms can receive dental care and treatments [14].

2.4 Rational use of Personal Protective Equipment (Ministry of Health & Family Welfare)

Personal Protective Equipment (PPEs) are protective gears designed to protect workers health by minimizing their exposure to a biological agent. (Figure-3).

2.4.1 Sequence for Donning of components of PPE:

First step: wear a head cap - Individuals using gowns, should use a headcover that covers the head and neck while providing clinical care for patients. Hair and hair extensions should fit inside the headcover.
Second step: Hand Hygiene – Hand hygiene is one of the principal pathways for reducing the transfer of microorganisms to the patients. According to WHO, SARS-CoV-2 can remain alive on different surfaces from the number of hours to several days. Since oral-faecal transmission of the virus has been reported for COVID-19, hand hygiene has become of the greatest importance for dental professionals/personnel. Hand hygiene can be achieved in two ways; handwashing with water and soap and hand disinfection using

COVID Screening Request Form		
Date :		
Full name :		
Date of birth :		
Screening questions	Affirmative	Negative
In the last 14days, have any members of your family or a close friend of yours have been infected by COVID-19?		
In the last 14days, have you been in contact with a COVID-19 infected patient?		
In the last 14days, have you or any close persons been on a journey?		
In the last 14days, have you had dry cough or difficulty in breathing?		
In the last 14days, have you had fever / temperature?		

Figure 2. COVID-19 Screening request form in dental practices [13]

Figure-3 : Personal Protective Equipment

alcohol-based solutions, both for 20 seconds.

Third step: Put on Gown - Coverall/gowns are designed to protect the torso of healthcare providers from exposure to the virus. Coveralls typically provide 360-degree protection. Using suitable protective clothing makes it viable to create a barrier to eliminate or reduce contact and droplet exposure, both known to transmit COVID-19.

Shoe covers: Shoe covers have to be made up of impermeable fabric to be used overshoes to facilitate personal protection and decontamination.

Fourth step: Put on N-95/FFP2/FFP3 - Protecting the airway from the particulate matter generated by droplets. Commonly used surgical face masks in dentistry when correctly worn and frequently changed offers around 80% filtration rate. COVID-19 measures around 120 nm (0.12 μm) and aerosol particle dimensions range from 3–100 nm. The use of FFP3 respirator provides a filtration rate of 99% of all particles measuring up to 0.6 μm. An N-95 respirator mask is an airborne particle-protective respiratory system with high filtration capacity. To supply the requisite air seal to the wearer, such masks are designed to attain a very close facial fit.

Fifth step: Put on Goggles and Face shield- Contamination of mucous membranes of the eyes, nose and mouth is more probable due to droplets generated by cough, sneeze of an infected person or during aerosol-generating procedures carried out in clinical situations. Hence it is important to protect them by using face shields/ goggles.

Sixth step: Put on Gloves - Nitrile gloves are preferred over latex gloves because they withstand chemicals, inclusive of certain disinfectants such as chlorine. There is an elevated rate of allergies to latex and contact allergic dermatitis among health workers. Non-powdered gloves are preferred to powdered gloves [15].

3. Implications in Prosthodontics

As patient needs, dentists should use their professional judgment to determine the emergency or urgent care. Urgent dental treatment is geared towards treating conditions that need urgent attention to relieve extreme pain and/or risk of infection and reduce the pressure on hospital emergency departments. These must be attended as minimally invasively as possible [16].

3.1 Denture Repair

In complete/partial denture cases, it is necessary to repair the fractured prosthesis to prevent mucosal irritation and trauma. Prosthetic devices can have an abundance of calculus and another tenacious bioburden. The debris should be removed to enable effective decontamination. To remove debris and contamination, the scrubbing should be done with a brush and antimicrobial soap. To remove the calculus, prostheses should be placed in sealable plastic bags or beakers filled with an ultrasonic purification solution. After this, the prostheses should be removed, rinsed under running tap water and dried before repairing the dentures. The denture is disinfected by immersing in 0.5% sodium hypochlorite for 10 minutes prior, which can otherwise lead to spread of infection.

3.2 If permanent or temporary restorations are dislodged, re-cementation procedures are performed after pre-procedural mouth rinsing.

A preoperative antimicrobial mouth rinse is generally thought to decrease the number of oral microbes. However, as set out in the Guideline for the Diagnosis and Treatment of Novel Coronavirus Pneumonia (5th edition) published by the People's Republic of China's National Health Commission, chlorhexidine, widely used as a mouth rinse in dental practice, may not be successful in killing 2019-nCoV. Since 2019-nCoV is vulnerable to oxidation, it is recommended to use pre-procedural mouth rinse containing oxidative agents such as 1% hydrogen peroxide or 0.2% povidone to reduce the salivary load of oral microbes, including potential 2019-nCoV carriage [17].

Choose and modify trays to have the proper size for making the impression to prevent coughing. For extremely sensitive patients, the use of oral mucosa anaesthesia to the throat before making the impression is a good option [18]. Disinfection of impression trays prevents the spread of infection (Table-2).

Table-2: Disinfection of impression trays [19]

Types of trays	Sterilization method
Aluminium	Heat sterilize via autoclave, chemical vapor or dry heat; ethylene oxide sterilization.
Chrome-plated	Heat sterilize via autoclave, chemical vapor or dry heat; ethylene oxide sterilization.
Custom acrylic resin	Discard after intraoral use in a patient; disinfect with tuberculocidal hospital disinfectant for reuse during the same patient's next visit.
Plastic	Discard.

Impressions taken from the patient's mouth are also significant sources of contamination. If an impression is taken, it must be properly rinsed under tap water to eliminate saliva, blood, and debris, and then disinfected preceding to delivery to prosthodontic laboratories (Table 3). The disinfection procedure is as follows;

a. Initial irrigation using tap water.
b. Placement of material in disinfectant.
c. Re-irrigation using tap water [19].

Crown/bridge cementation can be done as urgent dental care. Preceding a fixed prosthesis's cementation, it is mandatory to disinfect to prevent the spread of infection (Table-4) [20].

If there is any necessity for handpiece usage, rubber dam isolation, and use of anti-retraction handpiece is advisory to prevent aerosols spread and cross-contamination.

Rubber dam isolation: The use of rubber dam can significantly minimize saliva production- and blood-contaminated aerosol or spatter, especially in cases when high-speed handpieces and dental ultrasonic devices are used. It was outlined that the use of rubber dam could reduce airborne particles by 70% in the operating field's approximately 3-foot diameter [21].

Anti-retraction handpiece: Without anti-retraction valves they may aspirate and expel the debris and fluids during the dental procedures. The high-speed dental anti-retraction handpiece can significantly reduce the backflow of oral bacteria and Hepatitis-B Virus (HBV) into the handpiece and dental unit tubes compared to the handpiece without any anti-retraction function. Anti-retraction dental handpiece with specially

Table 3. Levels and types of disinfection of impressions [18]

Type of disinfection	Disinfectant	Recommended concentration	Type of impression material	Time of exposure	Commercial preparation
High level disinfection	Glutaraldehyde	2%	Irreversible hydrocolloid Zinc oxide eugenol Poysulfide Polyether Addition silicone	10 min 10 min 10 min 10 min	Cidex
Intermediate level disinfection	Sodium hypo-chlorite	0.5 % Or 200 – 5000 PPM	Impression compound.	10 min	Purex Clorox Chloramine T
	Iodophores	1 – 2%	Irreversible hydrocolloid, Zinc oxide Eugenol. Polysulfide' Polyether, Addition silicone	10 min	Betadine Hy-sine Ioprep
	Phenols	1 – 3%		10 min	Lysol Dettol Hi-phene
	Alcohols	60 – 90%		10 min	Isopropyl alco-hol
	Chlorhexidine	2 – 4%		10 min	Savlon
Low level disin-fection	Quaternary ammo-nium compounds Simple phenol detergents	Not recommended for impression disinfection			

Table 4. Disinfection of prosthesis, casts, wax rims, jaw relation records [19]

Stone casts	Spray or immerse in hypochlorite or iodophor
Fixed (metal/porcelain)	Immerse in gutaraldehyde
Wax rims or bites	Spray-wipe-spray with iodophors

specially designed anti-retractive valves or other anti-reflux designs is highly recommended for cross-infection as an extra preventive measure [22].

A high-volume evacuator (HVE) is a suction device that pulls a large amount of air over some time and is mounted into an evacuation system that is said to expel up to 100 cubic feet of air per minute. HVE can reduce aerosols, but clinicians should consider certain technical requirements when using HVE [23].

Sterilization and disinfection of dental instruments, materials and commonly used items prior to treatment procedure is mandatory (Table-5).

Urgent treatment procedures, aerosol-generating procedures (AGP) and non-aerosol generating procedures (NGP) will have to be managed in current situations. Urgent AGP includes preparation of abutment in previously placed implants where it is not recommended to delay prosthetic rehabilitation, Occlusal modification of a cement or screw-retained implant prosthesis where the interferences result in discomfort and/or inflammation.

Screw-retained prosthesis: Inspection of the access hole in case of loosening of the screw, Full mouth rehabilitation of a debilitated patient wherein functional rehabilitation is unachievable with a removable prosthesis.

Table 5. Sterilization and disinfection of dental instruments, materials, & few commonly used items [17]

		Steam Autoclave	Dry Heat Oven	Chemical Vapor	Ethylene Oxide	Chemical Agents	Other Methods & Comments
Burs	Carbon	-	++	++	++	-	Discard
	Steel	+	++	++	++	-	Discard
	Tungston-carbide	+	++	++	+	-	Discard
Dapen dishes		++	+	+	++	+	
Glass slabs		++	++	++	++	+	
Handpieces*		(++)*	-	(+)*	++		
Contra-angles		++	-	++	++		
Polishing wheels & disks	Garnet and cuttle	=	-	-	++	=	
	Rag	++	-	+	++	=	
	Rubber	+	-	-	++	-	
Protheses, removable		-	-	-	+	+	
Rubber dam equipment	Carbon steel clamps	-	++	++	++	-	
	Metal frames	++	++	++	++	+	
	Plastic frames	-	-	-	++	+	
Punches		-	++	++	++	+	
Stainless steel clamps		++	++	++	++	+	
Saliva evacuators, ejectors (plastic)		-	-	-	-		Discard (++) (single use/ dis-posable)
Stones	Diamond	+	++	++	++	+	
	Polishing	++	+	++	++	-	
	Sharpening	++	++	++	-	-	
Surgical instruments Stain-less steel		++	++	++	++	-	
Water-air syringe tips		++	++	++	++	-	Discard (++)

++ Effective and preferred method.

+ Effective and acceptable method.

- Effective method, but risk of damage to materials.

= Ineffective method with risk of damage to materials.

* Since manufacturers use a variety of alloys and materials in these products, confirmation with the equipment manufacturers is recommended, especially for handpiece's and their attachments.

In a case of full mouth rehabilitation, welding is required to repair a broken superstructure, Rehabilitation of an anterior region that affects the quality of life and hindering the day to day functions like speech, mastication etc.

NGP includes the following;

- Placement of prosthesis on already prepared abutments.
- Repair of the broken dentures/ prosthesis supported by implants in geriatric/ debilitated patients/ in patients affecting the function and quality of life.
- Tightening of loose overdenture attachments making the denture unstable or difficult to seat/ tightening of loose screws in a screw-retained prosthesis.
- Repair of a broken occlusal splint in cases of full mouth rehabilitation with high muscular forces.
- Re-cementation of a dislodged implant-supported cement-retained prosthesis, placement of gingival formers of previously placed implants, wherein delay in prosthetic rehabilitation can hinder functional day-to-day activities like mastication.

3.3 Modifications for implant-related procedures

Various alterations/ additions can ensure safety and increased success for implant placement's surgical procedure. Wherever possible, Hand instruments to be preferred over rotary instruments. Using surgical guides / full-guided surgery techniques will reduce radiological exposure and improve the precision to prevent failure and complication [24]. Implant placement procedures can be done at a low torque value (approximately 300 rpm) following the initial drill to decrease the aerosol generation. Using aggressive thread implants/ implant system with fewer sequential drilling systems can minimize the aerosols generated.

Gingival former should be placed at the time of surgery wherever indicated, and resorbable membranes should be encouraged to avoid a second surgical exposure reducing the number of appointments. Patients can be instructed to follow a post-procedural mouth rinse with a mouthwash containing active oxygen along with oral irrigation devices to promote healing and avoid difficulties such as peri-implantitis. Nylon and Polytetrafluoroethylene sutures can be preferred as they can be used for more extended periods and save a suture removal appointment [25].

Immediate loading should be preferred wherever indicated to minimize the number of appointments. One abutment-One-time concept can eliminate all the dis/reconnections taking place during the course of treatment and allows for immediate provisionalisation, thus reducing overall treatment time. A Screw-retained Prosthesis should be preferred in every case, as a provisional as well as a permanent restoration [26].

Angulated Screw Channel (ASC)/ Customized abutments facilitate a screw-retained restoration for any given circumstances. During provisionalisation with a screw-retained provisional restoration, filling the access hole with PTFE tape can be encouraged, avoiding composite or cement on top, thus preventing aerosol generation during removal. If any modifications have to be made in the prosthesis, it should be done outside the mouth using a low-speed rotary handpiece in an enclosed transparent chamber with a provision for suctioning minimizing the fragments generated [27].

4. Biomedical waste management

After use, the medical waste that contains disposable protective equipment should be delivered promptly to the medical center's temporary storage facility. The reusable tools and materials should be cleansed, sterilized, and carefully preserved in consent with the Protocol for the Disinfection and Sterilization of Dental Instruments. Medical and domestic waste generated by treating suspected or confirmed cases of COVID-19 is considered a medical infectious waste. Double-layer, yellow clinical waste bags should be used with a "gooseneck" knot. The surface area of the waste bags should be labelled and disposed of according to medical waste disposal requirements. All the biohazardous waste should be disposed of by government guidelines [28].

5. Prophylactic care

The National Task Force for COVID19 constituted by Indian Council of Medical Research recommended hydroxychloroquine for treatment of COVID-19 for high-risk cases. Asymptomatic health care workers involved in the care of suspected or confirmed cases of COVID-19: 400mg twice a day on day1, followed by 400mg once weekly for next 7 weeks to be taken with meals.

5.1 Contraindications

The drug is not recommended for prophylaxis of children under 15 years of age.

In persons with a known case of retinopathy, known hypertensive to hydroxychloroquine, 4-aminoquinoline compounds [29].

Hydroxychloroquine therapy is closely associated with reduced viral load/disappearance in patients with covid-19, and its effect is verified by azithromycin However, the drug system is not FDA approved, and work is still ongoing [30].

6. Conclusion

As COVID-19 has altered the lifestyle all over the globe. Considering the routes of COVID-19 transmission, even we as dental professionals have to alter and follow standard protocols for preventing the spread of infection. Dentists must have thorough knowledge about the signs and symptoms and follow strict infection control measures in such clinical situations. Without the potential to prevent community infection, prevention of health care transmission will remain a challenge.

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