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Effects of Fluorides: General Aspects – Fixed Orthodontic Appliances: Caries and Prophylaxis

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Effects of Fluorides: General Aspects – Fixed Orthodontic Appliances: Caries and Prophylaxis

Wirkungsweise von Fluoriden: Allgemeine Aspekte – Festsitzende KFO-Apparaturen: Karies und Prophylaxe

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ABSTRACT

Enamel and dentine consist mainly of the hard mineral crystalline material “apatite”. The tooth surface is in constant contact with its environment: with saliva, biofilm plaque and everything entering the mouth. These include cariogenic and erosive substances as well as substances that promote remineralization. Substances from the dental hard tissue are released into the surrounding fluid and substances from the environment are absorbed into the tooth and deposited in or adsorbed on the crystal lattice. In order for the teeth to remain intact, no more material may be released than is re-integrated: a dynamic equilibrium prevails. To prevent new damage (such as caries or erosion), a balance favorable to the teeth must be maintained. This can be decisively influenced by appropriate nutrition and oral hygiene. Fluoride also has a positive effect on this balance due to its properties. During orthodontic treatment, carious lesions often occur, especially in the area of the front and canine teeth. The brackets are a retention site for the biofilm and the commonly used aids (toothbrush with toothpaste at home, bowl with paste in the practice) do not reach important areas. New methods such as Guided Biofilm Therapy (GBT) and aids for a better cleaning of the bracket environment are presented.

ZUSAMMENFASSUNG

Schmelz und Dentin bestehen zum größten Teil aus dem harten mineralischen kristallinen Material „Apatit“. Die Zahnoberfläche steht in ständigem Austausch mit ihrer Umgebung: mit dem Speichel, dem Biofilm Plaque und allem, was in den Mund hineingelangt. Dazu gehören kariogene und erosive sowie die Remineralisation fördernde Substanzen. Stoffe aus der Zahnhartsubstanz werden in die umgebende Flüssigkeit abgegeben und Stoffe aus der Umgebung in den Zahn aufgenommen und in das Kristallgitter eingelagert oder adsorbiert. Damit die Zähne intakt bleiben, darf nicht mehr Material abgegeben werden als auch wieder eingebaut wird: es herrscht ein dynamisches Gleichgewicht. Um neue Schäden (wie z. B. Karies oder Erosionen) zu verhindern, muss ein für die Zähne günstiges Gleichgewicht aufrechterhalten werden. Dies kann durch entsprechende Ernährung und Mundhygiene entscheidend beeinflusst werden. Auch Fluorid hat durch seine Eigenschaften eine positive Wirkung auf dieses Gleichgewicht. Während kieferorthopädischen Behandlungen kommt es insbesondere im Bereich der Front- und Eckzähne nicht selten zu kariösen Läsionen. Die Brackets sind eine Retentionsstelle für den Biofilm und die üblich verwendeten Hilfsmittel (Zahnbürste mit Zahnpaste zu Hause, Napf mit Paste in der Praxis) erreichen wichtige Stellen nicht. Neue Methoden wie die Guided Biofilm Therapy (GBT) und Hilfsmittel für eine bessere Reinigung der Bracketumgebung werden vorgestellt.

Mode of Action of Fluorides: General Aspects

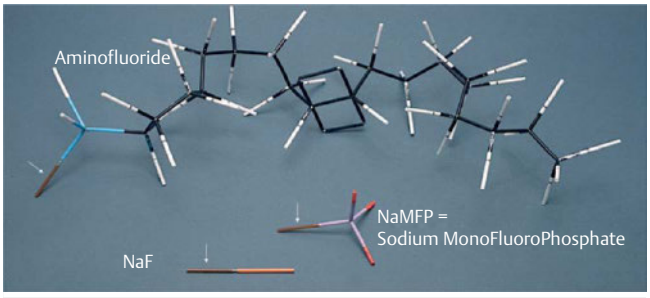
Tooth material

The dental hard tissue consists of highly mineralized enamel, as well as dentine and cement, which both contain significantly more organic material. The main – but not exclusive – constituent is calcium phosphate, which is bound in hydroxyapatite (HAP). However, several other ions are also incorporated. This leads to a less stable, more easily soluble apatite. Consequently, this increases the susceptibility of the enamel and dentine crystals to acids. If the dental hard tissue contains fluoride ions (F^-), fluorapatite (FAP) or a mixed form, fluoride hydroxyapatite (FHAP), are formed. As fluoride ions are anchored more firmly in the crystal lattice than OH^- ions, their partial replacement with fluoride ions can lead to a certain stabilization of the apatite structure. In this context, it should be noted that less than 5 % of the OH^- groups of HAP are replaced by fluoride in the outermost enamel layer of healthy human enamel. At a depth of 50 µm this ratio already decreases significantly.

Fluoride and its effects

Incorporated fluoride makes tooth enamel slightly less soluble in acid and thus protects against dental caries. This mechanism is of subordinate importance. The best protection is provided by fluoride dissolved in saliva or early plaque. This inhibits demineralization and promotes the remineralization of enamel, dentine and cement. The most important role of fluorides is therefore to shift the "caries balance" between attack and defense, loss and repair in favor of the integrity of the tooth [1]. It is therefore crucial that the supply of fluoride is maintained at the level required for dental caries prevention. Even small amounts of fluoride in saliva are sufficient for this mechanism. There is no significant difference in the effect between the different fluorides (▶ **Fig. 1**).

On the one hand, the dynamics of this dissolving process depend on the composition of the enamel, dentine and cement crystals, and on the other hand the bacterial composition of the plaque plays an important role. This explains the various critical pH values at which the dissolving process starts (enamel approx. 5.5, dentine approx. 6.5). This in part also explains the variations in caries activity between individuals, as the calcium, phosphate or fluoride contents of saliva and plaque vary from one person to another. However, the frequency of sugar intake and lack of oral hygiene influence these factors and also play an important role.



▶ **Fig. 1** Various types of fluorides. The binding site for F is marked with an arrow. In the case of aminofluoride, the major part of the molecule possesses surfactant properties. For the other fluoride compounds, surfactants are added separately.

It is now well proven that the decline in caries in industrialized countries during the last decades is due to the application of fluorides, mainly through local fluoride application and here primarily through the use of toothpastes containing fluoride. The use of fluoride table salt also increases the fluoride content in saliva following consumption.

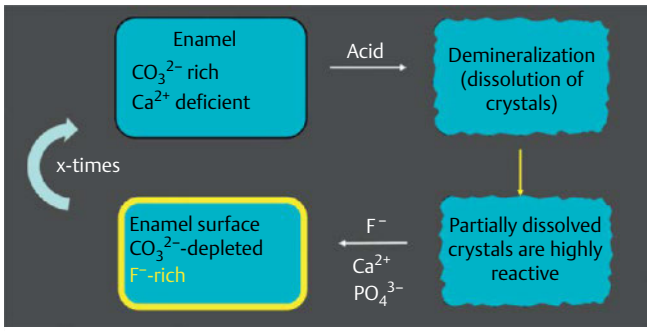
The inhibition of demineralization by fluoride

The incorporation of fluorides into the mineral components of the enamel only reduces its solubility to a slight extent. In contrast, small amounts of dissolved fluorides surrounding the teeth inhibit demineralization much more effectively and have a considerably greater potential for protection against caries than high levels of FAP in the enamel mineral. This was demonstrated on the tooth enamel of sharks, which consists of almost pure FAP. In comparison, healthy human enamel contains significantly less F^-, which, as already mentioned, is mainly located in the outermost layer. In shark tooth enamel with a fluoride content of 32,000 ppm, some 99 % of the OH^- sites in the crystal lattice of the enamel are replaced by F^-, whereas in human enamel this is less than 5 %. In experiments, carious lesions developed both in the shark's enamel as well as in the human enamel, with the depth of the lesions being slightly less in the shark tooth enamel. It could also be shown that the mineral loss in human enamel was even lower than in the shark enamel when the enamel was rinsed daily with a 0.2 % sodium fluoride solution [2]. This confirmed that the freely available fluoride ions in the solution surrounding the tooth play a far more important role in the prevention of caries than the fluorides incorporated in the enamel crystal. Here, the fluoride ions are in a dynamic equilibrium with the dissolved fluorides in the immediate enamel environment. This in turn leads to an equilibrium or supersaturation in the surrounding fluid with regard to fluoride(hydroxyl)apatite and thus to the precipitation of mineral on the tooth surface. Direct protection against demineralization is also attributed to this adsorption of fluorides on the crystal. On the other hand, the enamel crystal can be dissolved locally in the uncovered areas during an attack by acid. These low fluoride concentrations are also reached after consumption of food prepared with fluoridated table salt, as the F^- content in saliva increases significantly for about 30 min [3].

Promoting remineralization through fluoride

At a neutral pH value of 7, relatively low concentrations of calcium ions and phosphate ions in the tooth environment are sufficient to keep the dental hard tissue stable. If the pH value decreases due to the production of acid by the biofilm plaque, higher concentrations are required to prevent dissolving.

At a pH value in the plaque of approximately 5.5, undersaturation of the enamel begins, i. e. the concentration of calcium ions and phosphate ions in the plaque fluid is not sufficient to maintain enamel in a stable equilibrium state, resulting in the dissolution of enamel. Fluoride hydroxyapatite (FHAP) and fluoride apatite (FAP) on the other hand remain stable, even at lower pH values (▶ **Fig. 2**); here, undersaturation and the resulting dissolution start at a pH of approximately 4.7. If the pH increases, FHAP supersaturation will reoccur first, which means that FHAP and FAP will be formed again during remineralization, provided that fluoride dissolved in saliva is present in the oral cavity. Consequently, the proportion of stable



▶ **Fig. 2** Following an acid attack, the proportion of stable and low-carbonate FHAP (fluoride hydroxyl apatite) in enamel and dentine is increased at the expense of the carbonate-rich HAP (hydroxyl apatite), provided that fluoride is also present in the vicinity of the crystal.

and low-carbonate FHAP in enamel and dentine is increased during remineralization after each acid attack at the expense of the carbonate-rich HAP (▶ **Fig. 2**). Demineralized and subsequently remineralized dental hard tissue is therefore somewhat more acid-resistant than intact enamel [1].

In summary, it can be concluded that due to its low solubility, fluoride hydroxyl apatite is re-formed more quickly than the other calcium phosphate phases of the enamel, even in the slightly acidic pH range, which means that fluoride accelerates and promotes remineralization.

The fluoride content in healthy enamel is lower than in an initial lesion (chalk stain), as the latter has already undergone several phases of de- and remineralization [4].

The increased fluoride concentration in the surface area of the chalk stain is on the one hand based on the promotion of remineralization through fluoride, i. e. the formation of fluoride-rich apatite, and on the other hand also on an increased F^- absorption due to the porous surface of the chalk stain [5]. In the presence of fluoride, demineralized crystals act as seed for the deposition of new mineral. As already explained, fluoride accelerates this process, as remineralization is already possible at a lower pH value. Initial lesions are therefore relatively acid resistant and should not be treated if they can be cleaned.

Anti-microbial effect of fluorides

Fluoride can affect the 2 enzymes enolase and proton-translocating adenosine triphosphatase in the cell [6]. Based on the results of research to date, the caries-preventing effect of fluorides is indeed present in terms of processes in the oral biofilm, but is not of primary importance.

Fixed Orthodontic Appliances

Caries issues

Fixed orthodontic appliances, multibracket appliances as well as any other orthodontic intervention, including removable appliances, can increase the risk of caries [7]. A meta-analysis revealed that an average caries prevalence of 68 % and an incidence of 49 % can be expected in orthodontic treatment, particularly with multibracket appliances [8].

Øgaard and colleagues were able to demonstrate that initial lesions in teeth with fixed orthodontic appliances were already observed after only 4 weeks [9]. The issues relating to initial lesions occurring during treatment were analyzed in a review paper [10]. A total of 20 studies with 942 patients (mean age: 16.2 years) were included. On average, patients had 8.2 initial lesions (range 2.2–45.4) following orthodontic treatment. The paper explored the question as to whether these white spot lesions improved or could even be reversed with the additional application of various products. The following methods and products were used: ACP-CPP ("Tooth Mousse"), external bleaching, various fluoride applications, mouth rinses, varnishes, infiltration ("Icon") as well as a bioactive toothpaste. Highly concentrated fluoride varnish with monthly application was the most effective method for white spot remission following orthodontic treatment.

For these reasons, the treatment of orthodontic patients must also focus on keeping healthy teeth. The most simple method to avoid caries caused by orthodontic treatment is to avoid fixed orthodontic therapy. In the case of existing active initial lesions or persistent poor oral hygiene, this should certainly be considered before opting for fixed treatment. A study showed that the risk of demineralization was significantly higher in multibracket patients aged 11–15 years than in 19–24 year old multibracket patients. In the younger group, 52 % of all vestibular surfaces exhibited demineralization, in the older group this was only 7 % [11]. In cases with a very high risk of caries, fixed orthodontic treatment should therefore, if possible, only be initiated after puberty.

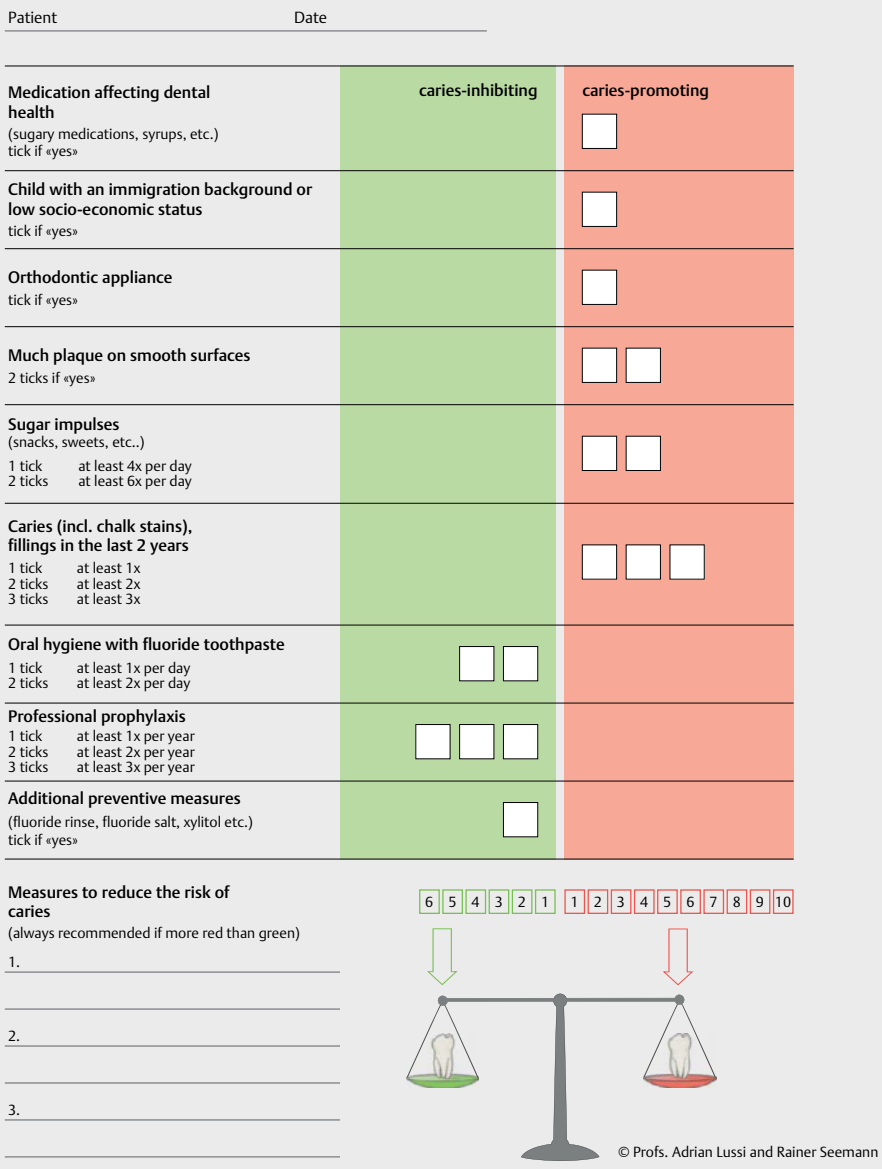
Good oral hygiene is also very important in prophylaxis in orthodontic patients to prevent caries lesions. Even after treatment, good oral hygiene must of course be maintained and plaque retention sites, such as the retainers, must also be cleaned.

Dental caries prevention

Diagnostics of caries, risk assessment as well as nutritional guidance

The first steps for adequate prevention are the diagnostics of caries, gingivitis/periodontitis as well as the determination of the risk of caries.

To conveniently determine the individual risk of caries, the schematic diagram illustrated in ▶ **Fig. 3** can be used. It is based on the findings of studies and recommendations, such as those of the American Dental Association [12]. The total number of caries-inhibiting factors (green) and caries-promoting factors (red), and thus the possibly skewed "caries balance" demonstrates the problem to the patient. The measures to correct the balance are discussed together and listed on the form. The risk analyses for children under the age of 6 years and adults are structured in a similar manner. If there is a high risk of caries, a multibracket appliance should be avoided initially. Among other things, patients should be introduced to improved oral hygiene and only undergo multibracket treatment after at least one year, when plaque control at home has been successful and the increase in caries has been stopped. Current bite-wing radiographs should be available if the approximal surfaces of the erupted permanent teeth cannot be assessed clinically.



▶ **Fig. 3** Determination of the risk of caries: the total number of caries-inhibiting factors (green) and caries-promoting factors (red), and thus the possibly skewed "caries balance" demonstrates the problem to the patient. The measures to correct the balance are discussed together and listed on the form.

The preventive measures should be coordinated with the family dentist: these can either take place in the family dentist's practice or at the orthodontist's during a follow-up session. The approximal plaque index (API) can be used during treatment with a multibracket appliance to monitor the clinical course. Here, it may be indicated to embark on risk-related, intensive prevention with shorter recall periods [13].

Studies have shown that the use of plaque indices specifically developed for patients with fixed appliances [14] is more advantageous and diagnostically conclusive than the conventional indices [15]. As in dentistry in general, dental caries prevention is based on several cornerstones. This includes nutritional guidance.

The consumption of soft drinks [16], which are frequently consumed during puberty when orthodontic treatment is performed, should be considered here [17]. It is therefore important to query the consumption of soft drinks, snacks, sweets ("sugar impulses", ▶ **Fig. 3**) and to draw attention to their cariogenic effect. Nutritional guidance is effective in caries prevention on an individual basis, particularly in the case of recognizable unfavorable behavior, and should therefore be employed in this way [18].

Fluoride application and cleaning of teeth

As fluorides do not act systemically but primarily locally directly on the tooth, the prescription of fluoride tablets has dwindled in virtually all countries, or is no longer practiced. Table salt fluoridation can be assumed to be an effective measure in preventing caries, although in countries which already have high levels of caries pre-

vention the added benefit of using a fluoride salt is difficult to demonstrate quantitatively due to the cumulative effect.

The daily use of fluoridated toothpaste is the basis of caries prevention with fluorides, as it is readily available and, when used regularly, the fluoride ions are continuously available for the caries-protective processes on the tooth surface. It is recommended to rinse with only a little water after cleaning one's teeth. On the one hand, this achieves a caries-reducing effect and, on the other, the majority of the toothpaste with its numerous additives is spat out [1, 19–21]. The caries-preventive effect can be demonstrated in all age groups and has also been demonstrated in subjects with a multibracket appliance [22]. It is further known that the effect of a fluoridated toothpaste increases with a higher frequency of tooth brushing.

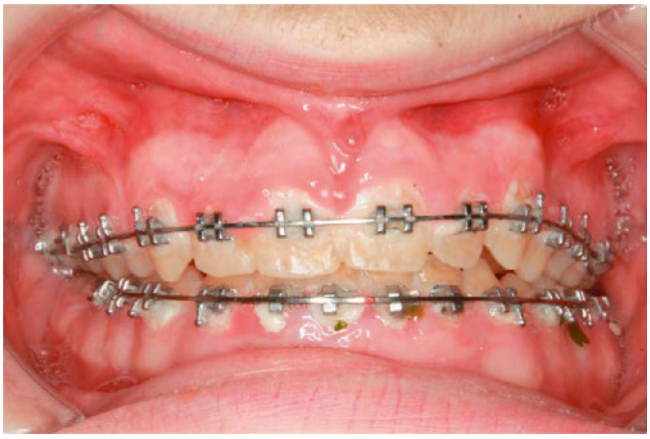
Mouth rinsing solutions containing fluoride are a good approach to achieving a caries-preventive effect with multibracket appliances. Here, commercially available mouth rinsing solutions containing a minimum concentration of 500 ppm fluoride should be recommended in addition to tooth brushing [23]. Patient compliance is often poor. Thus, it was shown that only about half of the adolescent subjects actually used mouth rinsing solutions, although they were instructed to do so daily [23].

A study in patients with fixed appliances revealed that during fixed treatment with regular application (every 6 weeks) of a fluoride varnish (23,000 ppm F^- such as CleanPro, Duraphat, Profluorid) the increment of caries could be reduced significantly. Therefore, professional varnish application should be performed routinely during the orthodontic recall appointments [24]. Highly concentrated fluoride varnishes are an efficient measure with very good evidence in the prevention of dental caries [25]. It is important here that the varnish is only applied to affected or endangered areas. There is some evidence that the use of a higher concentrated toothpaste (5000 ppm fluoride) is more beneficial in teenagers with a high risk of caries and inadequate oral hygiene than the use of conventional toothpaste with a lower fluoride content [26, 27]. Even with frequent applications, it should be noted that fluoride applications have their limits in terms of effectiveness for dental caries prevention, particularly in high-risk cases.

Which form of application is ultimately used depends on the patient's preference, i. e., depending on which type of fluoridation is preferred, the motto "never change a winning team" should be adhered to and the form of application should not be changed dogmatically.

Mechanical cleaning of the bracket environment

The facts presented above show that the usual preventive measures during orthodontic treatment are often not sufficient to ensure that patients can be discharged without caries after treatment. In particular, special aids need to be available which allow easy mechanical tooth cleaning in the presence of brackets, ligatures and archwires. Efficient removal of biofilm in the presence of the brackets is a sine qua non condition for caries-free teeth following orthodontic treatment. Cups (professional tooth cleaning) and toothbrushes (domestic tooth cleaning) often do not reach the important parts of the teeth (▶ **Fig. 4**).



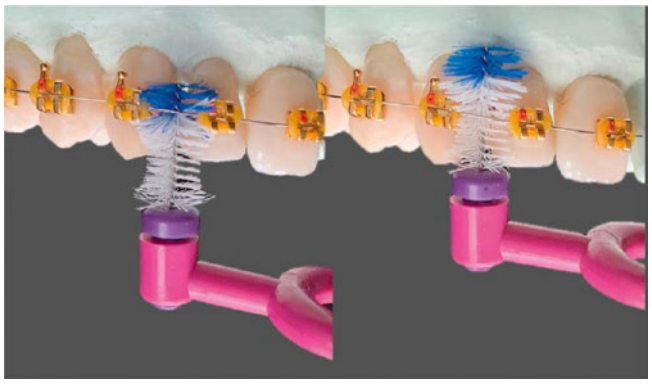
▶ **Fig. 4** Patient with very poor oral hygiene. Biofilm (plaque), gingivitis and dental caries are clearly visible.

For these reasons it is appropriate to offer better options for the efficient mechanical removal of biofilm in both domestic and professional prevention.

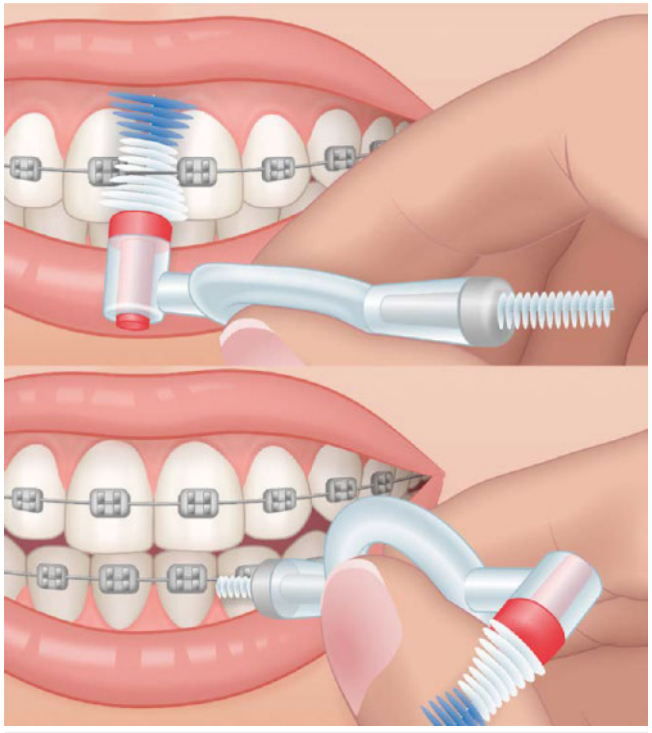
In this context, the focus is on the immediate surroundings of the brackets, whereby the other areas of the teeth and gingiva to be cleaned must of course not be neglected.

Cleaning of the bracket environment in domestic prevention

A fixed appliance considerably complicates cleaning of the teeth [28]. The majority of studies have shown that the use of toothbrushes alone is not sufficient to provide adequate cleaning. The areas cervical of the bracket in particular are often not reached by the brush. A wide variety of methods and aids are recommended. For example, single tuft brushes are used to clean the brackets and bands as well as the adjacent tooth areas during fixed orthodontic treatment. Interdental brushes, specially shaped hand or electric toothbrushes are recommended, or the adjacent enamel sections are sealed. The latter method exhibits only moderate evidence [29, 30]. For these reasons, an interdental brush was modified such that it can reach adjoining brackets and thus mechanically clean the caries predilection sites during orthodontic treatment (Top Caredent, Zurich, Switzerland). The hourglass-shaped interdental brush has proven itself in studies on cleaning interdental spaces and has been shown to be superior to the cylindrical brush shape [31, 32]. The differences between the orthodontic brush presented here and conventional interdental brushes are the pronounced hourglass shape, the filaments and the wire composition: the diameter varies between 9 and 5 mm, the filaments are extremely flexible and the plastic-coated wire with a diameter of 0.28 mm is very robust. The blue tip with its very fine filaments and the hourglass shape allows penetration into the space between the brackets from incisal or occlusal and cleans the area around the bracket, even if the brackets are placed further apart (▶ **Figs. 5** and **6**). The exact dimensions of the orthodontic brush were determined by A.L. measuring the distances between the brackets on the lingual and the vestibular side in adolescent and adult patients with fixed appliances. The blue tip with the very fine filaments also enables cleaning of the gingival margin. Here, the hourglass shape reduces



▶ **Fig. 5** Orthodontic brush: the fine blue filaments and the hourglass shape allow the brush to penetrate and clean the gaps between closely spaced brackets as well as when the brackets are positioned further apart. Here, the hourglass shape reduces penetration resistance and also enables cleaning of the horizontal parts of the brackets. The gingival margin is also cleaned.



▶ **Fig. 6** Orthodontic brush (see ▶ **Fig. 5**). A conventional cylindrical interdental brush on the other side of the holder is used to clean the interdental spaces.

penetration resistance and thus also enables cleaning of the horizontal parts of the brackets (▶ **Fig. 5**). A conventional cylindrical interdental brush is then used to clean the interdental spaces (▶ **Fig. 6**). This may in some cases also be used to clean retainers from incisal.

The decision "manual toothbrush versus electric toothbrush" is discussed controversially with regard to this indication. In conclusion, however, it can be stated that so far no significant superiority of the electric toothbrush has been proven. This is particularly true when the electric toothbrush is compared to the manual toothbrush with additional mechanical aids [33–36]. More important

▶ **Fig. 7** Removal of soft deposits with Airflow. The distance to the tooth surface is between 2–4 mm. The required working angle of 30° to 60° even allows cleaning under the ligature (source: Dr. Oksana Gulyaeva, Bashkir State Medical University, Ufa, Russia).

than the discussion on and recommendation of the type of toothbrush is whether it is used regularly and with proper attention at home in everyday life. Therefore, it is important not to give absolute recommendations, but to ask which aids are used and how much people like using these. This increases the patients' motivation. This way, the patients consider themselves to be a responsible part of the overall prevention concept.

In many cases, too much information, constraints and changes are given at the beginning of the instruction, which can prove overwhelming for the patient.

Cleaning of the bracket environment in professional prevention

Professional tooth cleaning should be employed in a risk-related manner and integrated into a concept as a motivational measure. Adolescents are amenable to arguments and causes: in a study of adolescents, the plaque and gingivitis indices obtained in the study group, in which detailed, explanatory prevention training was given, were significantly better than in the group with conventional instructions [37].

Great importance should therefore also be attached to good instruction and motivation by a qualified specialist.

Cleaning of the enamel sections adjacent to the brackets is difficult and virtually impossible with conventional methods without removing the inserted archwire. But even without the archwire, a cup, for example, does not reach all parts.

This is where Guided Biofilm Therapy (GBT®, EMS Nyon, Switzerland) provides an efficient and simple method. It is important here to first stain the biofilm so that the soft plaque can be removed selectively, thereby saving time. Staining also allows patients to be shown which areas are not well cleaned, motivating them to improve. The Airflow unit (EMS Nyon, Switzerland) is used to remove the soft plaque, whereby the distance to the tooth surface must be between 2 mm and 4 mm. As a working angle of 30° to max. 60° needs to be maintained, cleaning under the ligature is also possible (▶ **Fig. 7**). Dental tartar is then removed, for example with the Piezon PS (EMS Nyon, Switzerland), whereby the tip is guided parallel to the tooth surface and only the distal 2–3 mm of the tip touch the tooth.

Aerosol can be almost completely eliminated if a saliva ejector is used together with good suction (high vacuum suction; 300 l/min) operated by the dental assistant [38]. A recently published study showed that even when using the two-handed technique in combination with gargling/rinsing with an active rinsing agent prior to treatment, contamination of the aerosol is prevented. Adequate measures to displace soft tissue (e. g. Optragate (Ivoclar, Schaan, FL) or cotton rolls) combined with good suction are also important here [39]. The two-handed technique has the advantage that the direction of the aerosol is known to the person performing the treatment and that the suction device can be positioned at the right place.

The short recall intervals for monitoring the progress of orthodontic treatment allow the orthodontic practice to provide regular prophylactic care to patients and prevent caries and gingivitis.

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A.L. was permitted to perform the measurements of the distances between the brackets at the Clinic for Orthodontics of the University of Berne (Director: Prof. Christos Katsaros). These enabled an optimal design of the orthodontic brush.

Conflict of Interests

Adrian Lussi: consulting activity for several companies in the last 3 years, partly honorary, Rengin Attin: none.

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