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The Comparison of Root Resorption in Orthodontic Treatment with Clear Aligners and Fixed Orthodontic Appliances

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Table of content

Abstract

When choosing between clear aligner systems and traditional fixed appliances for orthodontic treatment, patients' aesthetic concerns may be a part of the decision-making process. Root resorption, a well-documented side effect of orthodontic procedures, emerges as a crucial consideration influencing treatment outcomes, patient satisfaction and oral health. This master thesis undertakes a comprehensive examination of the multifactorial and complicated relationship between aesthetic preferences, treatment modalities, and the incidence of orthodontically induced root resorption when using clear aligners or fixed orthodontic appliances. Various aspects of root resorption, including its aetiology, risk factors, and management approaches are discussed and evaluated. The research highlights the inherent benefits of clear aligner systems in reducing this issue, by carefully analysing the various effects of treatment modalities on root resorption prevalence. Key factors contributing to the lower incidence of root resorption associated with clear aligners include controlled force application, the ability to achieve milder and more controlled tooth movements, and shorter treatment durations. Additionally, patient-specific variables such as genetic predisposition, anatomical variations in root morphology, and previous dental trauma are examined in relation to their influence on root resorption susceptibility. The literature emphasizes the importance of diagnostic evaluation in the early detection and monitoring of root resorption, recommending regular radiographic assessments throughout the course of treatment. Furthermore, proactive management strategies aimed at minimizing root resorption risks and optimizing treatment outcomes are clarified, emphasizing the role of practitioners in delivering safe, effective, and patient-centred orthodontic care. In conclusion, this thesis offers valuable insight into the complex interplay between aesthetic considerations, treatment modalities, and the occurrence of root resorption in orthodontic practice during the use of clear aligners and fixed orthodontic appliances. The research intends to improve the quality of care provided to

orthodontic patients and support evidence-based decision-making by thoroughly addressing these factors.

Keywords: root resorption, clear aligner, fixed orthodontic appliance, orthodontically induced root resorption, orthodontic treatment

1. Introduction

Orthodontic treatment is a well-known and effective tool to correct malpositioned teeth, restore overall function and improve aesthetics (1). While conventional fixed orthodontic appliances have been the preferred treatment method for several years, clear aligners have become more popular as a more aesthetic satisfactory alternative (2). The possibility of root resorption, or the shortening of the tooth root as a result of acting orthodontic forces, is a crucial factor to take into account when contrasting these two choices (3). Root resorption can harm teeth permanently and have an impact on general oral health (4). While both techniques strive to align teeth, it is important to be aware of any potential implications either procedure may have on root resorption. Therefore, it is important to understand and compare the risk of root resorption with clear aligners and fixed orthodontic appliances (5).

Root resorption is a physiological process that could occur during or after orthodontic treatment. In contrast to root resorption in primary teeth, root resorption in permanent teeth is considered pathologic (3). During that pathologic process, the root of a tooth is shortened or lost due to the application of different forces. Some extend of root resorption is considered normal, but excessive or severe resorption can adversely affect long-term tooth health and stability. The relevance of root resorption lies in the stability, duration, and long-term dental health impact of treatment. It influences treatment outcomes, patient selection, and treatment planning (4).

Clear aligners are popular for their aesthetic and transparent appeal. This system uses gentle, controlled force to gradually move the teeth (6). Contrary fixed orthodontic appliances, apply a higher sustained force to control tooth movement. This raises concerns about the potential for increased root resorption (7). Hence the question arises if clear aligners induce less root resorption compared to fixed orthodontic appliances?

Existing studies suggest that clear aligners may induce less root resorption compared to fixed orthodontic appliances (8). It is thought that clear aligners' gentle and controlled forces cause less severe root resorption. Fixed appliances, on the other hand, may significantly enhance the likelihood and severity of root resorption due to their higher and continuous stresses (9). Understanding and comparing the effects of clear aligners and fixed orthodontic appliances on root resorption is crucial for informed treatment decisions (10). Additionally patient education is essential for understanding the risks and benefits of root resorption. Regular monitoring through 2D and/or 3D radiographic approaches, enables early detection and management of root resorption (11).

The aim of this review is to comprehensively analyse and compare the extend of root resorption associated with clear aligner therapy and fixed orthodontic appliances.

2. Mechanism of root resorption

2.1 Definition

Root resorption as a process, can be seen physiologically in primary teeth during the change of dentition or pathologically in the permanent dentition (12). The root of each tooth can be divided into three parts, which are defined by different mineral compositions and properties of the root covering cementum. Particularly related to root resorption through acting orthodontic forces is the apical part of the root. Especially the cellular cementum at the apex is known for its sensitivity to root resorption. Likewise, this area is affected with the highest apical pressure through applied orthodontic forces and has fewer mineral concentrations as the other parts of the root covering cementum. Due to the high forces involved in orthodontic treatment, the highest risk of root resorption is located at the apex of the tooth (13).

The mechanism of pathological external root resorption is associated with orthodontic treatment among other possible causes (14). During external apical root resorption, the root apex is getting shorter and flattened, which can be observed through dental radiographs before, during or after treatment (15). Orthodontic related root resorption is an induced inflammatory process through orthodontic forces applied to the tooth, whereby hyalinized areas of

the periodontal ligament are removed. Besides hyalinized tissues the cementum, defined as the covering of the root surface as an adhesive for periodontal fibers, are resorbed (16).

The orthodontic induced inflammatory root resorption can also be classified as a non-infection mechanism of action since the inflammatory process is not triggered by actively invading bacteria (17). The inflammatory process develops through orthodontic forces transmitted to the tooth and thereby resulting in clastic cell activity that results in loss of hard and soft tissue (12).

2.2 Prevalence

One of the most well-known and undesirable complications during or after an orthodontic treatment is the apical root resorption. This complication can be attributed to many factors and must be analysed and resolved individually prior orthodontic treatment by the orthodontist. This subjective can significantly influence the course, duration and time of the treatment (11,18). In general, Heboyan et al. revealed that the root resorption prevalence varies from 4 to 91% (4).

To categorize the severity of apical root resorption, Levander and Malmgren designed a scheme to represent and classify this known complication (19). The classification is based on the degree of severity of the apical root resorption (11). This approach is a visual qualitative method, which relies on the prejudiced view of the treating practitioner and not on the standardized radiographic technique. On the one hand, this scheme offers disadvantages, which can be attributed to the subjectivity of the classification procedure. On the other hand, each case is assessed individually by the dentist, which can display an advantage or disadvantage.

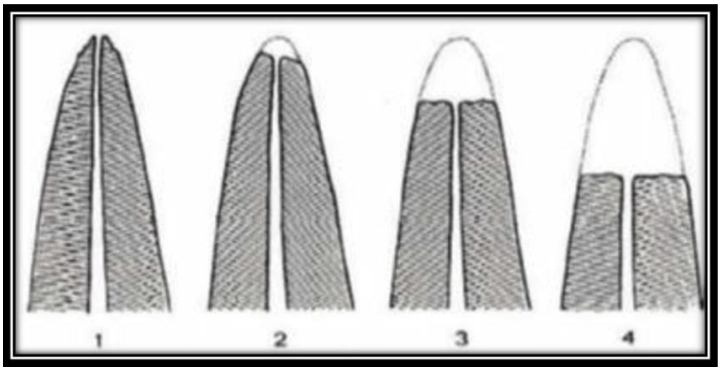

Figure 1: Schematic illustration of Lavender and Malmgren Classification for EARR (1988) (20).

According to that classification (Fig. 1), degree 0 means the absence of any resorption, degree 1 means aberration of the apical form, degree 2 means resorption up to 2 mm, degree 3 means resorption from 2 mm up to 1/3 of the root and degree 4 means severe resorption with a greater loss than 1/3 of the root length (11).

For severe apical root resorption, the frequency span differs from 1 to 5%, even in some cases it exceeds more than 5 mm and presents root resorption of 1/4 of the root length (18).

In addition, the prevalence of apical root resorption differs depending on the treatment principles (18). Li et al. stated that after a clear aligner treatment apical root resorption was diagnosed with a prevalence of 56,30%. In contrast to the more conventional treatment with fixed orthodontic appliances the risk of apical root resorption appeared with 82,11%. Additionally, the severity of root resorption in patients with a clear aligner treatment was not as distinctive as in patients with a fixed orthodontic appliance (11).

2.3 Aetiology

The appearance of apical root resorption is multifactorial and determined through many different factors before and during treatment. All these variables can be divided into patient-related and treatment-related factors (21).

In the literature many patient-related factors and their correlation are examined and discussed. As a result, many predisposing factors like the age of the patient at the start of the treatment, the gender, different malocclusion types, any parafunctional habits and allergies were excluded to have any impact on resulting apical root resorptions. However, a connection was found between treatment cases with including tooth extractions and previous detected root resorption (22).

With any orthodontic treatment, there are many variables that should be controlled and considered by the practitioner as they have been proven to pose a major risk for subsequent apical root resorption. The treatment-related factors like the magnitude and loading time of orthodontic force, the

force direction, the type of orthodontic appliance, the duration of orthodontic treatment and the different tooth movements may have an influence on the risk of apical root resorption (4).

All these factors should be considered individually prior treatment and during planning the following course of treatment. Every patient has different predisposing aspects, that could influence the risk of following apical root resorption. To avoid any unforeseen complications, the clinical and radiological assessment of the present state and patient history is crucial to provide the best possible treatment for each patient. For patients with already existing apical root resorption the risk of developing severe apical root resorption need to be considered and communicated with the patient (21).

2.4 Physiological process

During an orthodontic treatment, different kinds of forces are directly forwarded from the visible tooth crown to the tooth root, which can induce an inflammatory resorptive process (23).

The tissues involved in this resorptive process are known to be the cementum, periodontal ligament and the surrounding alveolar bone structures (24). The root itself is covered with cementum, which is capable of repair and protects the underlying dentin from resorptive processes, that could be triggered through the contact of dentin with precursor cells of osteoclasts. Orthodontic forces are acting as a frequent mechanical stimulus, which leads to a constant pressure exposure on the cementum of the root. The continuous stimulus can be compensated to a certain extent by the cementoblasts' own regeneration mechanism. However, if excessive and long-lasting forces act on the cementum because of orthodontic treatment, the cementoblasts can no longer keep up with their own repair mechanism and the underlying dentin is exposed (25). To maintain an equal cementum, a balance between the cementoblasts that form the cementum and the resorbing abilities of the surrounding osteoclasts are needed (24,26,27). If the osteoclasts predominate and destroy the cementoblast layer and the cementoid, the osteoclasts collide with the non-self-regenerating dentin, resulting in the irreversible resorption of the root dentin (24).

As known from recent studies especially the apex of a root is prone to develop root resorption (13). Nevertheless, resorption was also observed after orthodontic treatment at the cervical area of the root (25).

3. Clear Aligner therapy vs. Fixed orthodontic appliances

3.1 General principles of therapy

The most conventional treatment method used by many orthodontists, has been the treatment of various malpositions with fixed orthodontic appliances (28). These appliances have been preferred because they allow the practitioner great control and precise movements of the teeth (29). The treatment options with fixed orthodontic appliances cover a wide range, from small tooth movements and misalignments to complex problems such as skeletal discrepancies (30). Fixed orthodontic appliances can be placed either labial/buccal or lingual/palatal. A wide variety of bracket materials, such as metal and ceramic, are available on the market (29). Some materials want to offer the patient a more aesthetic option in comparison to the standard metal brackets (30). These appliances mainly consist of the anchoring brackets individually positioned and bonded with an adhesive system to the tooth and the connecting wire (29). Additionally, modifications can be done for different treatment modalities, as an example with attached hooks for the use of elastics to correct the bite relation of the upper and lower jaw (31). The individually attached brackets, can be either designed as traditional ligating or as self-ligating brackets. The self-ligating brackets offer free movement of the wire and thus the omission of regular adhesive or elastic bands. By omitting the elastics, that must be attached to regular stainless-steel brackets, less force must be used for tooth movements, as the self-ligating flap mechanism ensures free movement and less friction between the wire and associated bracket (32). Further, the literature shows that the use of self-ligating brackets has a positive impact on the entire treatment time of the patient, on chair-time with the practitioner and on the risk of occurring apical root resorption (28,33). Abbing et al. stated that the general duration of a treatment with fixed orthodontic appliances in adolescents and adults takes 24.9 months (34). However, treatment with fixed orthodontic appliances involves an aesthetic factor that every patient should consider and evaluate for themselve (28).

Since 1940 the alternative treatment option for mild to moderate malocclusions with clear aligners appeared on the market. From 1998 on, with the introduction of the manufacturer Invisalign, clear aligners became popular and established worldwide as an aesthetic alternative to fixed orthodontic appliances. Over the past years there has been a great development in connection with the materials used, auxiliaries, attachments and amplitude of different executing movements (35). Clear aligner therapy consists of each patient receiving individually made plastic aligners every two to four weeks, which must be worn at least 22 hours a day. The materials used to create this custom-made aligners are mostly out of polyurethane or ethylene vinyl. For patients, the aesthetic factor of the aligners is the focus, but each case should be evaluated about the severity of misalignments by a dentist, as the biomechanics differ fundamentally from fixed orthodontic appliances. The aligners move the teeth gently and with less force, which has advantages and disadvantages. Thus, difficult cases that manifest themselves in severe crowding, closing of big gaps, great bite problems and skeletal jaw discrepancies should resort to conventional therapy with fixed orthodontic appliances (36). The movement principle of the clear aligner is based on the fact that the crown of a tooth is completely covered and is pushing the tooth into the correct position by wearing the transparent aligners from week to week (35). This method of treatment is directly dependent on the reliable compliance of patients wearing the aligners, as neglecting this aspect means a prolonged overall treatment time. To ensure a quick and reliable result as a practitioner, the willingness to wear the aligner should be assessed and otherwise fixed orthodontic appliances should be used as an alternative (36).

3.2 Mechanism of tooth movement

The fixed orthodontic appliance consists of several parts that should be observed and ultimately contribute to the tooth movement. To exert force and the resulting movement of the tooth, brackets are individually placed with an adhesive system on all teeth, which in turn are connected by a force-exerting wire. Additionally in some appliances ligatures for attachment of the wire to the bracket and orthodontic bands for molars are used. The generated force from the wire is transmitted to the attached bracket, the

force therefore reaches a specific area on the tooth and initiates further biological processes that leads to tooth movement (29). The orthodontically applied force uses bodily movements of the tooth crown and root, such as uprighting, torquing, rotational, intrusive and extrusive movements (38). The biological process is based on mainly three different theories that are not yet completely understood in their overall context.

1888 Farrar came up with the Bone-bending theory of tooth movement (39). This theory states that all tissues around the area of the applied forces are transferring the energy, what consequently leads to bending of the surrounding bone and all adjacent structures. The principle follows the hypothesis of one pressure and tension side, where osteogenesis and osteoclastic activity are mainly involved focusing on the bone and the associated periosteum (Fig. 2) and endosteum (Fig. 3) (39).

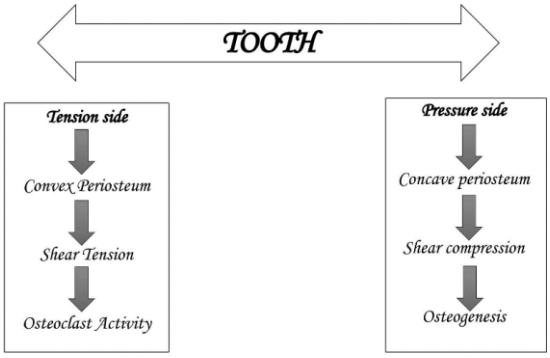

Figure 2: Flowchart presenting the effect of applied forces on Periosteum (39).

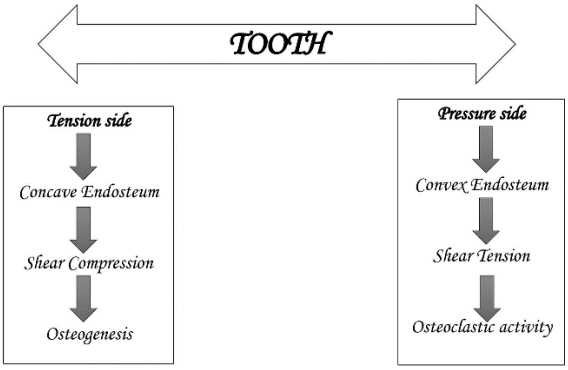

Figure 3: Flowchart presenting the effect of applied forces on Endosteum (39).

Bassett and Becker (1962) proposed the biological electricity theory (Fig. 4), whereas piezo-electric signals are transmitted through the bending of the adjacent alveolar bone and whereby a cascade of electron differences and temperatures activates cell activity and thus tooth movement (40).

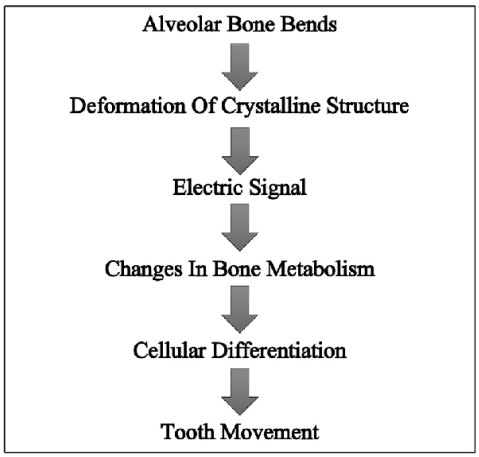

Figure 4: Bio-electric theory of tooth movement (41).

The pressure-tension theory (Fig. 5) was examined by Sandstedt (1904), Oppenheim (1911) and Schwarz (1932), based on variations of blood flow in the surrounding periodontium with admission and distinction of cellular activity (39,42–44). Through the direct attachment of the appliance and force mediation, all movements are under better control comparative to the clear aligner approach (45). The direct transmission of force through the fixed appliance, allows the application of large and continuous forces, which increases the risk of apical root resorption (16).

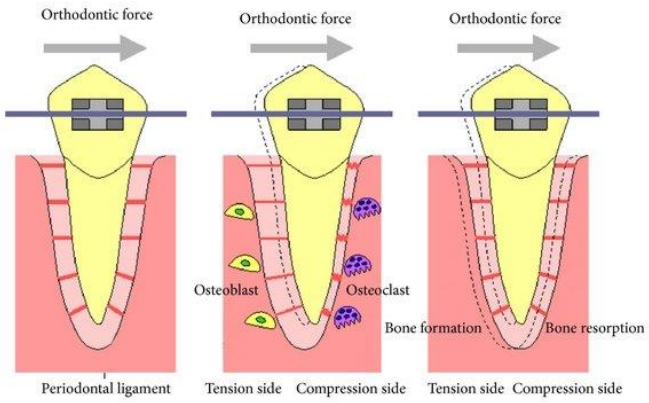

Figure 5: Schematic diagram of tooth movement. Applying orthodontic force to the tooth causes compression of the periodontal ligament. The compressed side of periodontal ligament is called the compression side and the side where the periodontal ligament is pulled is called the tension side. Osteoclasts appear on the compression side and osteoblasts on the tension side. The tooth moves as osteoclasts resorb bone while osteoblasts form bone (46).

The fundamental theories of tooth movement can also be applied in using clear aligners, however both approaches differ in the force transmission pathway (36,39). A clear aligner works different, as the force transmission is not focused on a specific area on the tooth, the force has several transfer points. By not adhering the tooth directly, but rather enveloping it, slightly lower forces are exerted on the tooth surface (35). On the one hand, this can have advantages when the risk of root resorption is considered, but this factor limits the treatment options for very complex tooth misalignments (16,35). Because there is no direct adhesion to the tooth, any tooth movement, that is carried out during the clear aligner therapy, cannot be controlled like with fixed appliances. In order to apply forces, negative impressions of the teeth are created and modified digitally to create clear aligners to slowly bring the tooth into the correct position using pressure points and flexible bending of the polyurethane or ethylene vinyl. The movement of the teeth is implemented by continuous wearing of the aligners, changing every 1-4 weeks depending on the difficulty of the case, until the teeth are in the correct position (36). This small movements are based on two different mechanisms.

The shape molding effect is constructed on the principle of creating a comparable shape of the targeted tooth crown with modifications and with the flexibility of the material to form the correct tooth movements. The existing difference in shape between the existing tooth and the clear aligner creates force transfer points on the entire tooth surface, which should ultimately lead to small tooth movements. Between the aligner and the tooth, there are surfaces that are in contact and other surfaces that balance tension. During the complete treatment with clear aligners, each aligner varies in shape and form to bring the teeth, by frequently changing the appliance, into the correct position.

Due to the rather uncontrolled movements of the clear aligner, there are certain aids, such as various attachments or power ridges, that create targeted movements (35). These auxiliaries are part of many treatments that are more complex than just mild misalignments to cause certain tooth movements (36). Auxiliaries are often attached to the tooth itself or in the aligner to transfer the force applied to a specific point on the tooth, to carry out controlled movements. Due to the smaller surface area of force

transmission about the attachment, the force of an aid provides a greater stress impact on the tooth itself (35). Of these two mechanisms, the shape-molding effect is primarily used, because it has a smaller impact on the tooth and the surrounding tissues, which demonstrably is one factor that reduces the risk of root resorption (16,35).

3.3 Prevalence of root resorption

The risk of developing root resorption in certain teeth during conventional orthodontic treatment with a fixed appliance is generally 20 to 100% if all patients are considered (11). However, this value is insignificant about a patient's own risk assessment of root resorption because it's determined by patient-dependent and treatment-dependent factors that differ in each individual case (16). In most cases, when root resorption is present, the level mild to moderate can be observed, as the level of resorption is only considered clinically significant at 1-2 mm of root resorption (47,48). According to Levander and Malmgren, to classify existing root resorption as severe, a greater loss than 1/3 of the root length must be visible (19,47,48). The occurrence of such extensive root resorption can only be observed in 1 to 5% of cases (47). Because the root resorption primarily takes place on the apex of the root, initially it has no negative impact on the patient; the root resorption is mainly asymptomatic and can be particularly diagnosed radiographically (47,48). The maxillary anterior teeth are mostly affected by root resorption with fixed orthodontic appliances, due to long orthodontic treatment time and increased distance, the apex of a root has to migrate (49). Anterior teeth show more root resorption than posterior teeth, independent of the upper or lower jaw (47). Whereas other literatures show an increasing occurrence of root resorption in the mandibular anterior teeth (3). For premolars and molars, a lower frequence and total resorption length of the root could be observed (50). Considering the severity of root resorptions, Li et al. observed that the maxillary canines and lateral incisors show a high degree of root resorption (11). Since the movement of teeth is due to the formation and breakdown mechanisms of the surrounding structures and the covering cementum, which can result in resorption of the root apex or lateral surfaces, a comprehensive risk assessment should be carried out with each patient before treatment (16,47).

During the orthodontic treatment with clear aligners, it is generally assumed that the likelihood of root resorption is greatly reduced compared to a treatment with a fixed appliance (51). Li et al. stated that the risk for apical root resorption during the clear aligner treatment showed to be 56.30% in comparison to 82.11% with a fixed orthodontic appliance in his conducted study. The significantly reduced risk of occurring root resorption can have various reasons. This lower value may be explained by some treatment differences with the removable and fixed appliances, which makes the general lower prevalence of apical root resorptions controversial (11). Since there are some limitations and the patient reliability factor when treating with clear aligners, generally mild to moderate misalignments are corrected with this system (36). In addition, due to the biomechanical standards, less force and therefore smaller tooth movements can be carried out (35). Both treatment-dependent differences could reflect the lower rate of root resorption development.

It is therefore often criticized that the compared cases used in the present studies are too different to make a definitive statement about the occurrence of root resorption after treatment (11). If you observe the changes in root length and evaluate them statistically before and after treatment, it becomes clear that with fixed appliances the root length varies on all teeth after treatment, but with clear aligners this change is only concentrated on the maxillary incisors and mandibular central incisors (51).

3.5 Patient-related factors

Every patient at the beginning of an orthodontic treatment, presents themselves to the dentist with an already defined initial situation. The practitioner must evaluate the risk of root resorption using an extensive clinical and diagnostic examination prior treatment (30). When evaluating the existing patient-dependent factors, the choice of orthodontic appliance initially does not matter. But if a patient shows an increased risk of root resorption due to existing predisposing factors, the choice of the appliance used later should be individually adapted (24). In patients with an increased risk of root resorption, there are some treatment-dependent scientifically proven variations that should be considered during orthodontic treatment;

this is preceded by a thorough patient history and discussion of the predisposing factors (21).

Since the individual risk of patients developing root resorptions differs significantly, although the type and method of treatment remains similar and standardized, the impact of genetics has been examined more closely (16). Behnaz et al. collected all the information about the influence of genetic variations on post-orthodontic root resorption. Ultimately, they found a connection between genetic variations in two different genes responsible for inflammation and bone remodelling, that may represent an increased risk of subsequent root resorption (52). Nevertheless, other researchers emphasize that the genetic factor and heritability are two different things to consider. Root resorption is a biological process, that can be traced back to genetic characteristics and variations, but it is not anchored in the germ cells and can't be passed on to the next generation, which does not indicate heritability (53).

Another factor that should not be neglected, is the previous exposure to systemic diseases such as certain allergies or chronic asthma (22). According to early research, by Brezniak et al. and McNab et al., asthmatic patients demonstrate an increased risk of root resorption of the maxillary molars (3,54). Brezniak et al. explains the relationship by the proximity of the maxillary molars to the sinus, which in asthmatic patients shows a chronic inflammation and a constant appearance of inflammatory mediators (3). Despite the previous assumption of a connection between systemic diseases such as asthma/allergies and root resorptions, Santos et al. changed the perspective. Santos et al. stated that a pre-existing systemic disease should not be inferred from an increased risk of root resorption after orthodontic treatment (55).

In 1988 Levander and Malmgren found a connection between certain root shapes and sizes and later appearing root resorption (19). Together with Nigul et al. an increased probability of root resorption was found on roots with a pipette-like and blunt shaped apex (19,56). Other researchers were able to confirm this relation and found root resorption, especially in long roots, in roots with trigonal sharp apexes and dilacerations and in lateral incisors of the upper jaw (16,57).

When it comes to endodontically treated teeth, researchers are divided into two parts, whether these teeth have a greater risk of suffering from root resorption than vital teeth or vice versa (16). Many people think that the endodontic treatment of a tooth makes the root more susceptible to root resorption, but according to the latest findings, the neuropeptides of the pulp tissue play a role in root resorption, which are ideally completely removed after endodontic treatment (16,47). If a good quality endodontic treatment has been performed, the tooth's blood supply and associated red blood cells should have been removed, which may result in a minimal reduction of root resorption. Although the reduction in root length resorption can be measured radiographically, it is clinically not visible (16).

If a tooth had suffered previous trauma that is not the result of orthodontic treatment, orthodontic treatment will cause even more root substance to be lost and root resorption to progress (47). The trauma usually damages the layer of cementum, precementum and the structures of the periodontal ligament, which process is based on the principle of root resorption. Recommendations suggest orthodontic treatment at earliest, 3 months after the trauma (48).

In summary, it is clear from the literature that patients who have already experienced root resorption have a greater risk of suffering from severe root resorption following subsequent orthodontic treatment. It does not matter whether the initial root resorption was caused by trauma or previous orthodontic treatment (21,58). If the patient's factors such as gender, malocclusion type, bruxism, onychophagia, biting objects, tongue thrusting and thumb sucking are considered, a connection with an increased risk of root resorption can be excluded (22,47,50).

3.6 Treatment-related factors

Once the potential risk of root resorption has been evaluated, after a thorough history and clarification of patient-dependent factors, the appropriate appliance should be selected to keep the risk of root resorption as low as possible (30). The patient has the option of wearing a removable appliance such as the clear aligner or a fixed appliance such as metal brackets with a wire. The decision about the device used should not only be based on the patient's preferences, but also on the risk assessment carried

out by the dentist regarding root resorption, as both device systems are fundamentally different and have differing effects on the risk of root resorption (13). In order, to be able to evaluate these differences and effects individually, the type and magnitude of forces, direction of tooth movement and duration of orthodontic treatment should be considered (16).

The type of orthodontic force used during the treatment-period is crucial when it comes to the risk of possible root resorption (16). Two different types of force transmission can be mentioned, such as intermittent and continuous forces, as they are represented in clear aligners and fixed orthodontic appliances (51). The removable clear aligner is worn ideally for approx. 22 hours a day and can be removed for eating, drinking and brushing your teeth. This treatment methodology corresponds to intermittent forces applied to the teeth to be treated, with a small timeframe for the root covering cementum and surrounding tissues to heal and regenerate after the period of loading (47,59). In contrast, the fixed orthodontic appliance, through the wire permanently attached to the bracket and tooth, uses continuous forces that are difficult to control. Since this appliance is permanently attached to the patient's teeth and is not removable like the aligner, the forces are permanently transferred to the apex, resulting in ongoing clastic activity and tooth movement (58). Thus, it is evident, that there is a higher risk of root resorption in continuous forces, such as fixed orthodontic appliances (16). From this thesis it could be stated, as Aras et al., that intermittent forces are used during treatment with clear aligners, which have a lower risk of occurring root resorption (60). Accordingly, patients with a high risk of root resorption should tend towards clear aligner treatment if this seems appropriate in their individual case and all other factors have been considered in the decision-making progress (21).

Not only the type of force, but also the magnitude of forces used during orthodontic treatment is crucial when it comes to the risk of root resorption (13). Topkara et al. stated that during the course of a treatment with clear aligners or fixed orthodontic appliances, if heavy forces are applied, the chance of developing root resorption increases significantly, in comparison to using light forces (21). With a clear aligner treatment, the design of the aligner simply covers the tooth, which, compared to fixed orthodontic appliances, leads to low force transmission and thus to smaller and

controlled movements of the teeth and a lower risk of root resorption (36). In fixed orthodontic appliances, through the application of heavy forces, the biological events like resorptive and reparative processes are impaired (58). Despite the existing literature confirming a connection between the use of heavy orthodontic forces and the risk of occurring root resorption, there are some researchers who observe no difference, despite the use of heavy forces (3,16). Nevertheless, Schwartz described that increasing force of 20-26 g/cm² can trigger the process of root resorption and all associated biological processes (3). Chan et al. set the preferred value of forces, that they do not generate an increased risk of root resorption, to 7-26 g/cm². Paetyangkul et al. found another connection; no matter how high the force is, if it becomes stronger, the risk of root resorptions also increases (61).

During orthodontic treatment, different movements of the teeth are performed with clear aligners and fixed orthodontic appliances, with some having a higher risk of causing root resorption than others. The possible tooth movements during a orthodontic treatment are bodily movements, tipping, extrusion, intrusion, rotation and torque (58). According to the literature, there is a connection between extrusive and intrusive movements, just as with bodily movements and tipping, when it comes to a possible increased risk of root resorption (47). Jacob et al. stated that especially during intrusive movements the risk of orthodontically induced root resorption is the highest compared to all other tooth movements (58). Topkara et al. mentioned that root resorption can also occur with extrusive tooth movements, but the risk of occurring root resorption with intrusive movements is about four times higher. Additionally, the general statement about tooth movements is that compressive forces pose a higher risk of root resorption than tensile forces (21). Dindaroğlu et al. tried to explain this phenomenon by saying that intrusive movements cause increased accumulated pressure points in the small apex region, which results in an increased risk of root resorption, because this intensified acting force operates through the root anatomy on a comparable small area (16). To build on this explanation, Jacob et al. added that the risk of root resorption with bodily movements is smaller than with tipping, since with bodily movements the force applied can act over a larger, distributed area. During the tooth movement of tipping, an increased force transmission was found at

some points at the alveolar crest and the apex (58). Ultimately, the forces produced during intrusive movements in teeth with lingual torqued roots that are moved by tipping have the highest risk of root resorption (21). Another treatment-related factor that correlates with an increased risk of severe root resorption, is the treatment length and the period of active treatment (21,58). Jacob et al. summarized the existing literature about the connection of the treatment length and an increased risk of root resorption. In his literature review he stated that there is an existing correlation between the duration of the treatment and the occurring increased severity of root resorption (58). Levander and Malmgren were already able to prove that a shorter treatment time means a lower risk of root resorption as a result of orthodontic treatment (3,19,62). To address the risk associated with fixed orthodontic appliances, Lopatiene et al. stated that patients who had the appliance for a longer period, had an increased average of level 2 root resorption. The factor of the duration of the treatment should not only be considered individually, but it also depends on the magnitude of forces applied. The risk of suffering from severe root resorption with fixed orthodontic appliances after a treatment time of 2.3 years is higher compared to 1,5 years of treatment where normally no root resorption appears (47). As a result of the lower and intermittent forces and the generally milder treated malpositions during the clear aligner treatment, the risk of a greater severity of root resorption through an increased treatment time is much lower (63). In addition, through the frequent treatment breaks, because of the removable capability of the clear aligner appliance, the cementum has time to regenerate and the process of pathological resorption is not getting started (35,36). An extended treatment time is automatically accompanied by further movement of the teeth with fixed orthodontic appliances, which increases the risk of root resorption (22). With clear aligners, only small movements are usually carried out, which can also lead to root resorption, but with a reduced risk (36,63). To reduce the risk for fixed orthodontic appliances, a treatment break of 2 to 3 months after an active phase with a passive wire or discontinuous force during treatment, would be an ideal compensation for the previous high force load (21).

3.7 Diagnostic evaluation

For diagnosing external root resorption during an orthodontic treatment, radiological assessment is a crucial modality since patients usually have no symptoms and only with a high degree of root resorption clinically visible tooth mobility becomes apparent (64).

As a preventive measure frequent radiological evaluation is an obliging method to prevent severe root resorption during the following treatment. Several options for radiographic examination are given in the field of dentistry. In connection with orthodontically induced root resorption especially panoramic images, periapical radiographs and cone beam computed tomography (CBCT) should be mentioned. The panoramic radiograph gives a large overview about all relevant anatomical structures and reflects the stage of root resorption in high quality. However, the quantity of overlapping structures may influence diagnosing possible teeth with external root resorption in a negative way. Compared to the panoramic image the periapical radiograph gives a detailed information about the shape and condition of the root. The level of root resorption can be precisely determined in these pictures, but this procedure is done mostly on individually selected teeth. The most precise radiographic modality is the CBCT, through the 3D representation of anatomical structures. Additionally to a more effective root resorption detection, some clear aligner systems integrate CBCT into their treatment process in order to visually compare the position difference of the teeth before and after treatment with the virtual set-up and the resulting CBCT (65). Nevertheless, this method is only considered in individual cases, since as a dentist the ALARA (As Low As Reasonably Achievable) protocol for radiation protection should be followed (66).

Concluding the main diagnosing tool to detect external root resorption, during a clear aligner or fixed orthodontic appliance treatment, should be the panoramic radiograph. If some teeth are already compromised or if a more detailed view is needed, the periapical radiograph plays a significant additional diagnostic assessment tool. For more complicated individual cases, there might be a need for an additional CBCT scan for determining the extent of root resorption (11).

3.8 Prevention and management

To prevent the development of severe root resorption and to detect it in an early stage of treatment, frequent radiological monitoring of the teeth and clinical evaluation are indispensable (11). Moreover, a precise anamneses of the initial situation before starting treatment for each patient and the previous dental history is essential to evaluate the individual risk of root resorptions (16).

Before starting treatment, some considerations should be made about the course of treatment and the existing risk of root resorption (58). The patient should be aware at the beginning of treatment that orthodontically induced root resorption during or after the treatment is a common and frequent phenomenon (13). Radiographic monitoring is recommended before, during and after treatment, and again annually in the area of the front teeth as the risk of root resorption is increased in this region. After a prior assessment of the respective patient's risk of root resorption, the treatment-dependent factors are determined by the practitioner individually. According to the latest literature, it is advisable to start orthodontic treatment at a young age, to choose between a clear aligner treatment and a fixed orthodontic treatment according the difficulty of the case and the individual risk of root resorption, to determine the treatment time as short as implementable, to regulate the magnitude and type of forces applied and to control the movements carried out individually to keep the risk of root resorption as low as possible (58).

In summary, every patient who undergoes orthodontic treatment is at risk of potential root resorption and should be aware of that, but the risk varies individually and is determined by many individual different patient-dependent and treatment-dependent factors (16).

During orthodontic treatment with fixed appliances, when root resorption is becoming visible radiographically, taking a break of active treatment using passive wires, which in turn do not exert any force on the teeth and allow the cementum and surrounding structures to regenerate, is a possible method to manage occurring root resorption from getting worse (21). For treatment with clear aligners, a treatment break from active forces is easy to reach

since the appliance is worn maximum 22h a day and the treatment itself can be paused by the dentist's instructions through the removable features if the development of root resorption becomes visible radiographically (35).

If the pretreatment X-ray reveals pre-existing root resorption and the orthodontically indicated risk of suffering from severe root resorption increases, there are a few treatment alternatives for the dentist to consider. Treatment with a fixed orthodontic appliance can be limited to teeth that have no root resorption or the patient is advised not to start orthodontic treatment at all. This treatment alternative could be difficult with a clear aligner, as the aligner is made from one continuous piece and usually covers all the teeth. Likewise, when treating with both appliances, care can be taken to minimize root displacement, or the alternative of extraction treatment followed by implantation would be more desirable (67).

4. Conclusion

For many patients the aesthetic appearance, before starting an orthodontic treatment, plays a significant role whether to choose a fixed orthodontic appliance or a clear aligner system (2). The focus for the practitioner is to choose the most suitable individual treatment and to reach the best possible result, without the appearance of any undesired side effects (30).

After years of research, it is known, that root resorption is a common and unwanted side effect of orthodontic treatment, determined through many different factors (3). Appearing root resorption can compromise the patient’s oral health and prognosis of the teeth (4). Orthodontically induced root resorption is a pathological process, mostly seen on the apex of the root (12,13). The risk to develop apical root resorption could be influenced through treatment-related factors from both differing treatment techniques with fixed orthodontic appliances and clear aligners (9,16). Additionally, each individual patient has determined patient-related factors that could influence the risk of apical root resorption (16).

To distinguish between mild and severe root resorption, Levander and Malmgren created a classification scheme (19). The prevalence of appearing root resorption in clear aligners with 56,30% is significantly lower than in fixed orthodontic appliances with 82,11%. Furthermore, generally milder

root resorption can be observed with clear aligners, than with fixed orthodontic appliances (11).

Patient-dependent factors such as genetic variations, pipette-like and blunt shaped root apexes, previous trauma, and patients with previous existing root resorption, have been associated with an increased risk of root resorption (19,21,47,52,56). Besides, the factors of systemic diseases such as asthma and allergies, endodontically treated teeth, gender, malocclusion type, bruxism, onychophagia, biting objects, tongue thrusting and thumb sucking, were not associated with an increased risk of root resorption (16,22,47,50,55).

Next to the patient-dependent factors, the treatment-dependent factors play an important role when choosing a clear aligner or a fixed orthodontic appliance (16). Regarding the intermittent orthodontic force used with the clear aligner system, this type of force transmission presents a lower risk of root resorption compared to the treatment with conventional fixed orthodontic appliances (47,51). As well the magnitude of force used is crucial, which is more favourable with an aligner treatment, due to the lower forces applied (36). The fixed orthodontic appliance exerts high forces on the apex of the root due to the direct attachment to the tooth, which increases the risk of root resorption (21). Moreover, the tooth movements carried out by the appliance used are significant, which means that intrusive and tipping movements have an increased risk of root resorption (47). Another factor is the duration of the complete treatment, as the risk of root resorption gradually increases with a longer treatment time (58). Since treatment with clear aligners usually corrects mild to moderate tooth misalignments and generally requires a shorter treatment time, there is a lower risk of root resorption when treating with the clear aligner principle (63).

The diagnostic evaluation to prevent or detect root resorption consists of frequent evaluation of radiographic images before, during and after treatment (11). Panoramic radiographs are normally utilized for frequent radiographic assessment, although for individual exceptions and isolated cases, periapical radiographs and CBCT scans may be used (66).

To prevent the development of root resorption, all risk factors should be kept as small as possible by the patient and the practitioner (30). Frequent radiographic assessment should be done to detect root resorption as quick as possible (11). If starting root resorption is detected radiographically, active treatment interruptions with passive wires or omitting of the aligner should be employed (21,35,36).

In general, the occurrence of root resorption is multifactorial, but the treatment-related factors can be controlled by the practitioner and should be taken seriously due to their major impact on occurring root resorptions (16,21). If orthodontic treatment with clear aligners causes less root resorption than with fixed orthodontic appliance, is still controversial. Nevertheless, there is a lower tendency for occurring root resorption throughout the entire course of treatment with clear aligners (8,51).

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