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Focus and Scope

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An *in vitro* study to evaluate and compare the remineralizing potential among Casein Phosphopeptide-amorphous Calcium Phosphate (CPP-ACP) with fluoride and surface pre-reacted glass (S-PRG) fillers using quantitative analysis

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ABSTRACT

Background: Early treatment of white spot lesions is essential to prevent the progression of the lesion.

Aim: To evaluate and compare the remineralizing potential of CPP-ACP with fluoride (Casein Phospho Peptide-Amorphous Calcium Phosphate) and S-PRG fillers (Surface Pre reacted glass fillers) using atomic absorption spectroscopy and colorimetric method.

Materials and methods: Forty sound human premolars were used in this study. They were divided into two groups (A & B), consisting of 20 samples in each. White spot lesions (WSLs) were established on the window (4x4 mm^2) created on the buccal surfaces of the samples. Samples in group A were treated with casein phosphopeptide amorphous calcium phosphate (CPP-ACP) with fluoride, those of group B were treated with S-PRG Fillers. The sample teeth were immersed in a demineralizing solution for 4 days. All the samples were subjected to loss of mineral content (wt %), i.e., calcium, using atomic absorption spectroscopy and phosphorus using the colorimetric method.

Results: Statistical analysis was performed using one-way analysis of variance, Tukey's and paired t-tests. Group A exhibited the highest remineralizing potential, followed by Group B. Statistically, a significant difference (p=0.001) was observed between the two groups.

Conclusion: There was a significant difference in remineralizing potential of CPP-ACP with fluoride and S-PRG Fillers. CPP-ACP with fluoride appears to be an effective technique in the remineralization of white spot lesions.

1. Introduction

Dental caries is one of the oldest diseases since mankind, and it is often described as a "pandemic" disease due to its high prevalence [1]. Signs of the caries process are the first molecular change in the apatite crystals of the tooth, to a visible white spot lesion (WSL), or even eventual cavitation. It occurs as a result of cyclic demineralization and remineralization of enamel due to altered pH levels. Demineralization is defined as the process by which minerals (calcium and phosphate ions) are removed from the tooth. Demineralization occurs at low

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pH when the oral environment is saturated with mineral ions, compared to a tooth's mineral content. In contrast, remineralization of tooth enamel is defined as the process whereby calcium and phosphate ions are supplied from an external source to promote ion-deposition on demineralized enamel crystals to produce mineral gain [2].

WSLs occur due to the breaching of the enamel layer by the pathogenic bacteria. These bacteria produce organic acids, resulting in leaching out numerous amounts of calcium and phosphate ions. These ions may or may not be replaced naturally by the remineralisation process [3]. The White Spot Lesions (WSL) are usually formed in patients who have undergone fixed orthodontic treatment. Other factors include xerostomia, high caries index, fluorosis and developmental hypoplasia. The white spot is most easily observed when the enamel is thoroughly dried. Therefore, the treatment of such lesions should improve the aesthetics and prevention of caries progression [4].

The first line of management of white spot is remineralization. The development of white spot lesions can be slowed or even arrested by various procedures such as removal of etiologic factors like maintaining oral hygiene and use of remineralizing agents such as topical fluorides, CPP-ACP, Bioactive glass, ACP technology, Tri-calcium phosphate, Xylitol, Icon, SDF and S-PRG fillers [5].

Calcium phosphate remineralization technology based on CPP-ACP with fluoride (Mi Varnish) has been recently developed, where CPP stabilizes high calcium and phosphate ions concentrations, together with fluoride ions, at the tooth surface by adhering to pellicle and plaque, thus preventing demineralization and enhancing remineralization. In S-PRG filers, a pre-reacted glass-ionomer technology is used. This technology forms a stable glass-ionomer phase in fillers by a pre-reacting acid-reactive glass containing fluoride with polyacrylic acid in the presence of water [6].

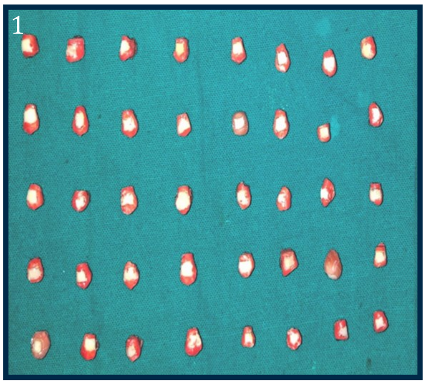
There is a lack of information regarding comparison among these remineralizing agents. Hence, this *in-vitro* study was designed to evaluate the remineralizing potential of CPP-ACP with Fluoride and S-PRG fillers in extracted human permanent teeth using atomic absorption spectroscopy and colorimetric method.

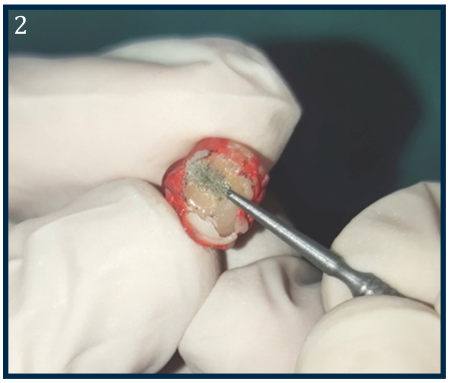
2. Materials and methods

In the present *in-vitro* study sound premolars, indicated for orthodontic extractions were included in the study. The extracted teeth with caries, morphological variations, fractured crowns, fluorosis and hypoplastic lesions were excluded. A total of 40 sample teeth were collected. The soft tissue deposits and calculus were removed from the teeth with a surface scaler. The crowns were resected from the roots. Collected sample teeth were coated with nail varnish (Colorama nail varnish, Maybelline), leaving a 4×4 mm^2 window on the buccal surface. Then, the 40 teeth samples were divided into groups such as Group A and B, which comprises 20 teeth each. Each teeth sample was immersed in demineralizing solution (composed of 1050ml of distilled water, 2g of calcium chloride, 2.2g of potassium hydrogen orthophosphate, 3g of acetic acid, 56 g of potassium hydroxide) for four days to create an artificial white spot lesion (Figure 1). The pH of the solution was maintained at 3.5.

After four days, the sample teeth were removed from the solution. On the artificially created white spot lesion of teeth samples, CPP-ACP with fluoride (GC, MI Varnish, India) was applied in Group A, and S-PRG Fillers (Shofu Inc., Kyoto, Japan) were applied in group B (Figures 2 and 3, respectively).

Post remineralizing solution application, the samples were immersed in the demineralizing solution for 4 days. Then, all the samples were tested for loss of mineral content (wt%), i.e., of calcium using atomic absorption spectroscopy (AAS) and phosphorus using the colorimetric method. AAS was used to perform trace elemental analysis which is important for variety of reasons. AAS has high sensitivity, often exhibiting detection limits at parts per trillion level and high selectivity due to the presence of extremely narrow spectral line. The technique is capable of analysing for multiple elements simultaneously and can easily be automated. Concentrations of atoms are measured by absorption or emission of specific wavelengths of radiation. As the quantity of energy put in to flame is known, the quantity remaining at the outer end can be measured. Whereas, calorimetric techniques are useful in the analysis of a wide range of substances. There is often a direct relationship between the intensity of the colour of a solution and the concentration of the coloured component (the analyte species) which it contains. This direct relationship forms the basis of the





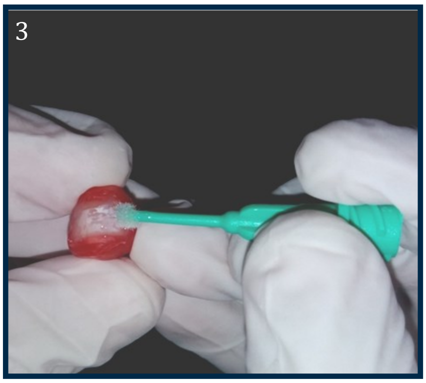


Figure 1. Samples showing white spot lesions.
Figure 2. Application of CPP-ACP with fluoride.
Figure 3. Application of S-PRG Fillers.

colorimetric technique. The loss of ions in groups A and B were recorded in microgram/deciliter (μg/dl).

The obtained data were subjected to statistical analysis using SPSS software, Version 22.0, USA. Data were summarised as Mean±SE (standard error of the mean). Pre and post groups were compared by paired t-test. Pre- and post-change (pre-post) outcome measures of two groups were compared by one-factor analysis of variance (ANOVA). The significance of the mean difference between the groups was done by HSD (honestly significant difference) post hoc test after ascertaining normality by and homogeneity of variance between groups by a two-tailed (α=2) test and $p<0.05$ was considered as statistically significant.

3. Results

The obtained data of remineralization of calcium and phosphorous in both the groups are given in Tables 1 and 2, respectively. Comparing Ca:P, the teeth applied with CPP-ACP with fluoride showed higher remineralization potential than those applied with S-PRG Fillers (Table 1 and 2, respectively). In addition, one-way ANOVA showed a significant difference (p=0.001) between the groups in the remineralization of both Calcium and Phosphorous (Tables 1 and 2, respectively).

After treating with CPP-ACP with fluoride (Group A) and S-PRG fillers (Group B), the teeth showed a decrease in the mean Calcium and Phosphorous ion levels (tables 3 and 4). This decrease in Calcium and Phosphorus ion levels was higher or significant in Group A compared to Group B. (Tables 3 and 4). Tukey t-test showed significantly different and higher remineralization in Calcium and Phosphorus of Group A compared to Group B (S-PRG Fillers). A decreased calcium and Phosphorus ions loss were observed after treating using CPP-ACP with fluoride, which showed a better demineralization preventing mechanism. This indicates increased remineralization potential of CPP-ACP with fluoride than S-PRG Fillers.

4. Discussion

Enamel white spot lesions are one of the common problems encountered by the dental practitioner and also a major esthetic concern [7]. The treatment of these white spot lesions should aim to assess the lesion progressions and improve the esthetics by eliminating the opacity [3]. Diminishing opacity caused by white spot lesion can be achieved by various non-invasive approaches, including the use of remineralizing agents. In this regard, fluoride varnishes have been the standard of practice for the professional application of fluoride [8]. Arends and Tencate (1981) [9] observed that salivary remineralization of enamel by topical fluoride had been shown to give rise to predominantly surface remineralization. Thus, achieving substantial remineralization of enamel is a big challenge.

The retention of fluoride on enamel and subsurface lesion remineralization depends on the availability of calcium and phosphate ions, and combining calcium, phosphate and fluoride ions can lead to loss of bioavailable fluoride ions. To overcome this incompatibility, recently, the combination of CPP-ACP with fluoride have been introduced as dental varnish (Mi Varnish) [10]. Kariya *et al.* (2004) [11] demonstrated

Table 1. Remineralization of calcium (µg/dl) of two groups (ANOVA)

Groups	Remineralization (Mean ± Standard Error)	F-value	Significance (p-value)
Group A (CPP-ACP)	2.14 ± 0.29	12.25	0.001
Group B (S-PRG)	1.81 ± 0.37		

Table 2. Remineralization of phosphorus (µg/dl) of two groups (ANOVA)

Groups	Remineralization (Mean ± Standard Error)	F-value	Significance (p-value)
Group A (CPP-ACP)	1.73 ± 0.13	26.59	0.001
Group B (S-PRG)	1.17 ± 0.12		

Table 3. Pre-test and post-test calcium ion levels (Mean ± Standard Error) of two groups

Groups	Pre-test (n=20)	Post-test (n=20)	Mean change (Pre-Post)	t-value	Significance (p-value)
Group A	45.07 ± 0.73	42.93 ± 0.72	2.14 ± 0.29	7.28	0.001
Group B	46.78 ± 0.58	44.98 ± 0.55	1.81 ± 0.37	4.82	0.001

Table 3. Pre-test and post-test phosphorus (µg/dl) of two groups (Mean ± Standard Error).

Group	Pre-test (n=20)	Post-test (n=20)	Mean change (Pre-Post)	t-value	Significance (p-value)
Group A	41.71 ± 0.62	39.98 ± 0.59	1.73 ± 0.13	13.21	0.001
Group B	40.49 ± 0.59	39.33 ± 0.56	1.17 ± 0.12	9.75	0.001

the improved acid-resistant effect of enamel by applying fluoride added CPP-ACP [11]. Studies affirmed that although the application of CPP-ACP often achieves the remineralization of superficial white spot lesions, this technique showed unsatisfactory results with respect to old and/ or deep lesions as well as to obtain aesthetics [10].

Newly introduced material S-PRG Fillers offers a more conservative approach. These S-PRG Fillers have the ability to release and recharge fluoride ions, and then they can achieve sustained fluoride release, which is acidity dependent. It releases ions like Sr, B, Na and F when it comes in contact with water or acidic solution [12].

Hence, the present study was conducted to evaluate the remineralizing potential of CPP-ACP with fluoride and S-PRG Fillers. The pH cycling protocol followed in the present study was as described by Babu *et al.* (2018) [8] because this model stimulates the *in-vivo* caries risk condition. The cycle of demineralization and remineralization was completed by immersing the sample teeth in the demineralizing solution, followed by applying the remineralizing agent. In the present study, the loss of ions was estimated by AAS and colorimetric method [13]. As observed in the current study, Ali A Assiry (2019) [13] has shown the loss of calcium and phosphorus ions on immersing in a demineralizing solution.

In the present study, the two remineralising agents were able to remineralise the white spot lesions. The teeth specimens treated with CPP-ACP with fluoride (Group A) showed the highest remineralising potential compared to the teeth treated with S-PRG Fillers (Group B). In tandem with the current study, Wokamatsu *et al.* (2018) [12] concluded that the application of PRG coat to WSLs is a more conservative approach. PRG barrier acts as an adjunct to a periodic fluoride application, promoting a beneficial remineralisation effect on WSLs [12].

Higher fluoride concentrations can cause rapid mineral precipitation on the enamel surface and obturation of the surface enamel pores that connect with the underlying demineralised lesion. Anticariogenic potential of CPP has been attributed to the ability of CPP to localise ACP at the tooth surface. CPP maintains supersaturation of calcium and phosphate ions, thus modulating the bioavailability of calcium phosphate levels and finally leading to an increase in remineralisation. Thus, CPP-ACP has shown to reduce demineralisation and enhance remineralisation of the enamel subsurface carious lesions. CPP-ACP has a remineralising effect on artificial subsurface enamel lesions and the remineralisation effect increased with an increase in the usage of the paste on the 1st, 5th and 10th day, respectively. This could be the reason for the highest level of remineralisation in the sample of Group A (CPP-ACP) with fluoride [14].

The ability to release and recharge fluoride ions is acidity dependent, and under external force, these carious lesions treated by S-PRG Fillers may collapse and lead to cavitation [15,16]. This could be the reason for the low level of remineralisation in the samples treated with S-PRG Fillers.

The present study found out that the mean Calcium and Phosphorus ions level decreased after the treatment. The decrease in Calcium and Phosphorus ions level was higher or significant in group A than in group B. Higher decrease in Calcium and Phosphorus ions loss post-treatment denotes that Group A with fluoride prevents demineralisation better.

This is an *in-vitro* study and does not imitate the diverse environment present in the oral cavity. Various factors which may affect dental caries development, such as the dynamics of the caries process, saliva, antimicrobial proteins and enzymes, are challenging to achieve in an in-vitro state. Therefore, further *in vivo* studies are needed to substantiate the effect of the remineralising agents used.

5. Conclusion

The teeth samples applied by the CPP-ACP with Fluoride exhibited better remineralisation than the teeth applied with S-PRG Fillers.

There was reduced calcium and phosphorus ions loss after remineralisation in Group A by indicating a better remineralising potential than Group B.

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Original Article International Journal of Dental Materials 2021; 3(3) **ISSN:2582-2209**

In vitro hydroxyapatite formation of a tetracalcium phosphate and anhydrous dicalcium phosphate based dentine desensitiser: TRIS buffer vs artificial saliva

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ABSTRACT

Background: Calcium phosphates (CPs) form hydroxyapatite (HA) in physiological solutions. These are commonly used to treat dentine hypersensitivity (DH) as they mimic the mineral composition of the natural tooth.

Aim: The present study aims to characterise the apatite formation ability of a commercially available calcium phosphate Teethmate™ (TM) in physiological-like media.

Materials and methods: In this study, 4mm (D) x 6mm (L) cylindrical samples of TM were produced and immersed in tris(hydroxymethyl)aminomethane (TRIS) buffer (pH: 7.3) and artificial saliva (AS) (pH: 6.5) for up to 24 hours. This was followed by characterisation of the samples after immersion using ^{31}P magic angle - nuclear magnetic resonance spectroscopy (MAS-NMR), X-ray powder diffraction (XRD) and dentine treated with the material using scanning electron microscopy (SEM).

Results: ^{31}P MAS-NMR and XRD analyses revealed that samples immersed in TRIS buffer solution formed hydroxyapatite within approximately 6 hours of immersion. This change was observed at around 12 hours for samples soaked in AS. The pH of the immersion media increased with increasing immersion time. SEM analysis showed a transitional phase formation of structures exhibiting plate-like morphology.

Conclusion: This study shows that TM converts to HA in vitro rapidly and provides an effective option for the treatment of dentine hypersensitivity.

1. Introduction

Dentine Hypersensitivity (DH) is a significant problem caused by exposed dentinal tubules. DH is characterised by a short sharp pain in response to thermal, tactile, evaporative, osmotic or chemical stimuli [1]. Pathologic exposure of dentinal tubules results from the dissolution of enamel or denudation of the root surface. DH can develop into pulpal inflammation as a result of an invasion of dentinal tubules by oral *Streptococci* and *P. Gingivalis* and can present the clinical features of reversible pulpitis [2]. So, early diagnosis and management is critical in the prevention of DH.

There are three main theories, which explain dentinal hypersensitivity, odontoblastic transduction theory [3], neural theory [4] and hydrodynamic theory [5].

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The prevalence of DH in the adult population ranges from 4 to 57% [6].

DH is treated by blocking exposed dentinal tubules with desensitising agents, such as soluble fluorides, oxalate and calcium phosphates (CPs), which reduce dentine permeability *in vitro* [6]. CPs are primarily used as bone graft substitutes and have seen significant developments in recent years, showing clinical successes and interesting biomineralisation properties [7]. CPs cements are particularly useful for the treatment of DH because in addition to reducing dentine permeability, they also chemically occlude dentinal tubules by forming hydroxyapatite (HA, $[Ca_{10}(PO_4)_6(OH)_2]$) and directly bonding to the tooth. CPs-based materials allow dentinal tubules to be sealed with a material naturally present in the tooth structure.

A commercially available desensitising agent Teethmate™ combines tetracalcium phosphate (TTCP, $[Ca_4(PO_4)_2O]$) and anhydrous dicalcium phosphate (calcium hydrogen phosphate) (DCPA, $CaHPO_4$) (Kuraray, Noritake Dental Inc., Tokyo, Japan). TTCP is also known as hilgenstockite, which was discovered by G. Hilgenstock in 1883 [8]. Once mixed with water or immersed in body fluids, these components break down to Ca^{2+} and PO_4^{3-} via a hydrolysis process resulting in nucleation and crystallisation of HA.

In vitro dentine permeability of Teethmate™ was previously studied, and it was found that this material can occlude dentinal tubules and reduce dentine permeability by 30 to 50% [9, 10]. The present study aims to understand the apatite formation ability of the material *in vitro* in artificial saliva (AS) and tris(hydroxy methyl)aminomethane (TRIS) buffer. TRIS buffer in this study provides an ion-free physiological pH medium to analyse the formation of apatite due to Ca^{2+} and PO_4^{3-} release from the material itself. Artificial saliva (AS) simulates the acidic environment in the oral cavity. These two combined give a comparison of the expected behaviour in vivo.

2. Materials and methods

2.1. Preparation of TRIS buffer solution

TRIS buffer solution was prepared by dissolving 15.090 g tris (hydroxymethyl) aminomethane (purity: ≥ 99.8%, Sigma-Aldrich, St. Louis, MO, USA) in Ca. 800 mL deionised water, adding 44.2 mL 1 M hydrochloric acid (purity: ACS reagent grade, Sigma-Aldrich, St. Louis, MO, USA), heating to 37°C overnight, adjusting the pH to 7.30 with 1M hydrochloric acid using a pH meter (Oakton, EUTECH Instruments, Malaysia) and filling to a total volume of 2000 mL with deionised water. TRIS buffer solution was kept at 37°C in an incubator.

2.2. Preparation of artificial saliva

The artificial saliva was prepared using potassium chloride (2.236 g/L), potassium dihydrogen phosphate (1.361 g/L), sodium chloride (0.759 g/L), calcium chloride dihydrate (0.441 g/L), mucin (2.200 g), and sodium azide (0.2 g) (purity: analytical grade, Sigma-Aldrich, St. Louis, MO, USA). The reagents were weighed using an electronic weighing scale and dissolved in 800 mL of deionized water. The pH was adjusted to 6.5 with potassium hydroxide.

2.3 Preparation of cement samples

To determine the apatite formation ability of the material, 4mm (D) X 6mm (L) cylinders (as given in ISO 9917-1:2007) of TM were produced (by mixing the reagents according to manufacturer’s instructions and letting them set in stainless steel moulds for 1 hour at 37°C. Produced TM samples were then immersed in 10 mL of TRIS buffer and artificial saliva for 15, 30 and 45 min, 1, 3, 6, 9, 12, 15, 18, 22 and 24 hours. After each time interval, the samples were collected, blot-dried and stored in the fridge until further analysis.

2.4 Preparation of dentine discs

Caries-free teeth were embedded in impression compound and were then sectioned mid-coronally using Accutom-5 (Struers A/S, Ballerup, Denmark) to produce 1 mm dentine discs.

2.5 ^{31}P magic angle spinning – nuclear magnetic resonance spectroscopy

^{31}P MAS-NMR analyses were carried out on a Bruker Avance 600 MHz (Bruker Corporation, Billerica, MA, USA) spectrometer at a resonance frequency of 242.9 MHz in a 4 mm (outer diameter) rotor at a spinning speed of 12 kHz. Each spectrum is a sum of 16 scans. Spectra were referenced to 85% H_3PO_4 (orthophosphoric acid, 0 ppm).

2.6 X-ray powder diffraction

The samples collected after each time point were analysed using an X'Pert-PRO diffractometer (PANalytical D.V., Almelo, Netherlands). Diffraction patterns were collected from 5° to 75° 2θ. The Cu K_α X-ray frequency was λ_1=1.54059Å.

2.7 pH measurement

The pH of the immersion media was measured using a pH meter (Oakton, EUTECH Instruments, Malaysia).

2.8 Scanning electron microscopy

Samples were mounted after being dried on aluminium stubs via a self-adhesive carbon tape and were then coated using a sputter coating machine with a conductive material. Samples were analysed using an FEI Inspect F (FEI Company, Hillsboro, OR, USA).

3. Results

^{31}P MAS-NMR results presented in Figure 1 shows three spectra, t-0 (powder) one taken at 30 sec and one at 45 min after mixing with water. The peak positions are 4.8 ppm, 3.7 ppm, -0.3 ppm and -1.4 ppm with peak integrals of 1, 0.93, 0.80 and 2.51, respectively. ^{31}P MAS-NMR results shown in Figure 2(a) (TRIS buffer) and Figure 2(b) (Artificial saliva) shows how the phosphorus environment changes with increasing immersion time.

During earlier time points, the peaks are broader, which shows that the material is poorly crystalline. With increasing duration in the selected media, the peaks associated with the phosphorus environment shift upfield and narrow down, which shows that the material is becoming more crystalline because the signal is coming from more magnetically equivalent sites.

X-ray diffraction analyses of the cements soaked in TRIS buffer shown in Figure 3(a) shows how the material gradually transforms to HA. Both, TTCP and DCPA phases can be observed at one and three hours. Similar results are presented in Figure 3(b), where samples immersed in artificial saliva show X-ray scattering from TTCP, which gradually transforms to HA. DCPA at selected time points is not observed in AS. DCPA shows much higher solubility (Ksp $10^{-6.70}$) than TTCP (Ksp 10^{-38}) [11].

The results presented in Figure 4(a) and Figure 4(b) shows how the pH increases in both media with increasing immersion time and reaches a cut-off point at around 9 hours in TRIS buffer and at around 15 hours in AS where there are no further increases.

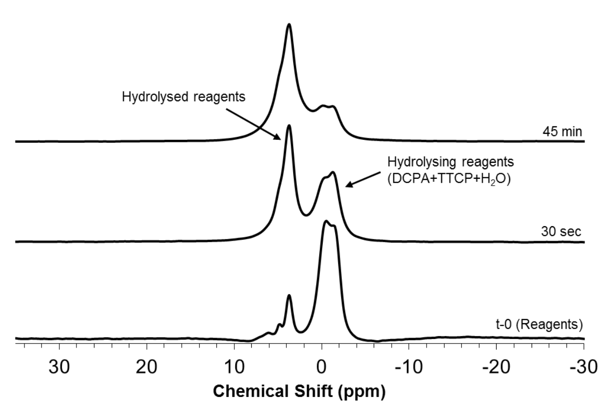

Figure 1. ^{31}P MAS-NMR spectra of the reagents mixed with water at 30 seconds and 45 minutes.

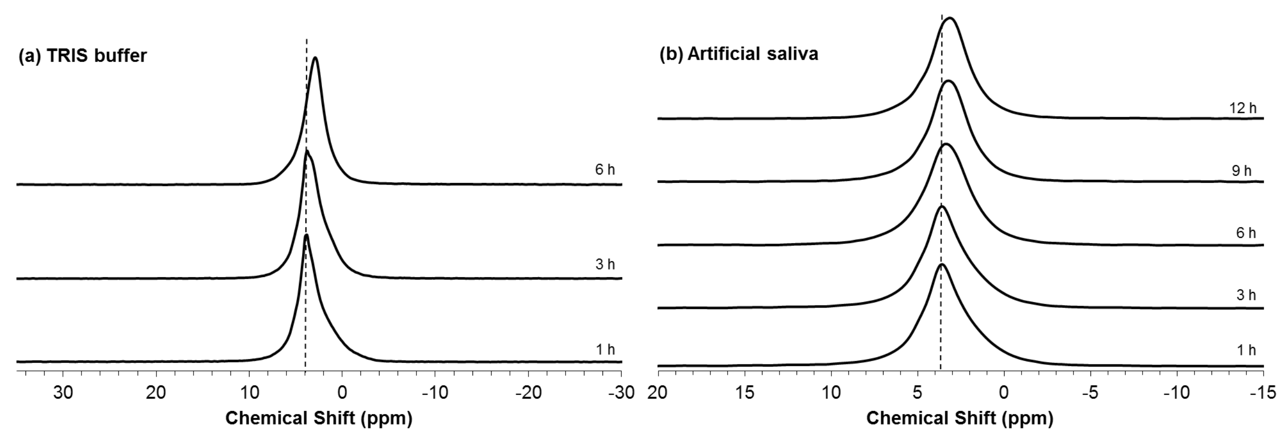

Figure 2. ^{31}P MAS-NMR spectra of cements immersed in (a) TRIS buffer solution (1, 3 and 6 hours); (b) artificial saliva (1, 3, 6, 9 and 12 hours).

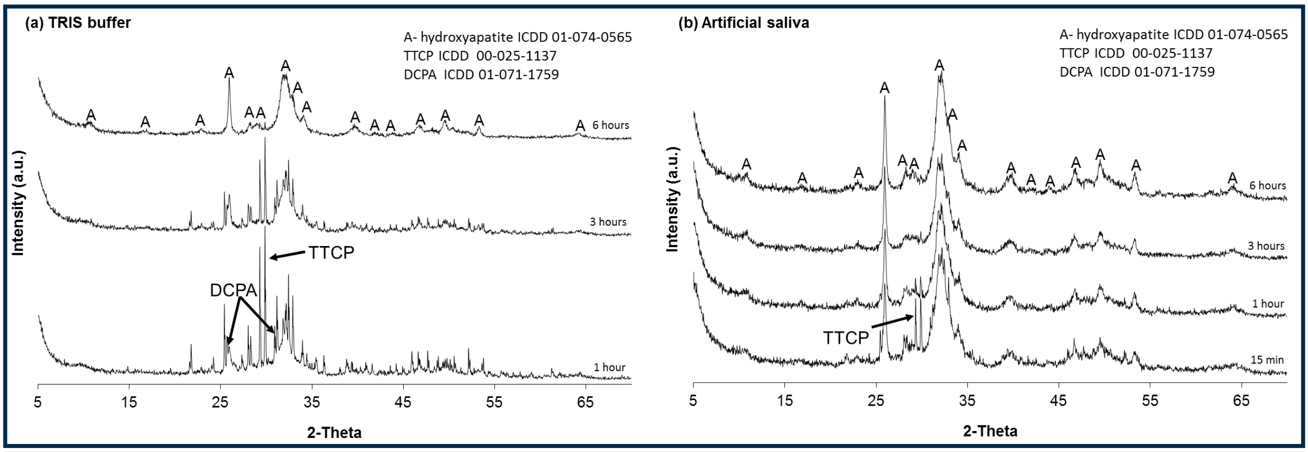

Figure 3. X-ray diffraction patterns of cements immersed in: (a) TRIS buffer solution (1, 3 and 6 hours); (b) artificial saliva (15 min, 1, 3 and 6 hours).

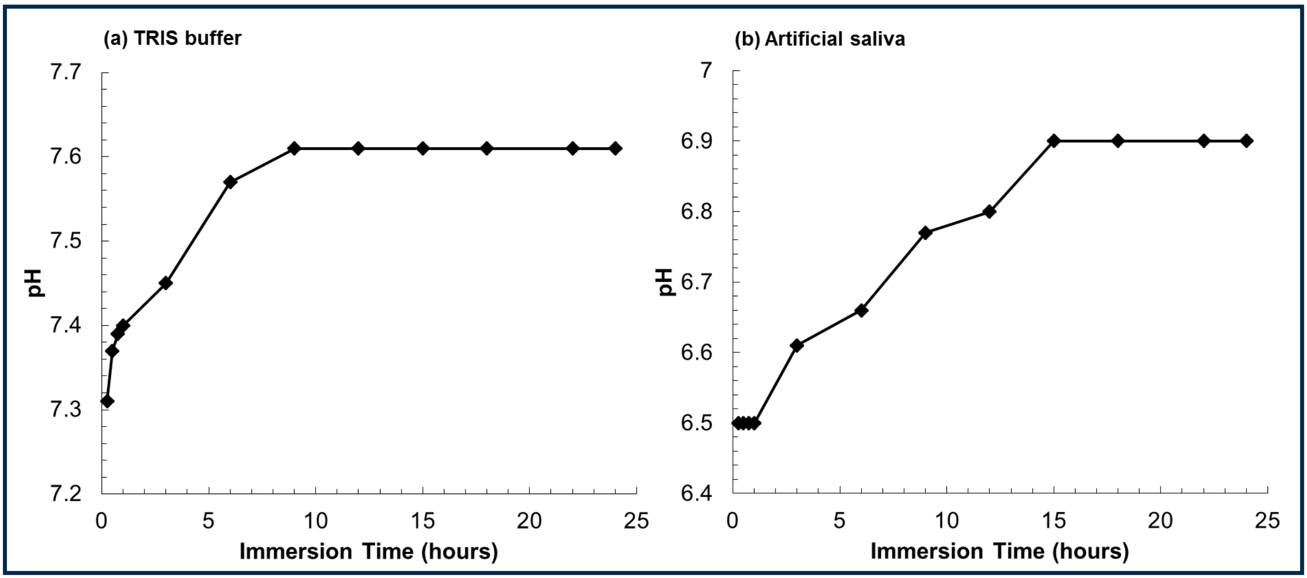

Figure 4. pH of the solutions with cement samples: (a) TRIS buffer solution; (b) artificial saliva; time: 15, 30 and 45 minutes, 1, 3, 6, 9, 12, 15, 18, 22 and 24 hours.

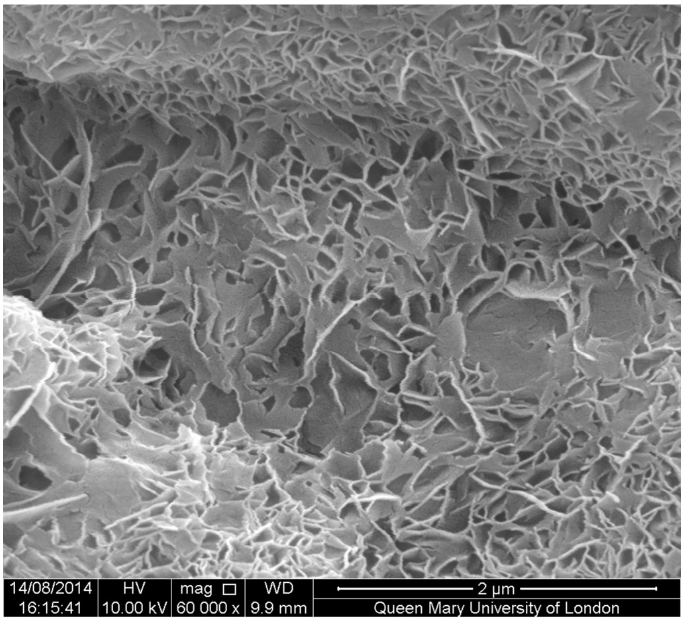

Figure 5. Scanning electron micrograph showing dentine surface treated with Teethmate™ (one hour in artificial saliva).

Scanning electron micrograph (Figure 5) of a dentine disc treated with the material and immersed in AS for one hour shows that after application, the material exhibits plate-like morphology (Figure 5).

4. Discussion

The occlusion of exposed dentinal tubules is necessary to prevent both dental pain and potential tooth infection. *In vivo* and *in vitro* synthesis of apatite is a highly complex multi-phase hydrolysis-nucleation-crystallisation process. It has been shown that the formation of HA begins with the nucleation of $Ca(HPO_4)_3^{4-}$ complexes which aggregate, take up additional calcium ions and result in the formation of $Ca_2(HPO_4)_3^{2-}$ post-nucleation aggregates, which form the basis of octacalcium phosphate (OCP, $Ca_8H_2(PO_4)_6{\cdot}5H_2O$) and HA structure [12]. OCP is considered a precursor phase in apatite formation in vivo and it is also a constituent of the human dental calculus, among other mineral phases, such as brushite ($CaHPO_4{\cdot}2H_2O$) and whitlockite (β-$Ca_3(PO_4)_2$) [13]. Using the classical crystallisation theory, it has been calculated that OCP phase formation is also a kinetically favourable process in physiological-like media [14]. The six non-equivalent sites of OCP are generally categorised into two groups, PO_4^{3-} (P1-P4) and HPO_4^{2-} (P5, P6). OCP can be described by an alternating layer structure of an apatite layer (P1-P4) and a hydrated layer (P5, P6). ^{31}P MAS-NMR peaks for pure OCP are observed at 3.7, 3.3, 2.0 and -0.2 ppm and are assigned to P1, P2/P4, P3 and P5/P6, respectively [15]. The signal at 2.0 ppm (P3) is assigned to the PO_4^{3-} at the junction of the apatitic and hydrated layers.

^{31}P MAS-NMR signals (-0.3, -1.4 ppm) from the reagents mixed with water (Figure 1) reduce in intensity and result in the development of new signals downfield (4.8, 3.7 ppm), which shows that TTCP and DCPA are reacting with water. The spectra shown in Figure 1 lack PO_4^{3-} (P3), which shows that the material does not contain pure OCP. The OCP phase may exhibit a dynamic structure when transitioning to HA with one species becoming dominant over another, which is evident from major environments observed from ^{31}P MAS-NMR (Figure 2) after immersion at around 3.7, 3.5 and 3.3 ppm preceding HA formation. These gradual changes in the chemical shift are also indicative of ongoing hydrolysis and reducing interatomic distances between phosphorus and calcium. It is known that OCP has a hydrated structure. Tseng *et al.* (2006) [16] demonstrated via $^{31}P\{1H\}$ cross-polarisation NMR experiments that water molecules enter the OCP structure during HPO_4^{2-} hydrolysis:

$$HPO_4^{2-} + OH^- = PO_4^{3-} + H_2O$$

Therefore, the signal (P3) may develop after the pH increases for the HPO_4^{2-} and OH^- to react. During further hydrolysis, the water molecules disassociate, which with the addition of calcium ions results in a HA structure.

X-ray diffraction results in Figures 3(a) and 3(b) show gradual conversion of the prepared material to HA. When immersed in TRIS buffer solution, the material formed hydroxyapatite in approximately 6 hours with a transient OCP between one and three hours. The conversion to HA phase was slower in artificial saliva where the material formed calcium-deficient HA at approximately 12 hours, with a transient OCP phase somewhere between approximately one and nine hours. The hydrolysis of the reagents was more rapid in AS than in the TRIS buffer as a result of the differences in the pH (AS: 6.5, TRIS: 7.3). The more rapid apatite formation observed in the TRIS buffer solution can be attributed to higher pH of the solution, which is a favourable factor in apatite formation [17]. This cannot be generalised and does not apply to bioactive glasses, which are used to regenerate bone, such as the Bioglass® 45S5 where at lower pH the material shows faster ion release, which facilitates a very rapid formation of HA (3 hours at pH 5.0 and 6 hours at pH 7.3) [18].

The conversion of DCPA and TTCP to HA can be observed from the reduction of intensities of the principal X-ray diffraction peaks associated with both phases. The material is engineered with an apatitic Ca to P ratio of 1.67 to facilitate stoichiometric and rapid apatite formation as described in equation 1 (Eq. 1).

$$Ca_4(PO_4)_2O + CaHPO_4 \rightarrow Ca_5(PO_4)_3(OH) \text{ (Eq. 1)}$$

However, it is notable that TTCP and DCPA exhibit different solubilities, so the reagents may not initially react in synergy.

The pH (Figure 4(a)) with samples in TRIS buffer reaches a cut-off point at around 9 hours with a pH of 7.6 where there are no further increases in the pH and this is the point at which the material is fully reacted and displays X-ray scattering characteristic to nanocrystalline HA. The pH of the samples immersed in AS (Figure 4(b) also show a gradual increase until it reaches a cut-off point at 15 hours with a pH of about 6.9, which shows that the material is fully reacted with no reagents remaining. These changes in the pH occur as a result of the production of hydroxide ions during the hydrolysis of TTCP as described in equation 2.

$$Ca_4(PO_4)_2O + H_2O \rightarrow 4\ Ca^{2+} + 2\ PO_4^{3-} + 2\ OH^- \text{ (Eq. 2)}$$

Bioactive glasses with a high phosphate content developed by Mneimne *et al.* (2011) [19] show similar apatite formation ability in TRIS buffer (pH: 7.3) where apatite was detected at approximately 6 hours after immersion. The bioactive glasses synthesised by Mneimne *et al.* (2011) [19] showed the formation of acid-resistant fluorapatite instead of HA, which from a clinical perspective can provide longer protection under acidic conditions found in the oral cavity.

It is also notable that HA shows higher crystallinity in TRIS buffer than in AS. The ^{31}P MAS-NMR results presented in Figure 2 show HA is observed at approximately 3.0 ppm at 6 hours (assigned to HA) in TRIS buffer and at approximately 3.1 ppm (assigned to substituted calcium-deficient HA) at 12 hours in AS. Carbonate or hydrogen phosphate substitution occurs in the presence of monovalent cations. Carbonated calcium-deficient apatite is also naturally found in enamel and dentine, which shows that monovalent salivary components take part in biological hydroxyapatite formation, which results in the formation of a less crystalline calcium-deficient form of HA. AS used in the present study is saturated with monovalent cations, such as K^+ and Na^+. Tas and Aldinger (2005) [20] studied apatitic calcium phosphates formed in Na-K rich solutions and suggested that the binding of Na^+ and K^+ at the divalent Ca sites of calcium phosphates in the presence of these cations may lead to the formation of vacancies at OH^- sites which then renders the material to be more prone to CO_3^{2-} substitutions at the OH^- and PO_4^{3-} sites.

Figure 5 shows an SEM of Teethmate™ precipitate (one hour in AS) exhibiting plate-like morphology. This suggests that the material undergoes HA crystallisation via an octacalcium phosphate route. Similar morphological features were also reported by Thanatvarakorn *et al.* (2013) [21] where investigators suggested that after immersion in AS the material formed was a combination of HA with transient-formed OCP. The average particle size of the material is 2.35μm (Supplementary Data), which is adequate to occlude dentinal tubules that have a diameter from 0.9μm (peripheral dentine) to 2.5μm (root dentine) [22].

Huang *et al.* (2016) [23] reported that strontium (Sr) can increase the potential of dentine regeneration. It was found that Sr can significantly influence the proliferation, odontogenic differentiation and mineralisation of human dental pulp stem cells (hDPSCs) *in vitro*, likely via the calcium-sensing receptor pathway. Thus, incorporation of a strontium phosphate or a strontium -containing bioactive glass additive in this material may induce a regenerative response. Keeping in view the limitations of the study, for further work it will be useful to analyse the samples using more advanced 2D CP/MAS experiments to elucidate the structure of the substituted sites.

5. Conclusion

The results presented in this study show that HA formation of a commercially available desensitising agent Teethmate™ is dependent on the composition and the pH of the immersion media. It was found that HA formation was favoured in a solution having a neutral pH as opposed to a solution with an acidic pH. The presence of monovalent cations and a low pH resulted in delayed and substituted HA formation. This may have clinical implications and may require patients to avoid eating and drinking soon after treatment.

Ethical approval and consent to participate: Caries-free extracted mandibular and maxillary molars were collected from the tooth bank with an approval from Queen Mary Research Ethics Committee QMREC 2011/99.

Conflicts of interest: Authors declared no conflicts of interest.

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Supplementary Data

Particle size analysis of Teethmate^{TM} powder component (μm)

Sample	1	2	3	STDV	Average
D[v,0.9]	8.11	8.83	11.3	1.67	9.41
D[v,0.1]	0.39	0.41	0.36	0.03	0.39
D[v,0.5]	2.34	2.33	2.38	0.03	**2.35**
D[4,3]	3.58	4.03	5.36	0.93	4.32
D[3,2]	1	1.03	0.96	0.04	1.00

The samples (*N=3*) were dispersed in deionised water and analysed using laser diffraction (Malvern 2000, Malvern Instruments, Worcestershire, UK).

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Evaluation of different custom angulated elastic glass fibre post on fracture resistance of maxillary central incisor: an *in vitro* study

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ABSTRACT

Background: Restoring Endodontically treated teeth (ETT) can be challenging for most dentists, particularly when a significant tooth structure is lost. Depending on the coronal tooth structure remaining and the technique used (direct or indirect), endodontic anchorage can involve either a cast post and core or a prefabricated post.

Aim: This study aimed to investigate the effect of different custom angulated, i.e.,0°,5°,10°,15° elastic glass fibre post (Everstick post) on fracture resistance of maxillary central incisors.

Materials and methods: Forty A total of forty-eight single-rooted maxillary central incisors were selected. All the samples were decoronated 2mm above the Cemento-Enamel Junction and endodontically treated. Post-space preparation was done for all the samples using peesoreamers ranging in size from 1-3. The samples were then randomly divided into four groups (n=12) based on the different angulations, i.e., the angle between the core and the long axis of the root, with 0°, 5°, 10°, and 15° angulations, respectively. The fit of each post in the root canal was verified. Before cementation, the coronal part of each post was bent according to their respective groups. Dual-cure resin cement was used for luting the posts and cured subsequently. The fracture resistance of all the samples was evaluated using the universal testing machine after they were mounted in self-cure acrylic resin blocks. The data were analysed using One- way ANOVA and Tukey's post-hoc test.

Results: Group-I exhibited the highest mean fracture resistance compared to other groups. However, One-way ANOVA showed no significant differences (p=0.161) between the four groups.

Conclusion: Everstick fibre posts are a preferable alternative for maxillary central incisors with core angulations up to 15° between coronal and radicular segments as they provide better fracture resistance with a more favourable stress distribution.

1. Introduction

The anterior teeth are critical for the aesthetics, occlusal integrity, and phonetics of an individual [1]. A compromised smile can be evident due to missing, fractured, or discoloured anterior teeth, resulting in a loss of self-esteem [2,3]. The tooth fracture etiologies include protruded teeth, fall, contact game injuries, and road traffic accidents [4].

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Restoring Endodontically treated teeth (ETT) can involve either a cast post and core or a prefabricated post depending upon the remaining coronal tooth structure [5]. Prefabricated posts may be either metal or non-metal posts. Analysis of the available literature shows that the post's primary function is to anchor the core to the root, providing reinforcement to the root [5].

The angulation between the root and the crown, particularly of the single-rooted anterior teeth, is called the Collum angle or an angle formed by the intersection of the long axis of the crown and root using the lateral cephalogram is known as Collum angle [6]. Previous studies demonstrated that the Collum angle differs among groups with different types of malocclusions [7,8]. The orthodontists divided patients into four groups according to Angle's classification of malocclusion: class-I, class-II Division-I, class-II Division-II, and class-III malocclusions. The average value of the Collum angle for class-I malocclusion is 6.1±5.2, and for class-II division-I malocclusions is 5.3±4.2, and for class-II division-2 malocclusions is 10.6±4.4, and 5.6±5.1 for class-III malocclusions. Compared to groups with other malocclusion types, the Collum angle of natural teeth for patients with class-II division-2 malocclusions were the greatest [9].

In addition to the crown-root angle, the labial surface of the anterior teeth is comprised of two planes. The two-plane labial surface in the anterior teeth enhances the aesthetic proportion of the teeth by reducing the visible segment. During the restoration of the ETT with the post in the anterior teeth, dentists should take the crown- root angle and facial angle of the tooth into consideration. Since the fabrication of the endodontic post, following the long axis of the root will lead to proclined incisal edge position in the crown, incompatible contour, and loss of incisal guidance. Hence, it is imperative for the restorative dentist to fabricate the post with a similar crown-root angle of the adjacent teeth for optimum rehabilitation [10].

To overcome these difficulties, a novel glass fibre post, Everstick, was introduced. This post is a flexible, resin-impregnated uncured glass fibre with an Interpenetrating Polymer Network (IPN). Limited literature is available on different custom angulated elastic glass fibre posts on fracture resistance of maxillary central incisors. Hence, this in vitro study was designed to evaluate the effect of different custom-angulated elastic glass fibre posts on fracture resistance of maxillary central incisors.

2. Materials and methods

The sample size was estimated using G power software at a 95% confidence interval. The sample size obtained for this study was 12 specimens for four groups. So, a total of 48 teeth were included in the study [11].

2.1 Preparation and obturation of root canals

A total of 48 extracted human maxillary central incisors with single root and single canal were collected from the Department of Oral and Maxillofacial Surgery, Vishnu Dental College, Bhimavaram, Andhra Pradesh, India. The teeth with calcified canals, cracks or fractures, development defects, multiple canals, root caries, and endodontically treated teeth were excluded. In order to standardize the samples, the anatomic crowns with similar dimensions (i.e., a mesiodistal diameter of 7±1mm and a labiolingual diameter of 6±1mm) were selected. Teeth were stored in distilled water at room temperature to prevent dehydration until their use, and throughout the study.

All the specimens were decoronated transversally by preserving 2 mm of tooth structure above the cementoenamel junction (CEJ) with a double-faced diamond disc. In each tooth, access cavity preparation was made with Endo Access bur (Dentsply, USA), patency was established with 15K file (Mani, Japan). Working length was calculated by the visual method under 2.5X magnification using a Dental operating microscope by inserting a 15K file into the canal until it was first visible at the apical foramen and working length was established 1mm short of this length. Biomechanical preparation for all the samples was done in the crown down technique using ProTaper universal system (Dentsply Maillefer Switzerland). During canal instrumentation, intra-canal irrigation between each instrument was done with 2 ml of 3% sodium hypochlorite by using a syringe with 30-gauge side vented needle tips (Neoendo, India). All canals were finally rinsed with 1mL of 17% Ethylenediaminetetraacetic acid and followed by a final rinse with distilled water. All the canals were dried with paper points. The root canals of all the samples were obturated with corresponding Gutta-percha (Prime Dental, India) by sectional obturation technique with a minimum of 5mm of apical gutta-percha from root apex using AH Plus sealer.

Post-space preparation of 10mm in length was done with peesoreamers from sizes 1-3. Irrigation was done with 5ml of 17% EDTA for 15 sec followed by 5ml of distilled water and dried with the paper points. All the teeth were randomly allocated into the following four groups (12 per group). All teeth were to be restored with a 1.5mm diameter Everstick post.

Group-I (n=12): The angulation of 0° core to the long axis of the root.
Group-II (n=12): The angulation of 5° core to the long axis of the root.
Group-III (n=12): The angulation of 10° core to the long axis of the root.
Group-IV (n=12): The angulation of 15 °core to the long axis of the root.

2.2 Placement Procedure of EverStick-Post

Posts were cut together with the silicone strap to the length of 14mm using sharp scissors. After cutting the posts to the required length, the posts were removed from silicon strips using tweezers, and the length was checked by inserting the post into the root canal space so that each post protrudes 4mm from the sectioned tooth surface. For appropriate fitting of the post into the prepared post space, additional Everstick fibres were added to the post space.

2.3 Fabrication and angulation of posts in each group

2.3.1 Group-I

The fit of each post in the root canal was verified; if the post does not reach the necessary depth, the apical end of the post was tapered with sharp scissors to fit in to post space. Before cementation, the coronal part of each post was placed at an angle of 0°. The angle between the long axis of the radicular part of the post segment and the coronal part of the post segment was kept at 0° by placing the teeth along with the post on a reference paper on which the angulations were drawn with the help of a protractor. After drawing the reference angulations on a paper, a glass slab is placed in 0° angulation, and the coronal part of the post segment is adjusted accurately to the required angulation by adapting to the glass slab.

2.3.2 Group-II

After drawing the reference angulations on paper, a glass slab is placed in 5° angulation, and the coronal part of the post segment is adjusted accurately to the required angulation by adapting to the glass slab.

2.3.3 Groups-III and -IV

After post space preparation, the post was placed as described in Group - I and Group - II with 10° and 15° angulations, respectively.

2.4 Post and Core fabrication

Fibre posts were pre-cured for 20 seconds within the canal to stabilise the angulation of the post's coronal portion, then removed and cured for 40 seconds. Then canal spaces of all the specimens were etched with 37% phosphoric acid (N etch gel, Ivoclar Vivadent, USA) for 15 seconds and then rinsed with distilled water and dried using a paper point. The fibre post was activated by applying an enamel bonding agent (StickRESIN GC, Germany), and the post was placed under a light shield for 3-5 minutes to prevent premature curing. Then the post was light-cured for 10 sec. Dual Cure Resin Modified GIC cement (Relyx luting 2, 3M ESPE, USA) was mixed for 20 seconds and applied to the canal walls. A thin layer of cement was placed on the post surface, and the post was inserted into the canal. Excess cement was removed, and the remaining cement was light-cured for 40 seconds using a LED curing light (Woodpecker, China) at an intensity of 800 mW/cm^2.

After cementation of posts, all the samples were etched with 37%phosphoric acid (N etch gel, Ivoclar Vivadent, USA) for 15seconds and then rinsed with distilled water and dried. A bonding agent (Tetric N Bond, Ivoclar Vivadent, USA) was applied with a micro brush, and excess was removed with gentle air blow and then light-cured for 20 seconds using a LED curing light at an intensity of 800 mW/cm2 according to the manufacturer instructions. Then standardized cores were restored using a resin core build-up material (Filtek Z350 nanohybrid composite (3M, ESPE, USA) with a height of 8mm measured from labial CEJ. The total core height comprised of 6mm of the core material and a prepared dentine ferrule that measured 2mm labially and 1mm proximally.

For all the samples to simulate the periodontal ligament, the roots were wrapped with adhesive tape to a depth of 2 mm below the CEJ and were mounted in self-cure acrylic resin blocks to a level 1mm apical to CEJ such a way that the coronal part of the post is parallel to the long axis of the mold to make the root tilts correspondingly.

Table 1. Mean fracture resistance (in N) and standard deviations of all 4 groups (One-way ANOVA)

Groups	N	Mean ± SD*	F - Value	Significance (*p*-value)
Group-I	12	351.78 ± 115.75	1.799	0.161
Group-II	12	349.64 ± 105.44		
Group-III	12	336.93 ± 78.31		
Group-IV	12	273.55 ± 74.97		

*Standard Deviation

2.5 Testing of samples for fracture resistance

All the specimens were subjected to a fracture resistance test using a Universal testing machine (Instron 8801, United Kingdom) at a crosshead speed of 0.5mm per minute. The acrylic blocks were secured in a prefabricated jig, which allows the plunger to apply the load on the palatal surface 3mm below to the incisal edge at an angulation of 130° to the long axis of the tooth. The load was applied until the specimen was fractured. The obtained data were subjected to statistical analysis using Statistical Package for Social Sciences, Version 22.0, USA.

3. Results

The mean fracture resistance (N) and standard deviations (SD) of all four groups are given in table 1. The Group–I (0°angulation) demonstrated the highest mean fracture resistance followed by groups-II, III and IV, respectively (Table 1). One-way ANOVA exhibited no statistically significant differences (p=0.161) among the groups (Table 1). Posthoc analysis also showed no statistically significant differences between the groups.

4. Discussion

The reconstruction of endodontically treated teeth is a great challenge in restorative dentistry since the tooth structure is totally or partially lost by caries, erosion, abrasion, previous restorations, trauma, or endodontic access [12]. The restorations of endodontically treated teeth are designed to protect the remaining tooth from fracture, prevent reinfection into the canal system and replace the missing tooth structure [13]. We often come across patients with fractured proclined anterior teeth seeking aesthetic corrections to improve their smiles. Several studies have reported the predominant prevalence of traumatic dental injuries in patients having such proclined teeth. Children and adolescents presenting inadequate lip closure or an increased overjet greater than 5mm is more likely to suffer from such dental traumatic injuries [13].

The utilization of post as a post endodontic restorative technique is usually recommended for mutilated endodontically treated teeth. If tooth structure loss is more than 50%, it would determine the use of posts to retain the core and distribute stresses [14]. The primary function of a post is to retain the core that replaces the missing coronal structure without compromising the apical seal of the root canal filling. Ideal post-core systems are expected to evenly distribute the functional force along the root surface. For better force distribution, the post should be as long as possible without endangering the apical seal [15].

For long-term success, there is a need to conserve the remaining healthy root structure. The reason for this change of paradigm is to achieve a more conservative approach with minimally invasive preparation and maximum tissue conservation, which is considered the gold standard for ETT. It is essential to select a post system that provides maximum retention to the core and requires removing the minimal amount of tooth structure. The recently introduced Everstick post system is a unique post made of impregnated fibres that can adapt to the shape of any root canal and avoid extensive preparations.

The maxillary anterior teeth with two plane labial surface and variation in coronal-root curvature necessitate the fabrication of post with different angulation between coronal and radicular segments [10]. Earlier research reports indicate the significant differences in the crown-root angles of maxillary central incisors among various malocclusions. The collum angle is described to range from 5°-15° between different malocclusion groups [7,8]. Hence the custom post with the crown-root angle of 0°, 5°, 10°, and 15° were selected for evaluation in the study.

The present in-vitro study was done to evaluate the effect of different custom angulations, i.e., 0°, 5°, 10°, 15° of elastic glass fibre post (Everstick post) on fracture resistance of maxillary central incisors. Statistically, no significant difference was observed between the groups in the mean fracture resistance. This may be due to the close elastic modulus of the Everstick post to dentin that flexes together under loading force. Also, the dentin-like behaviour of the post facilitates better stress distribution and yields high fracture strength values. In addition, several factors might influence the mechanical properties of FRC posts as the type of polymer matrix and length, diameter, number, and fibre-orientation of embedded fibres.

The presence of high molecular weight polymethyl methacrylate (PMMA) chains in the Everstick post act as a stress-breaker via plasticize the stiffness of highly cross-linked bisphenol A-glycidyl methacrylate matrix (Bis GMA), decrease stress concentration at the interface of fibre-matrix during deflection, and absorption of emerging stresses through the matrix. The silanized fibre of Everstick is another essential method for improving the fiber/matrix interface strength [16].

The multiphase polymer matrix of these Everstick posts consists of both linear and cross-linked polymer phases (semi-interpenetration polymer network, semi-IPN). The monomers of the adhesive resins and cement can diffuse into the linear polymer phase, swell it, and polymerize, form interdiffusion bonding and a so-called secondary semi-IPN structure; this will be reduced stress formation at post/dentin and post/ cement interfaces [13].

The interpenetrating network of Everstick post is designed to improve the bond between the post and the resin and to prevent adhesive failures and microleakage. The bonding of the fiber-reinforced post (FRC) with the Interpenetrating network resin matrix to the composite resin and adhesive cement was improved by an interdiffusion bonding mechanism resulting in a “Monobloc” type of restoration [17]. Everstick posts can be adapted easily to the shape of the root canals, thereby possibly reducing the number of voids and then the canal completely filled with post; for this reason, the adhesive surface, and the strength in the most critical part of the tooth are maximized [11].

The Everstick post system allows the additional number of unpolymerized posts to be added according to the canal morphology, which leads to better adaptation and better stress distribution. The root canal, which is completely filled with fibers is considered as a more effective reinforcement than one post only when compared under the same polymerization procedure [18].

According to the results from the study, the mean fracture resistance had a positive linear correlation with the decreased angle between the core to the long axis of the root. This could be due to the increased angulations; the off-axial forces seem to outweigh the axial forces, resulting in excessive tensile stress concentration resulting in decreased fracture resistance as obtained in this study [13].

The results obtained in this study were not in accordance with a previous study done to evaluate the fracture resistance of proclined endodontically treated teeth with cast metal post and Everstick post. The results of this study showed that 10°core to the long axis of the root group showed a mean fracture value higher than the 0° group. However, there was no statically significant difference between the two groups. In this study, porcelain fused metal crowns were fabricated for all the specimens. The crowns may act as a greater equalizer of forces because it tends to change the distribution of forces to the root, post, and core complex, with the post characteristics become insignificant [19].

According to Ferrario *et al.* (2004) [20], the normal biting force exhibited by the maxillary central incisors is in the range of 93 – 146 N. However, the mean fracture strength values obtained in this study were much higher than the anterior bite force encountered under normal clinical loading conditions. So, changing the core angulation up to 15° can be carried out safely using Everstick post systems as tested in the study.

However, further *in vitro* and *in vivo* studies with larger samples and teeth with more complex anatomies are needed to corroborate the results of the present study and to evaluate its clinical efficacy and applications.

5. Conclusion

Restoration of endodontically treated maxillary central incisors with Everstick post, there was a decrease in the mean fracture resistance with an increase in core angulation. However, there was no statistically significant difference in the mean fracture resistance among the four experimental groups, i.e., 0°,5°,10°, 15°

core angulations. It can be concluded that Everstick fibre posts could be an alternative for restoring endodontically treated maxillary central incisors with core angulations up to 15°.

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Clear aligners, the aesthetic solution: a review

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ABSTRACT

In the recent past, the demand for adult orthodontic treatment has increased multiple folds. As a repercussion of this stipulation, invisible orthodontic treatment has expanded its horizon. Efforts of using aesthetic brackets, wires, and lingual techniques to meet the expectations of adult patients have been practiced. Though, these techniques seemed to be promising in the initial days, soon decreased in popularity due to drawbacks associated with them. Clear aligners were offered as a newer and superior aesthetic alternative to overcome the difficulties associated with prior aesthetic approaches. These aligners are made up of different thermoplastic materials intended to move the malpositioned teeth in the desired corrected position following push mechanics. This article deals with new generation orthodontic treatment using aligners. It deals with history, generations, different materials used, and the distances yet to be travelled to become the benchmark and replace the existing conventional braces. This paper also gives a bird's eye view of the method of aligner fabrication and the significant differences between the regular braces and aligners used in orthodontics.

1. Introduction

With the growing demand of an alluring and glamorous society, many teens, adolescents, and adults seeking orthodontic treatment are demanding appliances that are both more aesthetic and comfortable than conventional fixed appliances. The amassed demand for the more aesthetic orthodontic appliance has led to the revolution of invisible appliances such as ceramic brackets, lingual brackets, and aligners [1]. Among these appliances, aligners are desired over the other by adults as they exhibit superior aesthetics and give more comfort. Similar to fixed devices, aligners also embrace a wide range of applications in correcting various malocclusions. In the current market, there are different types of commercially available aligners. The common aspect among them is that they all are fabricated using clear thermoformed plastic, which covers many or all teeth. Thermoplastic materials are polymers that are either in the linear or slightly branched configuration. Strong covalent and weak Van der Waals bonds hold the different units of the plastic together. On heating, the molecular chains move and make the plastic flexible and pliable to any desired shape, and subsequently, they are cool down to room temperature. During cooling, the molecular chains solidify and retain their new shape [2].

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Thermoplastic materials have been part of orthodontic treatments for decades, but their application was limited. However, with the advancement and progression of technology, these plastics can now be manipulated and used for correcting malocclusion [3]. These aligners are generally series of removable thermoplastic appliances that are custom-tailored, transparent, and esthetic alternatives to traditional metallic braces.

2. History

In the year 1945, Kesling fabricated retainers from wax setups of patients using rubber materials. Kesling witnessed that these rubber retainers did not just help in detailing the completed cases but also in minor tooth movement. He had predicted the possibility of considerable movements with these retainers. As Kesling’s trial was successful, this led to the opening of a new window in the field of orthodontics [4].

Later in 1959, Dr Henry Nahoum attempted to refine the technique put forward by Kesling. He developed a method with a vacuum to fabricate the appliance, which displayed a firm and excellent adaptation to the model/cast. The process involved the fabrication of a plaster cast by correcting the rotations witnessed in the patient's anterior teeth. The rotated anterior teeth on the cast were sectioned using a goldsmith's saw or a fissure bur. The sectioned teeth were arranged with wax according to the final estimated and desired outcome. Then, the appliance was fabricated using rubber material that was vacuum formed over the designed model, and the excess material was removed [5,6].

In 1971, Ponitz presented Invisible retainers using base plate wax on the prepositioned cast and suggested to cause limited tooth movements [7]. As time progressed, Sheridan and few others introduced interproximal tooth reduction and used a clear Essix appliance for facilitating proper tooth alignment [5].

Making impressions, pouring castings, and repeating the procedure a hundred times is not as simple as it appears. As a result, technology was used to make the method more convenient, such as the CAD-CAM (Computer-aided design computer-aided milling) technology. This technology uses graphics and predesigning the post-treatment customized models using software and executes it. This technology helped to eliminate the time-consuming process, to transform the slow weary process into large-scale production and a fast procedure [8]. As demand increased, investment in research and development (R&D) further increased and became a critical step in developing an alternative to conventional braces.

3. Types of materials

Various thermoplastic materials that are currently used for fabrication include polyvinyl chloride, polyurethane (PU), polyethylene terephthalate (PET), and polyethylene terephthalate glycol (PETG) [9].

Polyurethane is a versatile material that allows a wide range of applications. PU is primarily composed of di- and tri-isocyanates, and polyols [10] also contain some additional materials to improve the properties of plastic. Because of its characteristics, the material is frequently used in aligners. PU has a higher resistance to compression and tension, is harder, and has a higher load-bearing capacity, making it a popular material. Under loads, PU material changes its shape but later attains its original shape when the load is removed. Because of the material's flexibility, it is able to elongate and recover. The material also exhibits high tear resistance and a wide range of resiliency. PU is an opaque substance in general, and its opacity increases during the mixing process, limiting its use in invisible orthodontics [11].

Polyethylene terephthalate (PET) is commonly known as polyester, which is made up of combining ethylene glycol with terephthalic acid. The material can be drawn into tapes, films or fibres [12]. The material is employed in various daily commodities as well as in the medical field. PET is frequently used as a substitute for grafts, vascular prostheses, etc. The PET exits in both amorphous and crystalline forms, which influence the properties. The amorphous structure is transparent, whereas the crystalline structure is opaque and white. Crystalline forms exhibit good strength, hardness and stiffness, and amorphous forms demonstrate superior ductility [13]. PET material can be either rigid or semi-rigid depending upon the processing methods employed. The material displays excellent mechanical properties, toughness, resistance against various solvents.

PETG is a non-crystalline co-polyester, which is made up of 1, 4 - cyclohexane two methanol (CHDM), ethylene glycol (EG) and terephthalic acid (TPA) [11]. The material shows excellent transparency, adequate flow property, and resistance against solvent. PETG is the material that can either be punched, die-cut, printed, hot stamped etc. PET-G is the choice of material to fabricate complex and intricate designs. The PET-G materials are exceptionally durable, have high impact strength, and are resistant to chemical changes. PETG is a transparent thermoplastic material and exhibits roughness that is lower than glass. Various bending tests suggested that the PETG is a very ductile material [11]. The PETG is a modified and altered form of PET that transforms its form from semicrystalline to amorphous form turning the material to be more transparent and esthetically appealing. The Tg of the material is around 80˚C, allowing better handling of the material with features that resemble glass [14]. This modified PET also exhibits altered optical and mechanical properties. The improved transparency, mechanical properties and optical properties make PETG a promising material in the fabrication of aligners.

To improve the properties of these materials and their influence in the fabrication of aligners and tooth movement, research is being conducted on these polymers in various manufacturing processes, blending of various thermoplastic materials, and in varied proportions of these materials.

4. Types of aligners [15]

The aligners are broadly classified as vacuum-formed, and pressure formed. Nahoum differentiated between vacuum formed and pressure-formed appliances. Both the appliances use air pressure for their fabrication, but they differ in their pressure levels. While vacuum-formed uses a pressure around 3-14 psi, the pressure formed uses a pressure around 100 psi.

4.1 Generations of aligners [15]

The aligners have undergone many transformations to improve their efficiencies and treat various malocclusions more aesthetically, comfortably, and effectively.

4.1.1 First-generation aligners

These are supposed to be the initial or the earliest form of aligners. The results of the treatment were completely based upon the thermoformed plastics. No auxiliaries were attached to it.

4.1.2 Second-generation aligners

These aligners are manufactured along with the attachments to provide better tooth movement. The second-generation aligners also included the composite buttons on the teeth and inter-maxillary elastics.

The invention of newer generations have been undertaken to achieve better results and treat a larger spectrum of malocclusions.

4.1.3 Third-generation aligners

In the third-generation aligners, precision cuts, elastics, power ridges for lower anterior and upper incisors, optimal rotation attachment for premolars, and variation in canine attachments were available for treating class 2 and class 3 patients.

4.1.4 Forth-generation aligners

Next-generation smart-force, optimized root control attachments, a new multi-tooth approach for the open bite, new optimized multi-plane movements are included in the fourth generation.

4.1.5 Fifth-generation aligners

Fifth-generation aligners introduce the pressure area to allow for improved intrusion, enhanced deep bite attachments on premolars for extrusion, and bite ramps to generate posterior space.

4.2 Fabrication of aligners

For the fabrication of aligners, the pioneering methods are no longer used; instead, CAD-CAM is used. The dentist transmits the impression (either a 3D or a traditional impression) to the lab, which converts it into digital format (3D if a traditional impression is sent) and forecasts the treatment outcome back to the dentist. Once the dentist is satisfied with the preliminary result, the required amount of tooth movement to align them according to the agreed plan is calculated, and the thermoplastic trays are made accordingly. Every tray should exhibit around 1/10 mm of the desired movement. Once the number of trays required for the treatment has been determined, the trays are manufactured using a Rapid prototyping technology known as Stereo Lithography [16]. The method is exposing a laser to a photo-sensitive liquid resin, which cures the resin into a hard plastic-like consistency. Layer by layer, the operation is continued until the desired thickness is obtained.

Mild to moderate crowding, posterior dental expansion, tooth intrusion, molar distalization, aligning and levelling of arches, regulating anterior intrusion, controlling posterior buccolingual inclination, and Angle's class 1, class 2, and class 3 malocclusions are all indications for aligners.

Aligners may not be successful in cases with severely crowded teeth, growth discrepancies, impacted teeth, open bite, severely pointed teeth, extrusion of teeth, and teeth with short clinical crowns [17].

Compared to conventional braces, which are typically metal and exhibit metallic colour, aligners are clear/ invisible. Traditional braces must be worn 24 hours a day since they are fixed and cannot be adjusted by the patient, whereas aligners are detachable and worn for around 12-14 hours per day. Oral hygiene can be maintained with traditional braces by brushing them with bracket brushes and cleaning with water picks. However, with aligners, oral hygiene can be maintained by brushing and removing and cleaning the aligners with Lukewarm water. Conventional braces require a monthly check-up, whereas aligner trays are replaced every two weeks. Both traditional braces and aligners may need to be positioned or a retainer is worn primarily during nights post-treatment. The multiple benefits associated with traditional braces are more effective for complex cases, as aligners do not demand self-discipline. Limitations of traditional braces include persistent discomfort or soreness from wires and brackets until treatment is completed, tooth discolouration owing to poor dental care, difficulty in eating soft and sticky foods, and allergic responses in certain patients who have nickel allergies [18]. Compared to traditional fixed appliances, aligners are less uncomfortable, allow for better dental hygiene, and cause less root resorption [19].

The pull mechanism is used to move teeth in traditional orthodontics. In the case of aligners, the push mechanism is used instead of the conventional pull method. This push mechanism has also proven to be efficient. As a result, orthodontists must change their perspective from the pull mechanisms utilised in traditional braces to the push mechanisms employed in aligners.

The drawbacks of aligners include the fact that they are removable and hence do not apply continuous forces to the teeth. As a result, there may be a delay in tooth movement. Every meal necessitates the removal and reinsertion of the device. The success of the treatment largely depends upon the patient's compliance. Aligners cannot be used in treating skeletal class 2 and skeletal class 3 patients and may be limited to camouflage treatment as in traditional braces. The aligners in the oral cavity are constantly in contact with various beverages or colour staining liquids and solids, resulting in staining of the aligners and ultimately affect the aesthetics.

PU-based aligners are more susceptible to discolouration than PC- and PGET-based aligners [20]. Also, the physical properties of aligners alter if they are in the oral cavity for about 14 days. Microcracks, abraded surfaces, localized calcified biofilms, and loss of transparency are few to mention. Despite these minor changes in the properties, numerous studies observed no release of unreacted monomers from the aligner on storing it in artificial saliva for about 14 days. Therefore, it can be suggested that the aligners possess good chemical stability [21].

Intra-oral ageing also affects the mechanical properties of aligners include, imparts more brittleness, decreased wear resistance, attenuation of forces also reduced with an increase in aging of aligners. Many times, these aligners do not exhibit proper fit after some time in the oral cavity.

To improve retention, attachments are included. Increase the thickness of the material or add bevelled or ellipsoid attachments to the cast, ideally the bevel attachments, to improve retention. Customized attachments for each tooth are also effective, but they have yet to be adequately documented. The type of material utilised has an impact on retention [22].

In recent years, ramps have improved attachments, and power ridges have been utilised to repair significant malocclusions with better and more predictable results. If these few flaws are addressed, aligners have the potential to offer good outcomes and be an excellent alternative to traditional braces in orthodontics.

5. Conclusion

The use of trendy thermoplastic materials to treat malocclusion is becoming increasingly popular since they are user-friendly and offer promising outcomes. Aligners are among those rare procedures that minimise the psychological trauma that patients often experience during conventional treatment. Even among the esthetic-conscious population, aesthetic approval throughout treatment must lead to growing popularity. There are a few areas of concern where aligners have yet to be created to deliver superior results. If done correctly, these aligners would be a noble and successful breakthrough invention in the realm of orthodontics during this era.

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Mini-implants, mega solutions: a review

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ABSTRACT

Dental implants have evolved as a standard treatment option for the replacement of missing teeth. Though this treatment modality provides a high level of patient satisfaction and success, it cannot be performed in all cases. Implant use is also restricted when the quality and quantity of bone at the edentulous site is limited, in addition to medically impaired patients. Among the conditions are remaining ridges with reduced interdental spacing, atrophic edentulous maxillary and mandibular ridges, and narrow ridges such as the mandibular incisor and maxillary lateral incisor area. A proper augmentation method for the placement of a regular diameter implant (3.75 to 7 mm) can improve the height and width of bone at such sites. However, bone augmentation and bone grafting procedures are rarely undertaken due to financial constraints, the risk of subjecting the patient to additional surgical procedures, the added time factor, or the guarded prognosis of the grafted site. In such cases, mini-implants are the choice of treatment. Mini-implants have the potential to be a viable alternative to standard-diameter implants in some circumstances. Benefits of mini-implants can be gained by replacing a single missing tooth, or preferably they must be used in multiples to retain fixed dental prostheses and might serve as an inexpensive, and efficient solution for retaining overdentures in selected cases.

1. Introduction

A prosthodontist's primary goal is to restore function and esthetics by replacing lost teeth. The high success rate of dental implant therapy has been a major factor in restoring function and esthetics effectively. In distal extension, the placement of long-span bridges and implants are standard treatment modalities in fixed prosthodontics. However, conventional implants are not recommended for patients having ridges with less buccolingual [1], and mesiodistal width [2]. Further, interproximal bone loss may be observed when the distance between the implant and the adjacent tooth is less than 1.5 mm [3].

The standard diameter of endosseous implants ranges between 3.75 to 7 mm [4]. If they ought to be used in narrow ridges, bone grafting, ridge augmentation, and ridge expansion procedures are mandatory. Bone grafting, ridge augmentation, ridge expansion procedures are complex procedures, and the prognosis of bone grafting procedures is questionable [4]. The stabilization of implants mainly depends on the cortical bone. However, studies have shown the formation of trabecular bone in the grafted area, and there is no evidence of the maturation of grafted bone to cortical bone [4]. Therefore, in narrow ridges, mini-implants have become an alternative to conventional methods include bone grafting, ridge augmentation, and ridge expansion procedures [4]. Small diameter implants are

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available in a range from 3.0 to 3.3 mm and very small or “mini” 1.8 to 3 mm diameter implants [5]. Mini-implants are indicated in patients with reduced inter-radicular bone, narrow ridges, or reduced mesiodistal prosthetic space [6]. Multiple mini-implants can be used for removable full or partial denture stabilization [5] and are offered at a lower cost. Mini-implants are indicated in the narrow ridges of edentulous or partially edentulous arches. Especially in the anterior maxilla with a decreased palato-labial bone width and/or insufficient interdental space are present [7]. In the atrophic posterior mandible, inadequate buccolingual bone width is the common problem for implant placement. In these cases, mini-implants are the treatment of choice [7].

2. Mini-implant design

Standard implants with a diameter of 3.5mm to 7mm are available in a one-piece design with a fused abutment or in a two-piece design where the abutment is attached later [7]. Mini-implants manufactured with a diameter of 1.8mm to 3mm are available in a one-piece design with a ball-shaped head (Figure 1) used for stabilization of removable prosthesis and with a square head for fixed prosthesis. Abutments and screws are not used in mini-implants like they are in conventional implants. In case of mini-implants, in the mini-implants, the prosthetic teeth are held in place by elastic O-rings (Figure2) on a ball at the top of the implant. In orthodontics, mini-implants are used for indirect anchorage, these implants contain racket like head design. Abutment protrudes over the gingiva when an implant is placed in the bone. The transmucosal component of the neck of a mini-implant's must be smooth and vary in length based on the implant site's mucosal thickness [7-10].

3. Indications

Mini dental implants (MDIs) may be a viable treatment option in places with insufficient ridge width and/or interdental space, reducing treatment complexity and extending the benefits of implant-supported restorations to a larger patient population. [6]. Mini-implants can be indicated for restoration of mandibular anterior teeth [11]. Various case studies suggested that the mini-implants can be used successfully for retaining mandibular overdenture [12]. Multiple teeth can be replaced by splinting mini-implant with a regular diameter implant. Also, mini-implants can be used for posterior single tooth replacement. When used in high-stress bearing areas (posterior region), large amounts of cyclic loading may induce metal fatigue in the mini-implants. This fatigue may be due to the concentration of more forces per unit area of the implant body. Therefore, appropriate precautions are to be taken to control the occlusal forces by modifying the cusp or splinting the multiple mini-implants [13]. Additionally, they can be used in conjunction with larger diameter implants, and a splinted prosthesis is given for the uniform distribution of the loads [8]. Case studies with short-term follow-up were found to be satisfactory from the perspective of patient comfort and limited marginal bone loss [6,14].

4. Contraindications

The mini-implants are contra-indicated in medically compromised patients with uncontrolled diabetes, coagulation disorders, chemotherapy, and radiotherapy. Also, they are not recommended for patients with systemic diseases associated with wound healing and bone healing. Mini-implants are also not indicated in patients with chronic periodontitis, limited soft tissue coverage, insufficient bone height, parafunctional

Figure 1. Design of a mini-implant

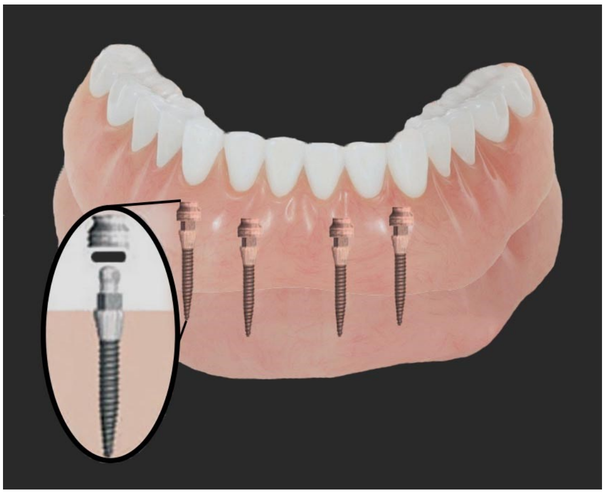

Figure 2. Mini-implant with O-ring

habits that cause predetermined vertical and lateral occlusal forces, and children until epiphyseal closure is complete [6,15].

5. Placement procedure

Proper diagnostic data is essential and OPG is a prerequisite for accurate presurgical planning and placement. Along with OPG, diagnostic models with radio-opaque markers CBCT are advised for 3D planning, particularly in very narrow ridges for proper planning to place the implant and angulation [15].

In the surgical procedure, crestal infiltration of local anaesthesia is adequate as the mini-implants are the least invasive [8]. Generally, raising a surgical flap is not required unless in a very narrow ridge with an abundant soft tissue where minimal flap raising is advocated after giving a crestal incision to visualize bone for precise implant placement with predetermined angulation [8].

During osteotomy, the use of a pilot drill is adequate [8]. Usually, osteotomy depth of one-third to one-half of the length of the chosen implant is sufficient for achieving primary stability [13].

6. Insertion procedure

The MDI (mini dental implant) is supplied in a glass vial suspended from a plastic cap (implant carrier) [14]. During insertion, the pouch is opened, and the implant is inserted into the osteotomy site. Then, the implant is torqued with a finger pressure in a clockwise direction with a downward direction until firm bony resistance is noticed to provide adequate primary stability [14]. To torque, the MDI ratchet wrench is used up to 40 NCM in small carefully controlled torques [14]. During torquing, a finger is placed on top of the ratchet wrench to minimize non-axial forces and ensure the correct seating of the implant to its final depth [14]. At the end of insertion, the head of the MDI should protrude from the tissue without exposing threads [14].

7. Insertion procedure

Mini-implant-retained overdentures and crowns are generally subjected to immediate or progressive bone loading because of the one-piece design of the implant. According to Wolff's Law, gradual bone loading is associated with superior bone healing [11,12]. Various case studies demonstrated a negligible bone loss around the implants, radiographically [15].

8. Advantages

Mini-implants exhibit all the advantages similar to those of standard implants. As the name suggests that they are smaller in size, and they are minimally invasive. The inflammation is less in the implant site leading to faster healing and allows immediate loading. They require simple surgical procedures and causing minimum discomfort to the patient. There is less linear or circumferential percutaneous exposure of the implant resulting in less vulnerability to bacterial attack at the implant-gingival attachment. Thus, the characteristic resorption to the first thread phenomenon seen with regular diameter implants does not seem to be prevalent with these implants. Also, they require very minimal osteotomy preparation, which does not remarkably compromise angiogenesis [1,5,9]. In cases of the narrow residual ridge, mini-implants have become a choice of treatment. Innovation of mini-implants minimized the necessity of grafting procedures, ridge augmentation. They are economically viable when compared to standard implants. In case of failure, they are easy to remove with minimal surgical trauma [8].

9. Limitations

Mini-implants cannot be placed in ridges with inadequate vertical height and in an individual with parafunctional habits and cases with reduced inter arch space [15]. The potential for fracture of the implant during placement is more due to its narrow diameter [5]. There is a lack of parallelism between implants because of their one-piece design. There is a need for multiple implant placement because of failure unpredictability due to lack of scientific guidelines and understanding [15]. There is limited scientific evidence about the long-term survival of these implants [7]. The clinical success of mini-implant-supported fixed restorations requires a thorough understanding of biomechanics through proper case selection and precise treatment execution [7,15].

10. Conclusion

Mini-implants are considered a feasible treatment option in appropriate circumstances based on the minimal scientific evidence and case reports available. Case selection becomes a significant criterion due to the small surface area of mini-implants leading to less bone-implant contact, which impacts the success of the implants. Stress variables also should be considered as prime aspects while placing mini-implants on a narrow ridge .

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