Review

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Review

Brief Narrative Review on Commercial Dental Sealants—Comparison with Respect to Their Composition and Potential Modifications

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Abstract: The scope of this paper is to compare different dental sealants and flow materials indicated for sealing pit and fissures considering their chemical formula. The narrative review aims to address the questions: What is the essence of different dental sealants' activity, how their chemical formula affects their mechanisms of caries prevention and what makes a dental sealant efficient mean of caries prevention. Another vital issue is whether the sealants which contain fluoride, or any other additions have potentially increased antimicrobial properties. Methods: An electronic search of the PubMed, Cochrane, Web of Science and Scopus databases was performed. The following keywords were used: (dental sealants) AND (chemical composition). Additionally, information about composition and indications for clinical use provided by manufacturers were utilized. The review aims are to find crucial elements of sealants' composition which affect their cariostatic mechanisms.

Keywords: sealants; dental; fluoride; marginal integrity; caries prevention; resin-based sealants; composition

1. Introduction

According to World Health Organization (WHO), dental caries is a major public health problem globally and is the most widespread Noncommunicable Disease (NCD). Moreover, the WHO states that: "Dental caries can be prevented by avoiding dietary free sugars (…) is largely preventable through simple and cost-effective population-wide and individual interventions, whereas treatment is costly, and is often unavailable in low- and middle-income countries" [1]. To present the scale of the phenomena of untreated caries, the results of systematic review on the global burden of untreated caries can be referenced to. It reported that between 1990 and 2010 caries prevalence worldwide affected 2.4 billion people [2]. Over recent years, methods of prevention of tooth decay are shifting towards minimal intervention dentistry. Tendency to preserve as many natural tooth tissues as possible and nonrestorative approach are promoted [3].

Fluoride is an important factor in caries prevention. It has a proved impact both on cariogenic bacteria and on maintaining balance between the processes of demineralization and remineralization. It may disturb bacteria's metabolism and adherence to the enamel. Moreover, fluoride ions, when present in saliva in a sufficient amount, delay demineralization and promote enamel remineralization [4]. It is worth mentioning that antibacterial properties of fluoride are as important as the process of remineralization of hard tooth tissues. The mechanism of fluoride's antibacterial action considers diffusion of fluoride ions into the bacterial cell. At acidic pH values, enolase and adenosine triphosphatase enzymes are inactivated. Fluoride is also indicated to block the carbohydrate cycle,

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nonetheless scientists dispute over the exact antibacterial effect of fluoride [5]. The aforementioned multidirectional activity of fluoride is depicted graphically on Figure 1.

Dental sealants were first introduced in the 1960s, in scope of helping to prevent dental caries, mainly in the pits and fissures of occlusal tooth surfaces [6]. Since their introduction to the market, sealants are frequently mentioned as dental materials serving for caries prevention and managing early caries lesions [4]. Their effectiveness in preventing and detaining pit-and-fissure occlusal carious lesions of primary and permanent molars was concluded in a clinical guideline by the American Dental Association and the American Academy of Paediatric Dentistry [7]. The aim of this narrative review is to summarize the information on fissure sealants with particular emphasis on their composition as well as physicochemical and biological properties.

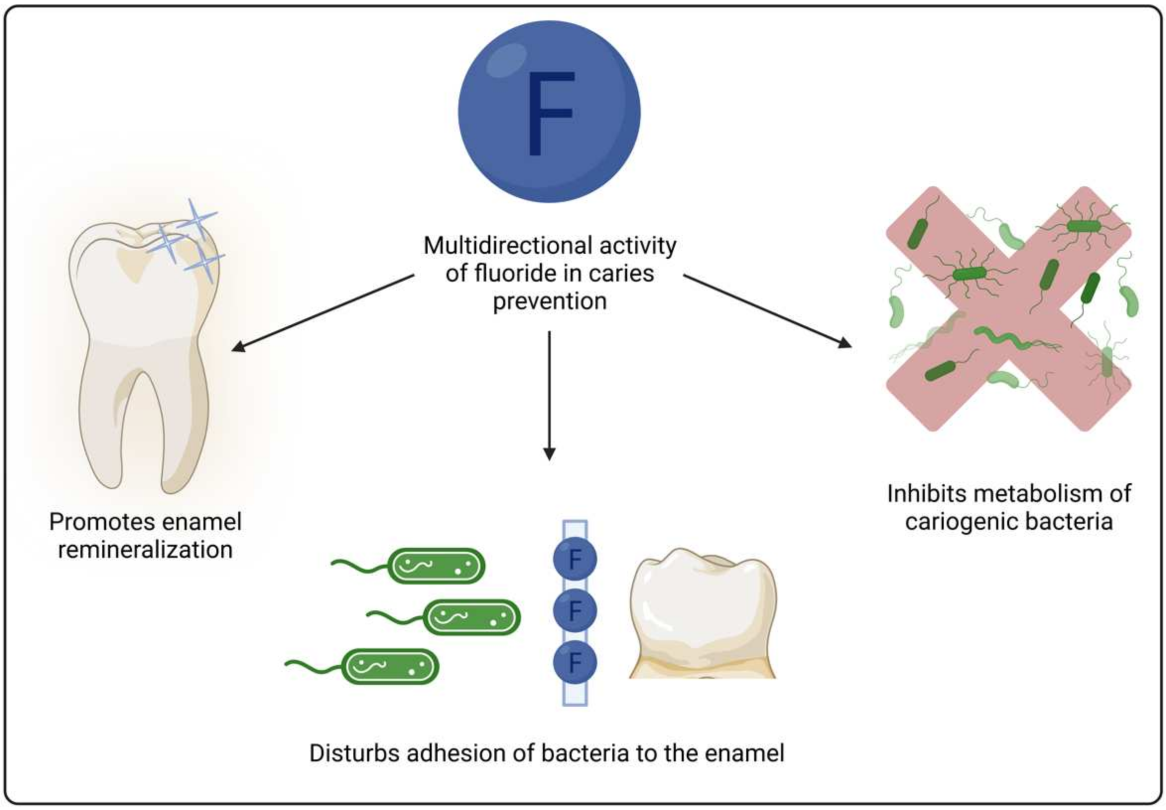

Figure 1. Graphical depiction of fluoride activity in caries prevention.

2. Methods

The review revolves around the following questions: What is the essence of action of different dental sealants and how their composition affects their effectiveness in caries prevention; Do the sealants contain fluoride and by means of what mechanisms they release it to the environment of oral cavity? An electronic search of the PubMed, Cochrane, Web of Science, Google Scholar and Scopus databases was performed. The following keywords were used: (dental sealants) AND (chemical composition) according to MeSH terms. Information about chemical composition of some commonly used dental sealants provided by manufactures were found.

3. Results

3.1. Comparison of Composition of Commercially Used Materials

Commercial sealants differ in the composition of matrix, added fillers or presence of fluoride. Their structure directly influences their properties. Therefore, a literature-based comparison of 19 different commercial sealants was performed. Juxtaposition was executed with respect to product name, abbreviation (for the sake of discussion), manufacturer, composition, presence of fluoride

(Table 1). Furthermore, the experimental properties influencing their clinical performance included shear bond strength, hardness and shrinkage. The references include peer-reviewed publications as well as Material Safety Data Sheets of the materials and other data shared by manufacturers. The table is lacking in parameters for few materials which indicate the gap in knowledge for further research on commercial materials.

The shear bond strength of the analyzed sealants ranged from 3.5 ± 0.8 MPa for FT up to 42.6 ± 3.2 for GS. In terms of hardness, HF possesses the lowest value (19.3 HV) and EGF the highest (99.3 ± 4.5 HV). Ultimately, shrinkage of the presented materials is within the range of 1.95 - 7.40% the lowest end being TEC and the highest TF1.

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Table 1. Juxtaposition of commercially used materials dedicated for sealing.

Product Name	Abbreviation	Manufacturer	Composition	Fluoride Presence	Shear bond Strength [MPa]	Hardness [HK] or [HV]	Shrinkage [%]	Reference
Helioseal F	HF	Ivoclar Vivadent, Lichtenstein	Bis-GMA, dimetacrylates fluorosilicate glass, silica, titanium dioxide, initiators and stabilizers	Yes	13.7 ± 7.0	19.3 HV	3.98	[8,9]
Embrace Wetbond	EW	Pulpdent, United States	Uncured acrylate ester monomers 55-60%, amorphous silica 5 %, sodium fluoride <2%	Yes	21.7 ± 2.0	23.9 HV	3.45	[8,10,11]
Fuji Triage	FT	GC Cooperation, Japan	Glass-ionomer, aluminofluorosilicate glass, polyacrylic acid, distilled water, polybase carboxylic acid	Yes	3.5 ± 0.8	52.0 ± 1.0 HV*	-	[12,13]
Smart Seal loc F	SSLF	Detax, Germany	bis(methacryloxyethyl) hydrogen phosphate, 2-propenoic acid, 2-methyl-2-hydroxyethyl ester, phosphate, 2-dimethylaminoethyl methacrylate	Yes	9.5 ± 1.4	-	5.06 ± 1.20	[14,15]
Fuji VII EP	F7E	GC Cooperation, Japan	Fluoroaluminosilicate glass, CPP-ACP, pigment, distilled water, polyacrylic acid, polybase carboxylic acid	Yes	5.0 ± 1.7	47.1 ± 6.0 HV	-	[12,16]
GCP Glass Seal	GCP	GCP Dental, Netherlands	Nanoparticles glass ionomer-based material	Yes	-	50.0 ± 1.5 HV	-	[13,17]
Ketac Molar	KM	3M ESPE, Germany	Al-Ca-La fluorosilicate glass, 5% copolimeracid (acrylic and maleic), polyacril enoic acid, tartaric acid, water	Yes	4.8 ± 1.0	89.9 ± 4.2 HV	-	[18,19]
Voco Ionofil Molar AC Quick	IMAC	Voco, Germany	Water, pure polyacrid acid, (+)-tartaric acid, aluminofluorosilicate glass and pigments	Yes	5.3 ± 0.6	79.9 ± 2.1 HV	-	[18,20,21]
Equia Fil	EQF	GC Cooperation, Japan	Polyacrylic acid, aluminosilicate glass, distilled water	No	-	99.3 ± 4.5 HV	-	[18]
UltraSeal XT plus	USXT	Ultradent, USA	Triethylene glycol dimethacrylate 10-25%, diurethane dimethacrylate 2.5-10%, aluminium oxide 2.5-10%, 2-hydroxyethyl methacrylate < 2.5%, amine methacrylate < 2.5%, organophosphine oxide < 2.5%, sodium monofluorophosphate < 0.1%	Yes	42.7	27.6 HK	5.98	[22,23]
Conseal F	CF	SDI, Australia	Urethane dimethacrylate base 7% filled with a submicron filler size of 0.04 µm	No	14.0 ± 0.9	-	-	[14]
Tetric Flow	TF	Vivadent	Bis-GMA (10-25%), urethane dimethacrylate (10-25%), ytterbium trifluoride, 1,10-decandiol dimethacrylate (2.5-10%), diphenyl(2,4,6- trimethylbenzoyl)phosphine oxide (0.1-2.5%), 2-(2-Hydroxy-5-methylphenyl)-benzotriazol; 2-(2H-Benzotriazol-2-yl)-p-kresol (0.1-1.0%)	Yes	16.8 ± 2.7	34.0 HV**	-	[9,24,25]
Tetric Evo Ceram	TEC	Vivadent	Dimethacrylate co-monomers (17-18 wt.%), barium glass, ytterbium trifluorid, mixed oxides and prepolymers (82-83 wt.%)	Yes	20.7 ± 7.2	51.0 HV**	1.95 ± 0.03	[24,26,27]
Wave	WV	SDI, Australia	UDMA, strontium glass	No	24.6 ± 1.5	-	5.00	[28,29]
Clinpro Sealant	CS	3M ESPE, Germany	TEGDMA, bisphenol A digilycidyl ether dimethacrylate, tetrabuttylammonium tetrafluoroborat, silane-treated silica	Yes	12.8 ± 8.3	21.5 ± 0.2 HV	6.60 ± 1.54	[15,30,31]
Grandio Seal	GS	Voco, Germany	Triethylene glycol dimethacrylate (10-25%), fumed silica (5-10%), Bis-GMA (2.5-5%)	No	42.6 ± 3.2	75.1 ± 2.0 HV	-	[31–33]
Fissurit FX	FFX	Voco, Germany	Triethylene glycol dimethacrylate (15–25%), Bis-GMA (5–10%), sodium fluoride (≤2.5%)	Yes	6.2 ± 0.7	-	4.30 ± 1.15	[15,34,35]
Dyract Seal	DS	Dentsply, Germany	Aminopenta, strontium-aluminium, macromonomer, fl uorosilicate glass, DGDMA, aerosil, initiators, inhibitor	Yes	8.3 ± 0.3	-	5.38 ± 1.30	[15,36]

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Teethmate F-1	TF1	Kuraray, Japan	2-hydroxyethyl methacrylate, TEGDMA, 10-methacryloyloxydecyl dihydrogen phosphate, methacryloylfluoride-methyl methacrylate copolymer, hydrophobic aromatic dimethacrylate, dl-camphorquinone, initiators, accelerators, dyes	Yes	-	26.7 ± 1.3 HV*	7.40 ± 1.17	[13,15]

* Recalculated from GPa; ** Coverted from HK.

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3.2. Modifications in Composition

Biomaterials used in dentistry are constantly evaluated to meet demands of clinical needs. Non-invasive approach and prevention are promoted in modern dentistry. Modifications of materials are performed to enhance their clinical behavior. Among desired traits of materials dedicated for sealing we may list durability, easiness of application or bacteriostatic potential.

In order to decrease biofilm viability on the surface of resin-based sealant its composition can be altered. Study presents that doping a methacrylate monomer matrix with 2.5 wt.% of 1,3,5-triacryloylhexahydro-1,3,5-triazine (TAT) in dental sealant's structure impacts its cytotoxicity, biofilm formation and physicochemical properties [37]. TAT exhibits antibacterial, antiviral, antifungal, and antiprotozoal activity. The results showed potential enhancement in antibacterial potential of dental sealant. The modified material did not show cytotoxic effect or decrease in any other physicochemical properties.

Another example of structural modification of dental sealant available on the market includes incorporation of methacryloxylethyl cetyl dimethyl ammonium chloride (DMAE-CB) into Helioseal pit and fissure sealant [38]. Since microleakage is claimed to be one of the major causes of secondary caries, authors of this study assumed, that it is crucial to increase it along with antibacterial activity of a sealant. Properties of a doped material including contact angle, degree of conversion, microhardness and microleakage remained similar to the origin material being a control group. A study concluded that the incorporation of small amounts (one percent of weight) of the monomer DMAE-CB into Helioseal may inhibit the growth of *Streptococcus mutans* and be an effective way of secondary caries prevention.

The antibacterial action of a dental material may be also obtained by an incorporation of acrylated hydroxyazobenzene (AHA) copolymers into a composite-resin matrix [39]. The study was based on samples of bisphenol A-glycidyl methacrylate and triethylene glycol dimethacrylate (bisGMA:TEGDMA) with and without AHA doping. It resulted in the same level of biocompatibility of both materials. Moreover, an inhibitory effect of AHA addiction on *Streptococcus mutans* biofilm growth was observed [40]. Authors claim, AHA may be incorporated into restorative and sealing materials in order to increase anticaries potential of dental materials.

As we may see in the Table 1. some of the materials for sealing contain fluoride in different forms, whereas others do not have it in their composition at all. Role of fluoride ions in caries prevention is important and was briefly described in the introduction paragraph. The study comparing sealant containing fluoride and without it showed differences in enamel hardness after cariogenic challenge [41]. Experiment was performed on blocks of human third molars and showed no significant differences between materials in aspect of marginal adaptation. However, it concluded that using fluoride sealant is recommended to prevent caries in high-caries-risk patients because of its favorable impact on enamel's hardness decrease. The chemical structure of aforementioned compounds used for doping sealing materials is depicted on the Figure 2.

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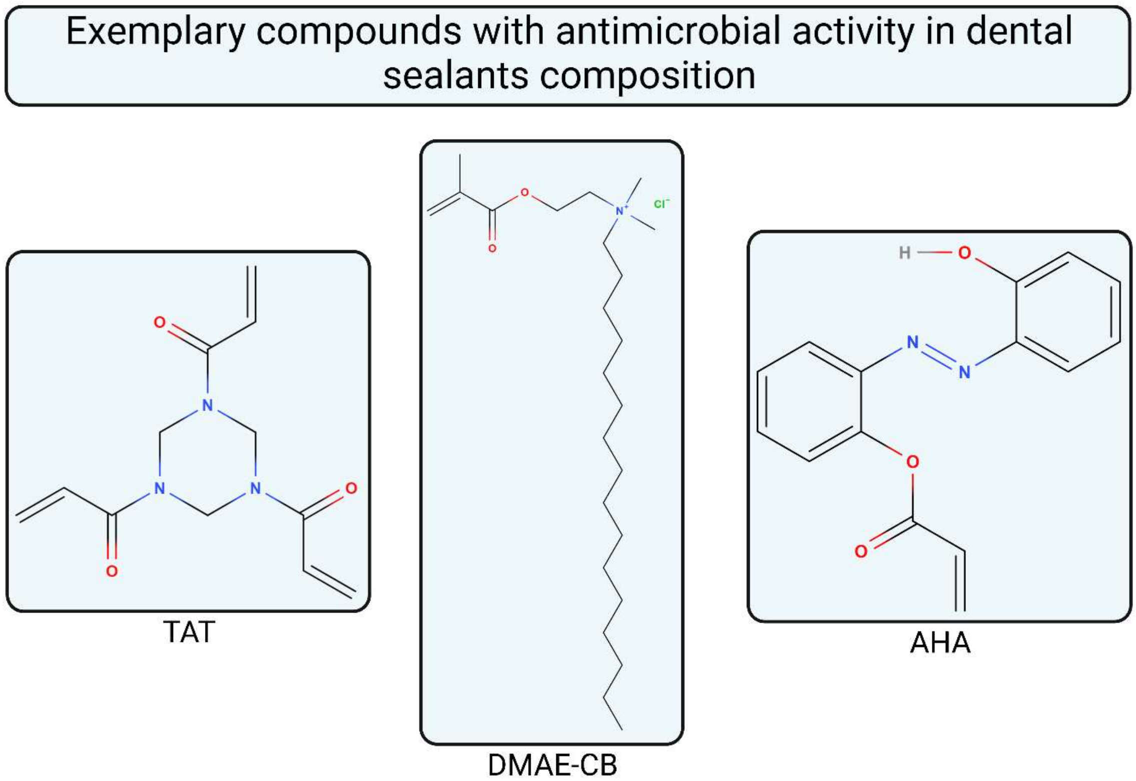

Figure 2. Exemplary chemical structure of compounds with antimicrobial properties used in dental sealants including 1,3,5-triacryloylhexahydro-1,3,5-triazine (TAT), methacryloxylethyl cetyl dimethyl ammonium chloride (DMAE-CB) and acrylated hydroxyazobenzenes (AHA).

3.3. Indications for Use

All of the considered materials defined as dental sealants are described by manufacturers as indicated to seal fissures, pits and *foramina caeca* of primary and permanent teeth. At the same time allergies or hypersensitivity for any ingredient of the material and inability to keep operative field dry are defined as contraindications. Flow composite indicated as suitable for sealing or releasing fluoride were also took into consideration into this study. Some of the materials are clearly indicated to extended fissure sealing, e.g., TF. Among analysed dental sealants that contain fluoride are HF, EW, FT, SSLF, F7E, GCP, KM, IMAC, USXT, TF, TEC, CS, FFX, DS and TF1.

The review based on several research, concluded that caries may be avoided in 60% of sealed surfaces [42]. At the same time, author notices that the beneficial effect is more significant in population of high caries baseline risk. The article points out that both resin and glass ionomer sealants are indicated as effective method of caries prevention. The time which is indicated as the most appropriate for sealing is a first year after eruption of the first molar and first two to three years regarding the second molar.

On may planes dental sealants are described as materials indicated to prevent caries and manage early carious lesions [4]. Once again, it is concluded that the most beneficial effect of sealing is obtained in the groups, mostly children, characterised by a high caries risk. Among the limitations of optimal sealant application authors list operator's and cooperation's dependent factors, such as optimum isolation, cleaning of the tooth surface and etching.

3.4. Microleakage and Adhesion

One of the desired features of restorative material is its durability. It depends on many factors and adhesion is one of them. The criteria considered in number of studies is marginal adaptation and microleakage as a factor describing material's potential of durability and efficiency. Adhesion depends not only on material itself but also on widely recognized surface preparation. Conditioning of the surface should provoke better retention of the material which is mainly mechanical as the physico-chemical interaction between the resin and etched enamel is small [43]. The essence of its action considering hard dental tissues bases on fulfilling the pores by resin monomers which are polymerised and are interlocked [44]. Etching has an impact on enamel dissolving rods and creating microporosities which can be penetrated by a material [45]. Adhesion which enables junction between dental material and hard tissues of the tooth is also a part of aforementioned non-invasive approach, as it promotes preserving sound dental structures. Producers usually provide user of the sealer with an instruction containing indications for use. Most of them advice to etch the enamel surface prior to applying a material by a 37% phosphoric acid for around 30 seconds (e.g. for 20-40 seconds such as in case of Arkona dental sealant [46]. It is a protocol commonly followed by clinicians which has support in numerous studies and sheets for the users attached to materials for sealing [47,48].

A lot of studies aim to find the best way of conditioning enamel surface so that pit and fissure sealing is most effective, which means has the lowest microleakage or better retention. The comparison of acid-etching, laser or combination of them both was tested in the contest of different sealants [49–52]. All above mentioned studies concern human teeth and natural enamel tissue. Most of them were performed on extracted teeth apart from one, which was conducted in the oral cavity of patients and controlled for one year [51]. This study concluded that both ways of conditioning – laser and acid-etching are successful in promoting sealant retention and in all cases there was no secondary caries detected. The studies on extracted teeth used an artificial samples ageing by using a thermocycling and water bath. The microleakage was assessed by imaging methods such as stereo-microscope, electron microscopy with energy-dispersive X-ray or SEM. It is worth mentioning that, all the researchers noticed some differences provoked not only by conditioning method but also by a material chosen. Better acid-etching (Effect of acid etching and different Er:YAG laser procedures on microleakage of three different fissure sealants in primary teeth after aging) In the most studies, no differences between acid or laser conditioning was noticed but combination of laser irradiation and acid etching resulted in a lower microleakage [50,52].

The study on twenty bovine incisors concluded that conditioning the surface of enamel provokes a higher bond strength under artificial aging. An ultrasound enamel preparation was compared with classical bur preparation on pit and fissure sealing in context of caries prevention[53]. Fissures of extracted third molars were prepared in different ways and sealed and assessed with SEM. Study shows that conventional bur preparation prior to sealing gives better retention and may be more effective in caries prevention than ultrasound preparation. Another approach is showed in the study which prepared an enamel not only with etching, but also with combinations with the use of the bonding agents or chlorhexidine digluconate [54]. Authors of this 6-month in vitro research claimed that microleakage reduction is most effective in case of conventional acid etching alone or with a one-bottle adhesive, while it is increased by applying of chlorhexidine digluconate. Conventional etching was also compared to self-etch method in a study conducted on third molars and shear bond strength was checked. This study showed superiority of self-etch preparation for applying a sealer in comparison to etching, adding that results depend also on chemical composition of the materials and content of 10-methacryloyloxydecyl dihydrogen phosphate [55]. At that point, it is worth mentioning that in general it is claimed, that self-etch systems require selective-etching by phosphoric acid anyway [56–58]. Conditioning enamel surface by acid-etching or no conditioning at all was also studied [59] and concluded that etching the surface promotes adhesion of the sealant and enamel.

Another aspect of adhesion considering composite materials is bonding procedures. Usually considering dental sealants, usage of bonding agent is not recommended by the manufacturer. However, it is regarded to use an adhesive to obtain better retention of composite materials. As mentioned at the beginning of this paragraph, adhesion is obtained by fulfilling the pores in the hard dental tissues by resin monomers which are polymerised and are micromechanically interlocked. Bonding agents penetrates microporosities, which were revealed after etching, by capillary attraction [60]. A clinical trial was performed at group of children aged 5-15, to compare retention of sealants with or without using a bonding agent within 12 months. The study concluded that ethanol-based bonding agent significantly increased the retention of sealants on different surfaces of teeth [61].

Taking all the above-mentioned studies into consideration we may assume, that conditioning the enamel prior to sealing has an impact on quality of sealing. That means, in general, there is significantly lower microleakage and better retention of the material. However, there are many studies promoting different approaches than given by the manufacturers which require further assessment to be commonly accepted. Bonding the enamel surface prior to applying sealant seems to be promising approach.

4. Discussion

Caries is a common disease. Due to difficulties with maintaining proper hygiene and greater susceptibility of milk teeth to caries, children are more exposed to it than adults. It is estimated that nowadays 621 million children in the world suffer from tooth decay. In Europe it affects 20 to 80% of children, depending on the level of development of the country [62]. Fissure sealants are commonly used materials, especially in the paediatric dentistry. Sealing is an effective way to prevent caries in permanent molar and premolar teeth. Lacquers are also utilised in case of minor carious lesions located in the fissures, as well as PRR method. The content of fluoride in the materials enable remineralization of hard tooth tissues and has a bactericidal effect. These are key features for young people who often have poor oral hygiene [63–65].

Numerous studies prove the high effectiveness of fissure sealants in prevention of caries formation. According to Fernandez Barrera M.A., the differences between the effectiveness of individual products of different companies are not clinically significant [66]. Considering materials used in the dental office, their price may be regarded as an important economical factor. While dental caries is a very common health problem globally and dental sealants are perceived as accessible mean of caries prevention, the differences in their prices may be significant. Therefore, it is important to choose the optimal material that will have good tissue retention and effectively prevent the caries formation. Multiple researches clearly indicate high effectiveness of fissure sealants in caries prevention [67]. Yet, the chemical formula and mechanical properties of the material are not the only factors that determine its efficacy. The clinical success of sealing pits and fissures lays also in operator's dependent factors and cooperation with the patient. Furthermore, it is worth to note, that sealing materials are compared to another method of prevention – fluoridation. Nonetheless, the application of fluoride usually considers full dentition present in the oral cavity of the patient instead of selected teeth surfaces. It should be emphasized that properly applied sealing does not have to be repeated regularly so as fluoridation [68].

As the meter of fact, market offers a wide variety of dental materials dedicated for sealing. The multiple studies prove their effectiveness in caries prevention. The beneficial effect of sealing pits and fissures depends both on sealing procedure and material's choice. Modifying dental sealants striving for increasing their cariostatic potential may be an interesting direction of dental materials' development. The research should not only be a R&D focus, but also a subject of interest of scientists around the world.

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