Resin Infiltration of Non-Cavitated Proximal Caries Lesions: A Literature Review

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Abstract

Background: Noninvasive measures involving fluoridation, dietary control, and oral hygiene instruction, as well as invasive restorative methods, are the standard treatment options for interproximal caries. Intermediate treatment options, similar to pit-and-fissure sealing on occlusal surfaces that has been shown to be effective in preventing and inhibiting caries, have not yet been established on interproximal surfaces. Recently, the application of resins on interproximal caries lesions has been studied and improved, leading to the development of new materials, which infiltrate and seal the cavious lesion, improving the inhibition of caries progression.

Aim: The aim of this literature review was to revise the in vivo and in vitro scientific evidence of the ability of resin infiltration (RI) to arrest non-cavitated proximal caries lesions.

Materials and methods: Electronic search of English scientific papers from 2007 to 2017 was accomplished using Pub Med search engine. The keywords used were ‘resin infiltration, dental caries’, ‘resin infiltration, carious lesions’, ‘resin infiltration, caries lesions’, ‘caries infiltration’ and ‘Icon DMG’ with the ‘clinical trial’ filter activated.

Results: One hundred and forty articles were reviewed as well as some references of selected articles. Fifty studies described the ability of resin infiltration to arrest non-cavitated caries lesions. Conclusion: Data show this new technique complements existing treatment options for interproximal caries by delaying the time point for a restoration and consequently closing the gap between noninvasive and invasive treatment options.

Keywords: Resin infiltration; Dental caries; Carious lesions; Caries infiltration; Icon DMG

Introduction

Dental caries is a major public health concern commonly affecting children in their early childhood. It has a negative impact on children’s oral as well as general health [1]. The caries prevalence rate in the Jeddah city has ranged from 70 to 76% in 6-year-old children [2].

Special attention has been devoted to early proximal carious lesions, with maximum preservation of tooth structure [3]. This is mainly because restorative therapy for interproximal lesions requires removal of a substantial amount of sound tissue and this brings tooth into a circle of treatment and retreatment [4]. Therefore, early detection and treatment of such lesions will limit the need for invasive treatment in the future.

Restoring the tooth structure by dental filling and restoration was the first choice for treating dental caries [5], but in the last years, the treatment has been changed from the large invasive technique to noninvasive or minimal invasive preventive techniques [6].

Several noninvasive techniques have been developed to treat early caries lesions [7]. Smooth surfaces caries, have benefited from the preventive effects of fluoride agents, such as fluoride toothpaste and fluoridated water. Fluoride application improves the re-mineralization process of the demineralized tooth structure [8]. It was reported that the application of Duraphat fluoride varnish twice per year with 6 months’ interval, significantly reduces the incidence of proximal caries [9].

Sealants were first introduced to protect the pit and fissure surfaces in the 1960s by Cueto and Buonocore [10], as a part of preventive programs to protect pits and fissures on the occlusal tooth surfaces from dental caries. Such sealants prevented dental decay by preventing the growth of bacteria that cause dental caries [11].

The prevalence of decay was decreased in the industrialized countries between 1970 and 1980 due to the use fluoride and fissure sealant [12]. In addition, sealant prevents caries on both occlusal and proximal teeth surfaces [13], but due to the low penetration ability of the resin material, the resin infiltration (RI) material with less viscosity was needed [14] to penetrate to the lesion base, arrest the lesion, providing mechanical support and also improving the aesthetics of the enamel [15].

Infiltration Concept (ICON®) is a relatively new resin product developed in Germany and used in the treatment of incipient lesions [16]. It improves the retention and prevents caries on smooth surfaces, but not pit and fissure surfaces [17].

Resin infiltration is a micro-invasive method that fills the incipient lesion pores via capillary action [18], which blocks further diffusion of the bacteria by creating barriers and stops lesion development, restoring the tooth without anaesthesia and drilling to preserve the natural anatomy of the tooth form [19].

The ICON® infiltrates the lesion, make the bacteria inactive and prevents caries progression [19] compared to the sealant which only work as mechanical barrier between the tooth structure and the oral environment [11].

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Copyright: © 2018 Meligy OAESE, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.
The ICON\textsuperscript{\textregistered} is available on the market as two products according to their use; the first one is known as ICON caries infiltrate proximal and is used in early interproximal caries lesions. The second one is known as Icon - Caries Infiltrate smooth surface and is used to treat all other smooth surfaces [20].

The commercial ICON\textsuperscript{\textregistered} kit contains 15% hydrochloric acid as etchant, ethanol for drying and the infiltrate resin material [21]. The ICON\textsuperscript{\textregistered} system contains 15% hydrochloric acid etchant [21], while the sealants system contains 37% phosphoric acid etchant [22].

When applying RI in etched demineralized enamel, resin will fill the porosities of demineralized enamel surface [23]. This technique will mask the opaque white spot lesions [24], in smooth buccal or lingual surfaces and inter-proximal surfaces [20].

The aim of this literature review was to revise the in vivo and in vitro scientific evidence of the ability of RI to arrest non-cavitated proximal caries lesions.

**Materials and Methods**

Electronic search of English scientific papers from 2007 to 2017 was accomplished using PubMed search engine. The keywords used were ‘resin infiltration, dental caries’ , ‘resin infiltration, carious lesions’ , ‘resin infiltration, smooth surfaces’ , ‘resin infiltration, proximal’ and ‘Icon DMG’ with the ‘clinical trial’ filter activated.

**Results**

One hundred and forty articles were reviewed as well as some references of selected articles. Fifty studies described the ability of RI to arrest non-cavitated proximal caries lesions.

**Discussion**

**Bonding in dentistry**

Bonding of different materials to the enamel and dentin is one of the most important developments in the dentistry [25]. Many improvements have been made in this field since its development in the 1950s [26]. Etching techniques for bonding to enamel have changed the practice of dentistry. Although bonding to the dentin has been challenge, ongoing developments are improving the reliability of dentin bonding agents [26].

Understanding the history of bonding agents is very important, as bonding has become a base of modern dentistry. In the previous 50 years, there has been development in the bonding agents. New concepts on restorative and adhesive dentistry have been advanced during this period. In 1955, Buonocore developed the principles of adhesive dentistry when he used the techniques of bonding and acids for surface treatment before application of the restorative material. Several options were discovered to maintain bonding between filling material and the tooth structure. This discovery included the improvements of resin materials which controlled adhesive properties, development of available materials, adhesive material between the tooth and the filling and chemical treatment of the tooth surface to create a new surface to which the materials adhere [25]. Later, Buonocore recommended that the formation of the resin tags was the phenomenon that allows the adhesion of resin to the acid etched enamel. The micromechanical bonding is widely accepted today.

The main aim of dental adhesives is retention of fillings. Etching to enamel development was another challenge in bringing bonding of materials to the tooth structure. Different acids, as phosphoric acid, with dissimilar etching times were tested for etching of the enamel [27]. The ability to bond to enamel is reliable and widely accepted today. Bonding to dentin has been more difficult than to enamel, because enamel contains less protein than dentin and the dentin pores contain fluid which inhibits bonding to dentin [28].

Preventing the leakage along the restoration’s margins is an advantage of a good adhesive. Most of the esthetic resin restorative materials are using adhesive systems and the major limitation of the earlier filling materials is the lack of adhesion to the tooth structure [25]. Acid treatment is a significant method used to accomplish adhesion of bonded restorations to the tooth structure [25]. Buonocore, in 1955 found that conditioning enamel with 85% phosphoric acid for 30 seconds help the resin bond to the tooth enamel. Also, this new bonding technique can be used for different restorative materials as pit and fissure sealants [26].

Buonocore, in 1955 suggested the formation of resin tags as the primary attachment mechanism of resin to phosphoric acid-etched enamel. The acid etching mechanism removes about 10 micrometers (um) of enamel and creates a porous layer of 5-50 um deep to allow for the resin penetration into the porous layer [26]. Etching increases the surface area of the enamel substrate by exposing the organic material of the enamel, which can then serve as a network to which the resins can adhere [26]. In other words, etching creates spaces deep along the interprismatic areas to which the resin can penetrate. When the low viscosity resin is applied to the etched area, it flows into the micro-porosity channels of this layer and polymerizes to form a micromechanical bond with the enamel surface [26]. Conventional adhesive systems consist of three components: an acid conditioner, a primer and an adhesive resin [29].

Adhesion is being defined as the attraction between molecules of different materials at the interface [30]. Several factors must be considered in bonding between the restorative material and the tooth structure, as adhesive properties, the use of adhesive interface and the alteration of the tooth surface to help adhesion [25]. Adhesion can be categorized by three different mechanisms, chemical adhesion, which includes covalent, ionic and metallic bonds, physical adhesion, which includes secondary valence forces such as Vander Waals forces, hydrogen bonds and London dispersion forces and mechanical adhesion which is defined as penetration of one material into a different material [31].

The dentin bonding agents usually consists of conditioner, primer and adhesives. Conditioner (etchant) which is used to prepare the dentin surface and applied before the primer, the etchant is usually washed off before the application of the primer, etchant as phosphoric acid, citric acid, nitric acid or oxalic acid are always used. Primer are the bi-functional molecules, of which one functional group contains a hydrophilic component to facilitate wetting and adhesion to the dentine and the opposite end is the hydrophobic group which readily bonds to the bonding resin. Different primers are used as HEMA (Hydroxy-Ethyl Methacrylate), PMDN (Pyromellitid diethylmethacrylate), NPG-GMA (N-phenylglycine glycidyl-methacrylate), NTG-GMA (N-tolyglylic glycidyl-methacrylate), PENTA (Phosphonated pentaacrylate ester) and glutaraldehyde. Adhesives chemically bond to the primers and provide an increase in additional micro-mechanical and macro-mechanical surface retention. Different types are used that bond to the primed dentinal surface as Bis-GMA (Bisphenol-glycidyl methylacrylate), UDMA (Urethane-dimethacrylate), TEGMA (Triethylene glycol-methacrylate), and 4-META (4-Methacryloxy-ethyl trimellitate anhydride) [29].
In 1955, Buonocore introduced the concept of acid etching. Acid etching step is used to achieve adhesion to enamel. Acid etching of the enamel removes the inter-prismatic mineral crystals, increase the surface energy, surface area, and create micro-porosities on the enamel surface into which the bonding agents can flow, resulting in reliable enamel bond strengths. There are three types of etching patterns, Type 1 etching pattern is the most common type, and it involves preferential removal of enamel prism cores, but the prism peripheries remain intact. Type 2 etching pattern is the reverse of the type 1, in which the peripheries are removed and the core remains intact and Type 3 etching pattern is less distinct and includes areas resembling both of the other patterns and also etching patterns that appear unrelated to the prism morphology [26].

Pits and fissure sealants

Sealants are coatings applied to the pits and fissures of mainly molar teeth which prevent the growth of bacteria that promote decay in pit and fissure surfaces of molar teeth [32].

In 2002, Simonsen said that ‘the term pit and fissure sealant is used to describe a material that is introduced into the occlusal pit and fissures of caries susceptible teeth, thus forming a micro-mechanically bonded, protective layer cutting access of caries producing bacteria from their source of nutrients’. Hyatt in early 1923 introduced pits and fissure and fissure producing bacteria from their source of nutrients. The idea was not fully accepted, which led to the use of Blacks’ extension for prevention cavity preparation [33]. The prophylactic odontotomy was done on sound teeth to prevent cavities, whereas Black’s principle was applied on teeth with caries.

Early before the fluoride, various chemicals as zinc chloride and ammoniacal silver nitrate were used on the tooth surface, but it wasn’t successful [33]. After the introduction of fluoride into the practice of dentistry, development of preventive materials started specifically for pit and fissure surfaces [33]. The revolution came in 1955 by Buonocore, when he developed the acid etching technique. Cyanoacrylates were used as sealant materials in the 1960s, but did not last long. In the late 1960s, a new successful material was developed known as the Bisphenol A and glycidyl methacrylate (BIS-GMA) with methyl methacrylate monomer. The American Dental Association (ADA) issued an initial acceptance for the first Bis-GMA material in 1972 and gave it full acceptance in 1976. Bis-GMA sealant materials are the mostly used today resins and urethane-based resins and considered a basis for development of other products [34]. In 1960, sealants were developed for the protection of pits and fissures of occlusal surfaces and buccal and lingual pits from dental caries as they prevent the growth of bacteria in pits and fissures and therefore prevent dental caries. Now, there are two types of sealants available, the resin based sealants, composites and the glass ionomer sealants [32].

Four different generations were developed from resin sealants based on the mechanism of polymerization and the material content. The first-generation products were activated with an ultraviolet light, the second and third generations were auto-polymerized and visible-light activated, respectively and finally the fourth generation contained fluorides [32].

In 1974, McLean and Wilson presented the glass ionomer sealant [32]. Glass ionomer sealants contain fluoride and prevent caries through the release of fluoride but it has inadequate retention [32]. In 1990, a combination of composites and glass ionomer cements known as comomers were developed. The battle against decay has a long history, which includes the preventive innovations such as early physical blocking of fissures with zinc phosphate cements, mechanical fissure eradication, prophylactic odontotomy and chemical treatment with silver nitrate [35].

Acid etch bonding technique was a new technology in the use of bonding in prevention of pit and fissure caries. New methods of caries prevention have focused on the pit and fissure surfaces, as the smooth surfaces have become less susceptible to decay with the advent of fluoride. The disproportional occurrence of caries on pit and fissure surfaces continues to date, with these surfaces accounting for approximately 91% of dental decay. The high risk of pit and fissure caries on almost all the molars has driven the dental profession to view sealants as a highly advantageous procedure [35].

Dental sealants have become an essential part of contemporary restorative dentistry. The advent of the acid etch technique, availability of new restorative material and a better understanding of the caries process has helped clinicians make better recommendations [36].

The resin-based sealants are divided into categories based on their polymerization as auto-polymerizable, which polymerize by themselves/ without any source for activation, photo-polymerizable, which polymerize after exposure to a source of light of a particular wavelength, and the combination of both [37]. Another category of material is a composite that incorporates particles of glass hardened glass ionomer cements within its mass. The other two types of glass ionomer are those with light-polymerized liquid and those modified with inclusion of metal [38]. Glass ionomer cements were developed in 1974 by Wilson and Kent and consisted of calcium or strontium alumino-fluorosilicate glass powder (base) combined with water soluble polymer (acid) [38]. The term ‘glass ionomer cement’ is applied to materials that involve an acid-base reaction as a part of the setting reaction. As the cements contain fluoride ions, significant amounts of these ions are released during this reaction, without affecting the physical properties of the hardened cement [33]. Since development of sealant material in 1960s it has been used widely by clinicians.

Resin infiltration

Superficial sealing of caries lesion is introduced as a safe method for controlling caries progression in non-cavitated enamel caries [21]. The ICON® (infiltration concept) were developed using a microinvasive technique. The material concept is based on infiltration into the porosity of the tooth structure and stopping further progression of the lesions. On the other hand, it shows many drawbacks such as difficulty in retention and high flowability when applied, in addition to the need for smooth proximal surfaces [39].

A method of treating caries has been introduced, by using RI materials that infiltrate and fill the pores of the early interproximal caries [40]. The idea of treating early caries lesions was established in 1970. Through years, this technique was developed to become easier and more effective in penetrating caries [41]. From there, RI was developed [42].

The research group led by Buonocore conducted the first experiments to penetrate low viscosity resins into carious lesions. After the advent of bonding agents and development of sealants, very few studies on infiltration of early carious lesions were conducted. In 1976, Robinson et al. published their earliest study on the concept of infiltration using adhesive compound called resorcinol formaldehyde on carious lesion, they found that the penetration of the resin greatly increased when etched with HCl for 5-10 seconds. An effort was
made to develop a new infiltration material with better properties such as having low viscosity, bactericidal, hydrophilic, mechanically supportive and cosmetically acceptable. Also, another material known as Chlornaphthalene was tested on the surface of the lesion and showed gradual penetration into the caries porosity, were 60±10% of the lesions pore volume had been occupied by the resin [43].

Robinson et al. conducted an in vitro study that compared resorcinol formaldehyde and other commercially available resins including Scotch bond TM (3M Dental products), All-bond (Bisco Inc., III), Amalgam bond (Parkell Biomaterials, NY) and Cyanoacrylates. The study showed that all the polymers reduced the available pore volume significantly after the first and second application and after the third application only resorcinol-formaldehyde and scotch-bond further reduced the pore volume significantly. The resin material had the potential to infiltrate into lesions and protect them from caries attack [44]. White spot lesions showed resistance to acid attack when etched with phosphoric acid and sealed with a resin material when compared to none treated white lesions [45].

Using an unfilled resin for sealing white spot lesions show its effectiveness in preventing further demineralization [46]. Evaluating the effectiveness of sealing active proximal caries lesions with an adhesive system after one year using the McNemar’s test showed regression on lesion and no further progression was seen [47]. Various RI materials showed promising results in terms of infiltration into the lesions and prevention from acid attack [47].

ICON® is an abbreviation for Infiltration Concept, introduced into the field of dentistry in 2008 for treating white spot lesions. It depends on a micro-invasive technique that is used for the treatment of white spot carious lesions on the buccal, lingual and proximal surface of the teeth [48].

Nowadays the RI material became commercially available as kits that contain all the material needed during the procedure, such as ICON® (DMG, Hamburg, Germany) [21].

Minimally invasive treatment of white spot lesion has been proposed in the past as using combination of micro-abrasion paste containing silicon carbide micro-particles in soluble water paste and 6.6% hydrochloric acid and enamel remineralization paste containing casein phospho-peptide amorphous calcium phosphate complexes (CCP-ACP) [49].

The major disadvantage of using this technique is the high amount of enamel that is eroded as part of micro-abrasion. The infiltration technique has several advantages over other techniques. First, deeper lesions can be improved by infiltration techniques which can’t induce remineralization and the esthetic improvement [49]. Secondly, when it is compared to other techniques, the infiltration is much less invasive [50].

ICON® caries infiltration technique is an alternative therapeutic technique to prevent the further progression of enamel lesions. The aim of this treatment is to block the porosities within the body of the white spot lesion with a low viscosity light-cured resin that has been improved to penetrate the porous enamel [50]. Infiltrates are light-curable and have low viscosity, low contact angles to the enamel and a high surface tension to complete penetration into the lesion porosity [50]. Before the applying RI material, the enamel is conditioned using 15% hydrochloric acid gel. The resin penetrates into the lesion driven by a capillary force. The ICON® infiltrate resin material was developed after pilot studies done at the University of Kiel, Germany, where they had experimented various mixtures of resin materials such as TEGDMA, BisGMA and ethanol using various mixing ratios [50]. A mixture of highest penetration coefficient was preferred as an infiltrate [51], so as to create a diffusion barrier within the lesion and not on the lesion surface. Once the resin material is infiltrated, excess material was removed from the surface of the lesion using a cotton swab and the material infiltrated. Curing was done using a ultra-violet light [51].

ICON® is available on the market as two products according to their use. The first one is known as ICON® caries infiltrant-approximal and is used in early interproximal caries lesions. The second one is known as ICON® caries infiltrate-vestibular and is used after removing the orthodontics appliances [52].

A single ICON® package consists of an infiltrate which is a composed of tetra ethylene glycol di-methacrylate, additives and initiator, an acid conditioner to etch the enamel surface made of 15% hydrochloric acid and ethanol. ICON® works on the principle of the light-scattering phenomenon. The sound enamel has a refractive index of 1.62. The porosities of a white spot carious lesion are usually filled with either a watery medium or air, which have refractive indices of 1.33 and 1, respectively. The whitish appearance of the lesion is because of the difference in the refractive index between the enamel crystals and the medium within causing scattering of the light. The micro-porosities on lesion body are infiltrated with the resin material which has a refractive index of 1.46, thus making the differences between the enamel and porosities negligible, so that the lesion appears similar to the surrounding enamel [50].

After the ICON® infiltration material was developed; many in vitro studies investigated the efficacy of the RI in penetrating and infiltrating the artificial caries lesions. They found that teeth treated with RI were more resistant to caries progression and had good prognosis compared to non-treated teeth [53].

An in vitro study done by Paris et al. [42] evaluated the penetration co-efficient of four experimental resin materials, to evaluate the effect of infiltration composition and penetration co-efficient (PC cm/sec) on inhibition of progression of proximal caries lesions. They found that the four experimental resins have different penetration co-efficient and that there is no significant different in the mineral loss between the four types.

Also, Meyer-Lueckel et al. [40] conducted an in vitro study to evaluate the penetration coefficient of ICON® in comparison to a commercially available adhesive using confocal microscopy and transverse microradiography. They found that that the maximum penetration depth and penetration percentage was significantly higher for the ICON® compared to the adhesive. Penetration of the resin infiltrating material is hampered by the mineralized surface layer of the white spot lesion. Etching should be done to remove this surface layer [17]. Different types of etching gels were used in removing the surface layer. Studies showed that using 15% HCl for 90 to 120 seconds is highly effective compared to 37% phosphoric acid [17].

The caries infiltration technique has mostly been tested on non-cavitated lesions; the effect of RI in cavitated lesions is unknown. Testing ICON® infiltrating technique on cavitated lesions on the proximal surface of premolars was done to evaluate infiltration patterns of proximal caries lesions differing in International Caries Detection and Assessment System (ICDAS) codes 2, 3, 4 or 5. Evaluation using microscopes measured the lesion depth, area of demineralized enamel, cavity depth, cavity width, cavity area, and extent of the resin penetration, also called as infiltration depth, and infiltrated area in
demineralized enamel and area of the cavity filled with infiltration. The resin infiltration penetrated deeply in all the demineralized parts but lesions with ICDAS codes 3, 4 and 5 had no infiltration. The depth of infiltration in ICDAS 4 and 5 was significantly lower compared to code 2 [54].

Few clinical studies were done to assess the efficacy of the ICON® material. Kim and his colleagues conducted a clinical study in 2011 at the Department of Pediatric Dentistry at Pusan National University to evaluate the effectiveness of the resin infiltration technique in masking white spot lesions on the maxillary anterior teeth following orthodontic treatment white spot lesions with ICDAS code 2, teeth with enamel defect were completely masked [55].

Through times, management of early proximal caries was a challenge [56], sealing early proximal lesions is very effective on stopping caries progression [57]. Resin infiltration would be the future of treating early caries lesions, since it's easily used non-invasive and painless technique.

Before etching and infiltration, deproteinization is recommended to improve surface roughness achieving a better outcome [58]. Also, treating early caries lesions with a combination of resin-infiltrated and fluoride varnish showed promising results compared to fluoride varnish only [59].

Treating proximal lesions with resin infiltration was more effective than non-operative measures. ICON® was effective in preventing the progression of the caries lesion when compared to no treatment [42].

Several clinical methods have been used for caries diagnosis, such as visual, tactile and radiographic methods. In addition, scanning electronic microscope (SEM) is an effective method of examining the surface changes in incipient caries in vitro [60].

Arnold et al. [61] used both light and electron microscope to study the infiltration of resin in initial caries lesions. They found that using different types of microscopes are effective in studying the pathways of infiltration of the resin into initial caries lesions.

Initial caries has several zones and each zone has different pore volumes. The superficial layer had low pore volume, while bodies of the caries lesion had 25% pore volume and finally the translucent zone at a depth of the lesion had 1% pore volume. The normal enamel contains only 0.1% pore volume [61]. So, low viscosity resins have been developed to infiltrate the initial caries lesions [62].

Acute caries cannot be infiltrated with RI, while chronic lesions show inhomogeneous infiltration with resin [61].

The RI technique has many advantages such as providing mechanic stabilization for the demineralized enamel structure, no structure loss of the affected or neighboring teeth, occlusion of the micro pore structures in the body of the lesion, arresting or decreasing lesion progression, reducing secondary caries, delaying the need for a restoration, no postoperative sensitivity or pulp inflammation, reduction of gingivitis and periodontitis risk and good esthetic results in masking white spot lesions [19].

Taher et al. [63], compared the surface roughness values of ICON® with healthy enamel using a profilometer. Contrary to the current study, no statistically significant difference was found between the infiltrate and healthy enamel, indicating that this material might be suitable for the treatment of enamel subsurface lesions.

Pyne et al. [64] conducted a study using AFM where they saw a generally smooth surface and some shallow depressions in healthy bovine enamel, which were thought to be caused by polishing. When compared to the Icon group, the control group showed much smoother surfaces visually and lower surface roughness values numerically. The Icon group showed non-homogenous surfaces with small granular particle mounds showing amount and distribution differences.

Hashizume et al. [65] stated that mature human dental enamel has a high degree of mineralization making structural studies somewhat less straightforward than for other tissues, particularly for mode of imaging involving transmission electron microscopy. Despite the variety of available in vitro tests for measuring surface changes, the most common form of reporting roughness average (Ra) within dental studies has been the surface profile Ra (Ra, arithmetic average) or the root mean square (Rq, geometric average). Profilometric means are usually used to evaluate surface roughness. Roughness is a measure of surface texture. It is often quantified by the deviations of the surface from its ideal form. If the deviations are large, then the surface is considered to be rough, meanwhile, the surface is considered smooth if they are small [66].

There are many studies in the literature which investigate the properties of the infiltrate [67], only one study aimed to evaluate the material at a Nano-scale using AFM [68]. This study evaluated the effect of water storage on surface Ra of healthy human enamel after application of ICON® and Seal-Rite™ using AFM and tridimensional micro computed topography. They found that fissure sealant group revealed the lowest Ra values and the Seal-Rite™ material was less affected by water storage than ICON® [68].

In RI technique, the infiltrant must be applied twice to decrease polymerization shrinkage and for the micro pore structure to be occluded [55]. When the demineralized enamel micro porosities are successfully infiltrated by RI, a decrease in surface roughness is expected [19]. The surface roughness caused by dental treatments is dependent on the materials being used. While some dental materials result in a smooth surface, some materials can create a relatively rough surface. Rough surfaces have an increased risk of bacterial adhesion and plaque accumulation compared to smoother surfaces and as a result rougher surfaces increase the risk of demineralization [69].

Qualitative methods such as SEM, and quantitative methods such as contact and non-contact profilometry as well as confocal laser scanning microscopy are other alternative methods to investigate surface roughness [70]. Unlike these other methods, the probe of the AFM device has the ability to determine the surface topography of the material vertically (X and Y axis) and horizontally (Z axis) on the Nanoscale. Thus, the images establish the topographic profile of the scanned surface accurately and numeric data obtained provides a reflection of these images. In addition, AFM provides higher resolution images and lacks the disadvantages and limitations of SEM such as vacuum and coating [71].

In a study by Ulrich et al. [58], ICON® was applied to natural lesions to investigate the surface roughness parameter Sa using a 3D scanning microscope, it was found that the ICON® samples had a higher surface roughness value compared to healthy enamel.

According to Paris et al. [72] before curing the resin, the excess infiltrate material should be removed because the remaining thin resin layer will increase the plaque accumulation and caries development. They found that the instruction manual provided by the manufacturer stated that the excess material was wiped off using a cotton roll before curing. Following the AFM analysis, it was observed that even after polishing a small amount of resin remained and rough areas were detected on the scanned samples' surfaces. The Sq values of the ICON®
group were significantly higher than the control group consisting of healthy enamel.

Previous studies stated that if a surface has a roughness value less than 200 nm (0.2 lm), then this roughness will not contribute to plaque accumulation, but if the value is higher, then plaque accumulation will be unavoidable [73].

Characteristic parameters as micro-hardness of infiltrated lesions might be influenced by monomer and solvent composition of infiltrates. Furthermore, repeated application of the infiltrate is recommended as it may influence such parameters. The commercially available infiltrate (ICON®) is based on TEGDMA. The addition of Bis-GMA in experimental infiltrates was intended to increase micro-hardness of infiltrated lesions, since Bis-GMA molecules have a more rigid molecular structure due to their aromatic backbone. Thus, Bis-GMA resins show higher flexural strength and elastic modulus than TEGDMA, thereby increasing the hardness of the polymer [74]. Furthermore, Bis-GMA was shown to decrease both polymerization shrinkage and contraction stress of TEGDMA-based composite resins [75]. Bis-GMA has a higher viscosity, thus reducing the penetration coefficient of the resin [62].

Paris et al. [76] conducted a study to evaluate micro-hardness and demineralization resistance of artificial enamel lesions infiltrated with various experimental infiltrates in vitro. Experimental infiltrates differed in their monomer composition and solvent content: Adding Bis-GMA to the usually TEGDMA-based infiltrates may reduce polymerization shrinkage due to higher molecular weight, but might concurrently reduce penetration depth. Adding ethanol as solvent may improve penetrability due to increased penetration coefficient of the resin, but reduce lesion hardness. The influence of such altered infiltrate composition and penetration coefficients on penetration depth and lesion progression of natural caries lesions has been investigated previously by Meyer-Lueckel in 2010 [62]. The influence of infiltrated composition on micro-hardness as well as the influence of once or twice application of infiltrates on micro-hardness and lesion progression was also investigated and the result showed significant increase in the micro-hardness and reduced mineral loss after demineralization compared with untreated lesions and the addition of Bis-GMA or ethanol solvent did not improve physico-chemical resistance of infiltrated lesions. Repeated resin application improves lesion micro-hardness and seems to also have beneficial effects on demineralization resistance [76].

Resin infiltration is currently indicated as its increase micro-hardness compared to untreated or remineralized carious lesions [77]. Hardness measurements of restorative materials were shown to correlate with other mechanical properties, like fracture resistance, elasticity, yield and compressive strength or abrasion resistance [78]. Reported surface micro-hardness for sound human enamel is 352 HVN [79] and for carious enamel is 0.29-3.29 GPa [80], while for the lesion infiltrated by resin is 33 HVN-0.32 GPa [76].

Infiltrated proximal lesions do not need to resist masticatory forces, but reinstate proximal surfaces, thus resisting proximal abrasion or attrition to preventing cavitation of lesions [76].

Conclusion

Data show this new technique complements existing treatment options for interproximal caries by delaying the time point for a restoration and consequently closing the gap between noninvasive and invasive treatment options.

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