SASAN NARAGHI

STABILITY OF ALIGNED MAXILLARY ANTERIOR TEETH AFTER ORTHODONTIC TREATMENT

Amount of changes with different retention methods
and without retention

**STABILITY OF ALIGNED MAXILLARY ANTERIOR TEETH
AFTER ORTHODONTIC TREATMENT**

Malmö University
Faculty of Odontology Doctoral Dissertation 2021

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To my beloved family, they matter most

“Retention is one of the most difficult problems in orthodontia;
in fact, it is *the problem*.”

Albin Oppenheim, 1934

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PREFACE

This thesis is based on the following four papers, which are referred to as Paper I to IV.

Paper I. Naraghi S, Andrén A, Kjellberg H, Mohlin B. Relapse tendency after orthodontic correction of upper front teeth retained with a bonded retainer. *The Angle Orthodontist*, 2005; 76:570–576.

Paper II. Andrén A, Naraghi S, Mohlin B, Kjellberg H. Pattern and amount of change after orthodontic correction of upper front teeth seven years post-retention. *The Angle Orthodontist*, 2010; 80:620–625.

Paper III. Naraghi S, Ganzer S, Bondemark L, Sonesson M. Stability of maxillary anterior teeth after two years of retention in adolescents - A randomised controlled trial comparing two bonded and a vacuum-formed retainer. *European Journal of Orthodontics*. Accepted for publication November 2020.

Paper IV. Naraghi S, Ganzer S, Bondemark L, Sonesson M. Comparison of post-treatment changes with and without retention in adolescents treated for maxillary impacted canines—A randomised controlled trial. E-published ahead to print March 5, 2020, *European Journal of Orthodontics*, cjaa010.

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ABSTRACT

Well-aligned anterior teeth are the major reason for the patients seeking orthodontic treatment, and keeping teeth aligned and stable afterwards is a goal for the orthodontist and the patient. Relapse after treatment is a common problem, and it is defined as when teeth go back to their previous positions. Removable or fixed retainers have been used to avoid relapse after treatment. It has been common practice to use removable retention to retain anterior teeth in the maxilla. However, in recent decades, it has become increasingly common to retain with bonded retainers.

Almost all previous studies on retention devices in the maxilla were based on removable retainers. Consequently, there existed knowledge gaps and lack of short-term and long-term studies on the capability to maintain the stability of the maxillary anterior teeth with bonded retainers. Hence, the reason for the papers in this study. In addition, it is not known if retention is needed in all orthodontic patients or if there are patients, based on their initial malocclusion and individual variations, who may not need retention after treatment.

The research questions addressed in this thesis thus originate from knowledge gaps and clinical needs concerning retention strategies after orthodontic treatments. To provide strong clinical evidence, randomised controlled trials (RCT) as well as intention to treat (ITT) methodology has been assessed. The results are expected to be beneficial for the patients who will be offered the most effective retention strategy for maxillary anterior teeth based on patients' preferences.

In Paper I and II, 45 and 27 adolescents' patients were collected from the Orthodontic Clinic in Mariestad, Sweden. At the time when Paper I and II were conducted, there were no studies that had evaluated the long-term effect of bonded retainers in the maxilla. In two RCTs, Paper III and IV, 90 and 63 adolescents' patients were collected from the Orthodontic Clinic in Växjö, Region Kronoberg, Sweden.

Paper I: The aim was to investigate the amount and pattern of relapse of maxillary anterior teeth previously retained with a bonded retainer.

Paper II: The aim was to investigate the amount and pattern of changes of maxillary anterior teeth seven years post-retention, which previously were retained with a bonded retainer.

Paper III: The aim was to evaluate post-treatment changes in the irregularity of the maxillary six anterior teeth and single tooth Contact Point Discrepancy (CPD) of three different retention methods.

Paper IV: The aim was to evaluate whether retention is needed after orthodontic treatment for impacted maxillary canines and with moderate pre-treatment irregularity in the maxilla.

Key findings in Paper I

- The contact relationship between the laterals and the centrals is the most unstable contact. Canines are the most stable teeth.
- There was no difference in the relapse pattern between rotational displacements and labiolingual displacement.

Key findings in Paper II

- There was a strong correlation between irregularity at one- and seven-years post-retention. Stable cases one-year post-retention were stable and unstable cases deteriorated with time.

Key findings in Paper III

- All three retention methods showed equally effective retention capacity and all the changes found in the three groups were small and considered clinically insignificant. Thus, the null hypothesis was confirmed. All three methods can be recommended.

Key findings in Paper IV

- Changes between the retention and the non-retention group were statistically but not clinically significant. Since satisfactory clinical results one-year post-treatment were found in the non-retention group, retention does not appear always to be needed.
- Most of the changes occur within the first 10-week period after treatment with no retention.

Key conclusions and clinical implications

Both removable and bonded retainers are effective for holding teeth in position and can be used for preventing the relapse. It can be enough to retain with bonded retainer 12-22 instead of 13-23. It might be possible to avoid retention in selected cases in the short-term, but a longer evaluation period is needed.

POPULÄRVETENSKAPLIG SAMMANFATTNING

Efter en tandregleringsbehandling måste tänderna fixeras för att de inte ska gå tillbaka mot sina ursprungspositioner, det vill säga tänderna har gått i recidiv. För att undvika recidiv efter ortodontisk behandling används avtagbara plastskenor eller fastlimmade metalltrådar, så kallade retentionstrådar, som fästs på insidan av de sex framtänderna. Retention används från minst ett år till obegränsad tid.

Syftet med studie I och II var att undersöka storleken och mönstret på recidivet efter ortodontisk korrektion av överkäkens framtänder som har varit fixerade under ca tre år med en retentionstråd. Förändringar på kort och långsikt studerades. Studien gjordes på avgjutningar av patienters tänder som framställdes i gips (studiemodeller). Kontaktpunktsförskjutningarna mellan de sex framtänderna mättes med hjälp av ett digitalt skjutmått. Modellerna skannades och eventuella rotationer av överkäkständerna från hörntand till hörntand analyserades. Alla värden jämfördes med situationen före behandling, direkt efter behandling samt ett år respektive sju år efter det att retentionstråden togs bort.

Syftet med studie III var att analysera tre metoder för att retinera och stabilisera överkäksframtänderna efter tandregleringsbehandling. Jämförelser gjordes mellan retention under två år med en limmad tråd på de fyra framtänderna (12–22), en limmad tråd på sex tänder (13–23, de fyra framtänderna och de två hörntänderna) och en avtagbar nattandställning som omfattade samtliga tänder i överkäken.

Syftet med studie IV var att utvärdera om det var möjligt att undvika retention i fall där överkākshörntänderna blivit kvar i käken och måste dras fram med fast tandställning. Patienterna lottades i två grupper. I den ena gruppen retinerades tänderna och i den andra gruppen var de utan retention.

Utvärdering av studie III och IV gjordes också på gipsmodeller. Modellerna 3D-skannades och mätningar av kontaktpunktsförskjutningarna mellan de sex framtänderna genomfördes med hjälp av ett datorprogram. Rotationer av överkākständerna från hörntand till hörntand mättes mot en referenslinje.

Studie I visade små men signifikanta förändringar mellan tandkontakterna ett år efter att retentionen togs bort. Särskilt förändringsbenägna var laterala incisiver, därefter centrala incisiver och minst förändringsbenägna var hörntänder.

Studie II visade ett starkt samband mellan förändringar ett och sju år efter retentionen. De tandkontakter som redan hade börjat recidivera efter ett år, förvärrades ytterligare vid långtidsuppföljningen efter sju år.

Studie III visade att alla tre former av retention, limmad tråd 13–23, 12–22 samt avtagbar vakumpressad plastskena (Essix) var effektiva i att hålla kvar framtändernas positioner i överkäken.

Resultaten från studie IV, att inte använda retention över huvud taget, var kliniskt godtagbara ett år efter att tandställningen togs bort. Den största förändringen i gruppen utan retention skedde inom tio veckor efter borttagning av tandställning.

Klinisk betydelse

Både avtagbar och bondade retainrar är effektiva för att stabilisera överkākframtänder. För retention av överkākframtänder kan det vara tillräckligt med en limmad tråd mellan fyra framtänder (12–22). Efter tandreglering av retinerade hörntänder i överkäken kan det vara möjligt att undvika retention på kort sikt, men längre utvärderingsperiod behövs.

THESIS AT A GLANCE

Study	Purpose	Study/design	Sample	Main outcome parameter	Main findings
I	Investigate pattern and amount of relapse of maxillary anterior teeth retained with bonded retainer one-year after retainer removal.	Case series	45 patients. Retrospective and single centre.	Little's irregularity index. Contact point displacement between teeth. Rotations of six anterior teeth to raphe.	The contact relationship between the laterals and centrals are the most unstable contact. Canines are the most stable teeth. There was no difference in the relapse pattern between rotational displacements and labiolingual displacement.
II	To evaluate long term effects of the first study seven-years post-retention	Follow-up of case series	27 patients from the first study participated.	Little's irregularity index. Contact point displacement between teeth. Rotations of six anterior teeth to raphe.	There was a strong correlation between Little's irregularity index and contact point displacement one- and seven-years post-retention.
III	To compare differences between three retention methods in keeping position of aligned teeth after orthodontic treatment during two years in retention.	Randomised controlled trial	90 patients randomised into three groups: Group A) bonded retainer 13-23. Group B) bonded retainer 12-22. Group C) vacuum-formed retainer covering all erupted teeth.	Little's irregularity index. Contact point displacement between teeth. Rotations of six anterior teeth to sagittal plane.	All three retention methods showed equally effective retention capacity and all the changes found in the three groups were small and considered clinically insignificant. All three methods can be recommended.
IV	To investigate changes after orthodontic treatment of impacted canines between study group with no retention and control group with retention one-year post-retention.	Randomised controlled trial	63 patients randomised into two groups, study group with no retention after an interim period of 10 weeks and control group with retention.	Little's irregularity index. Contact point displacement between teeth. Rotations of six anterior teeth to sagittal plane.	Changes between the retention and the non-retention group were statistically but not clinically significant and since satisfactory clinical results one-year post-treatment were found in the non-retention group retention does not appear to be needed. Most of the relapses in the non-retention group occurred during the 10-week post-treatment interim period, and, thus, this period was useful in identifying patients who might have a relapse immediately after treatment.

INTRODUCTION

Background

The goal of orthodontic treatment is to create a normal or so-called ideal occlusion that is morphologically stable and aesthetically and functionally well-balanced (1). There is an association between ideal occlusion, function, and aesthetics and quality of life (2, 3), however, their relation is still in many aspects unclear.

An ideal occlusion is supposed to go hand in hand with optimal oral function and health and, not least, acceptable aesthetics. There is, however, limited evidence supporting the belief that an ideal occlusion improves chewing ability and speech and reduces the risk for development of temporomandibular disorders (TMD) (4). Nevertheless, orthodontic treatment reduces occlusal interferences (5).

Young individuals show more of their maxillary anterior teeth, but with ageing, they show less because of the lengthening of the nose and the upper lip covering more of the maxillary anterior teeth (6). However, as adults, they may show more of the lower incisors (7).

Irregularity, in general, has not shown significant correlations to caries and periodontitis (8, 9). Studies have shown that aesthetics, no doubt, is the major motivating factor for orthodontic treatment both in adolescents and adults. Visible teeth irregularities are the most important treatment motivating conditions (10-13). In a qualitative study of teenagers on a waiting list for orthodontic treatment, the authors found that the treatment decision was forced on the individual (14). Factors like being as others, influence from media and, not least, dentists were important.

Even if the concern for aesthetics seems to be most significant in young individuals (15), there is a considerable concern for aesthetics in older subjects (16-19). These studies show that patients are interested in

well-aligned anterior teeth and do not care so much about malocclusions in molar areas. Therefore, from the patient's point of view, aesthetics and stability of the maxillary anterior teeth is of considerable importance for treatment and maintenance of the treatment results (11, 17). After the orthodontic treatment and retention period, when relapse may occur, it is mainly the visibility of anterior teeth irregularity that causes a lack of satisfaction (20) and calls for new treatment (10, 14, 18). Some studies indicate that malposition of anterior teeth may contribute to low self-esteem and a general feeling of dissatisfaction (11, 14, 16) and have negative effect on quality of life (21-24).

However, despite the importance of aesthetics in the maxillary anterior region for the patients, most of the studies on retention has been in the mandible. In Sweden, 30-35 per cent of children and adolescents, and young adults up to 22 years of age are offered free orthodontic treatment. In other words, at least every fourth young individual is wearing some type of retention device after their orthodontic treatment to sustain the results. Maintenance of retainers for a very long time or permanently costs society and patients time and money, including some side-effects on stability for the patients, especially for the retainer failure (25). Some of these patients probably do not need to wear a retainer for such a long time because their teeth may be stable. Unfortunately, we do not know which patients have stable occlusion and who does not.

Factors influencing stability and relapse

Dental arch changes in untreated subjects

"There is nothing permanent, except change", said Heraclitus, a Greek philosopher and it is true when looking at dental arches. The results of changes with age could include: decreases in arch length and intercanine width; minimal overall changes in intermolar width, overjet, and overbite; and increases in incisor irregularity which occurs, regardless of orthodontic treatment or not (26-30). From adolescence to adulthood, there is a significant increase of intermolar distance in the mandible in male subjects and a significantly more rounded lower dental arch form and reduction in arch depth in both sexes, leading to the increased irregularity of the lower incisors (31). In a cast analysis study, arch size and form were measured in a longitudinal survey of untreated adults, at 20 years

of age and again at 55 years of age (32). During this period, arch lengths decreased significantly with time. The arch widths increased, especially in the molar area, and even some small expansion occurred in the canine region in the maxilla. These slow changes did not affect the inter-arch relationship. In a longitudinal study from 25 to 45 years of age, they found changes that were, on average, of small magnitude but statistically significant ($p < 0.05$) (33). Both genders experienced a significant increase in dental crowding in both arches and it was more pronounced in the anterior segments and more severe in the lower front.

Thilander, in a longitudinal study of a population with normal occlusion between the ages of 5 and 31 years, found anterior crowding, especially in the mandible (34). The author explains it as the natural migration of teeth even in the absence of third molars. The conclusion from these studies is that dental arches change over time and the natural path is the reduction of the arch length and migration of teeth, leading to crowding in anterior regions, especially in the lower arch, until 55 years of age. Stability or minimal changes were observed for subjects between 47-58 years of age (35).

Dental arch changes in treated subjects

Changes to the dental arch are mostly similar to the untreated population (36, 37). In a 20-year longitudinal study, changes in arch width of the maxillary and mandibular canine and molar in 60 subjects, older than 20 years of age, were examined (38). Half of the subjects were treated orthodontically. When comparing these two groups, the arch width and length decreased in both groups. Some intercanine expansion occurred in the maxillary arch but only in the treated group. It seems that expansion in the maxilla is more stable and do not affect the irregularity of maxillary incisors (27, 39, 40) as it does in the mandible (27, 41).

Orthodontic relapses are usually described as changes toward the pre-treatment status. These changes occur very fast, and in animal studies, it is less than one day to 21 days (42, 43) and ranges from 30 to 85 per cent of total active tooth movement if the teeth are not kept in their new position (42). This is the reason why, after orthodontic treatment, the result must be stabilised by some type of retention device to prevent relapse. However, after this first period of remodelling of periodontal structures (44), comes the later period of changes (45). These changes generally involve the natural ageing process, which contributes to the total crowding. In a recent study, the authors concluded that 25 per cent of

post-treatment changes are because of normal age changes (46). For these reasons, many orthodontics advocate lifelong retention to even prevent these ageing mechanisms, especially in the anterior region in the mandible (47-53). As previously mentioned, malalignment of maxillary anterior teeth is often the foremost reason why patients seek orthodontic treatment. The focus from now on will therefore be on the maxillary anterior teeth. There are many reasons for relapse after orthodontic treatment and its effect on maxillary anterior teeth. It can be compared to an iceberg, as illustrated in Figure 1. The part an orthodontist can see, and influence is above the surface. The part which is below the surface, the orthodontist cannot influence, but is well-aware of its presence and impact. Some factors depend on the patient's cooperation like habits and posture, and some factors are based on genetics like growth, which are out of the orthodontist's control.

Figure 1. Reasons to relapse illustrated as an iceberg. Below the water surface, the orthodontist has no influence but on the surface are the entities which can be controlled by the orthodontist.

Occlusion

Stable occlusion is a well-known parameter to achieve stable results and reduce the risks of relapse (10, 54-57). In a prospective and longitudinal study, the authors concluded “Settling of the occluding teeth seems not to improve the functional occlusion after fixed appliance removal. Thus, it is necessary to check the functional occlusion before the appliance is removed to eliminate unsatisfying functional occlusal contacts” (58). Hence, if we do not have good or preferably excellent occlusion before debonding, there is a risk that settling does not compensate for treatment shortcomings. We know that settling occurs after removing the fixed appliances, no matter what kind of retention we use (59-63). However, it may take longer in cases with Vacuum-formed retainer (VFR) in both jaws, especially in females (64).

Well-aligned teeth

Several studies emphasise on well-aligned teeth to reach better stability. Surbeck et al. found that the pattern of pre-treatment rotational displacement of maxillary anterior teeth tended to repeat itself post-retention (65). This finding was confirmed in later studies (66, 67). It has been suggested that incomplete alignment during treatment is a risk factor for relapse and slight over-correction during active treatment of severely rotated teeth, is recommended (65). The high percentage of teeth tending to return to their original positions (68).

In another study, they found that the maxillary incisors irregularity increased significantly (1.52 mm) during long-term post-treatment (69). None of the studied clinical factors, Little’s irregularity index, intercanine, interpremolar and intermolar widths, arch length and perimeter, demonstrated to be predictive of the maxillary crowding relapse.

Contact point displacement

Buccolingual- and mesiodistal tipping together with the rotation of the tooth are reasons to contact point displacement (CPD) between adjacent teeth. These changes solely or in combination cause irregularity and misalignment between teeth shown in Figure 2.

Figure 2. Reasons for contact point displacement

Effect of rotations on contact point displacement

The CPD changes caused by rotation is depending on the tooth width and amount of the rotation. When a central incisor is 9 mm, a rotation of 12.8 degrees round its long axis gives 1 mm of CPD, see Figure 3.

A lateral incisor of 7 mm, a rotation of 16.4 degrees gives 1 mm of CPD, as illustrated in Figure 4.

Figure 3. Effect of rotation on central incisor causing CPD

Figure 4. Effect of rotation on lateral incisor causing CPD

When tipping is involved together with the same amount of rotation, the CPD increases more which is illustrated in Figure 5.

Figure 5. Combination of tipping together with rotation

Tooth shape

It is known that triangle-shaped mandible incisors may cause crowding and are more prone to relapse than more square-shaped teeth (70). Creating contact surfaces instead of contact points in triangle-shaped teeth and reducing tooth width by interproximal reduction (IPR), have been used

with relatively good results with better stability in orthodontics especially in mandibular anterior teeth (71-73).

Root position

In maxillary front, the laterals and canines erupt sometimes in palatal position because of the eruption direction or/and in combination with space deficiency. Uprighting the root is a demanding and time-consuming process. There must be enough space for the root of the malpositioned tooth to be able for the orthodontist to move the root in proper position by adequate biomechanics. If the root is not uprighted with adequate root torque, there is a great risk of relapse of the tipped crown to the previous position (74). Excellent finish and proper position of the crown and the root are important for the end result and the stability of achieved alignment (57).

The alveolar bone

The cortical thickness reflects overall bone mass and density. Studies show that women with osteoporosis have thinner cortex in the mandible (75). Animal studies showed that tooth movement was higher in affected rats with osteoporosis than normal individuals (76). It is hypothesised that persons with thinner mandibular cortices experience greater levels of dental relapse after orthodontic treatment—a reflection of decreased bone density with less bone support for thinner mandibular cortex.

In a retrospective study of relapse of lower incisors and cortical bone thickness, the authors found that subjects with thinner mandibular cortices had more dental relapse after orthodontic treatment (77). They concluded that greater relapse occurs in patients with decreased bone support based on cortical thickness.

During orthodontic tooth movement in adults, the alveolar bone loses at mean 24 per cent of its density around the six maxillary anterior teeth after seven months of orthodontic treatment (78).

Gingival and periodontal fibres

The periodontal space (distance between the root cementum and the alveolar bone) is called the periodontal ligament (PDL) (79). It is about 0.25 mm and occupied by cells, vessels, fluid, nerves, and fibres. These fibres consist of collagen fibres that are arranged into fibre bundles. The portion of these fibres that are embedded into either cementum or bone is called Sharpey's fibres. These fibres occasionally pass through the bone

of the alveolar process to continue as principal fibres of an adjacent PDL. They run buccally and lingually to connect with the fibres of the periosteum. Other fibres are: Circular (runs around the tooth in the free gingiva), dento-gingival, dento-periostal, alveolo-gingival, and trans-septal fibres, see Figure 6 illustrating different fibres.

Figure 6. Different fibres surrounding teeth. Periodontal ligament (PDL), circular fibres (CF), dento-gingival fibres (DGF), dento-periostal fibres (DPF), trans-septal fibres (TSF) and alveolo-gingival fibres (AGF)

When we move teeth orthodontically, resorption of alveolar bone at the pressure side occurs rapidly and allows the movement of teeth through the bone. The periodontal ligaments and Sharpey's fibres act as an anchorage zone for new bone and new cementum.

The middle and most apical part of the root is more stable to relapse, whereas the marginal third of the root is unstable (74). After movement is completed, the new site for the tooth and the periodontal ligament is re-established on the pressure side, similar to an unmoved tooth. On the tension side, where the formation of new bone is required, re-establishment

of the bone occurs more slowly, and the periodontal ligament maintains tension on the bone, seeking to draw the tooth back to its original position causing relapse (48).

The challenge is to establish conditions preserving the new position of the tooth. Reitan described the relapse that occurred after tipping of the teeth in dogs without retention (44). He noticed that some relapse already occurred after two hours, partly caused by the up righting of the tooth. Relapse continued to occur during the following four days. After that, this process stopped because of the hyalinised zone (cell-free zone) this time on the tension side (44). A similar pattern was observed in children after tipping teeth without subsequent retention.

The periodontal ligament remodels fast, but the gingival fibres have a slow turnover rate and take as long as 232 days to remodel after experimental tooth rotation (44). Therefore, some authors suggest fiberotomy when teeth are derotated by orthodontic forces (80, 81) to eliminate the tension caused by stretching the supra crestal fibres (82).

Muscles and soft tissue

Teeth and alveolar bone are affected by the forces from muscles and soft tissues around them. The equilibrium theory has been discussed for decades (83, 84). Influential factors are, intrinsic factors like tongue and lips, extrinsic factors like habits (85), forces from occlusion and forces from the periodontal membrane (84). Forces from the tongue during swallowing are 2.5 times higher than forces from the lips and 1.5 times higher during the resting position. Two aspects, amount and duration of the forces are important. Forces during swallowing and occlusion are high but their duration is low.

On the other hand, forces during the rest and speech are low but much longer (83). A healthy periodontium stands against this unbalance. When it is compromised in patients with periodontitis, it can be noted that anterior teeth are flared outward in the maxilla and the mandible. Also, habits influence the balance negatively and may induce different forces, based on the magnitude and duration of the habits, to the teeth during the retention period.

Common retention devices in the maxillary arch

Several different fixed and removable retainers, solitary or in combination, have been used to retain maxillary anterior teeth after orthodontic treatment (Figures 7-11). Fixed retainers in the maxilla may involve two teeth as in median diastema to eight teeth in cases of extraction of first premolars. The most common length is, however, 13-23 and 12-22 in which in the first one the wire is attached with composite to all six maxillary anterior teeth and in the latter from one lateral incisor to the other lateral incisor involving all four incisors. It has been advocated in the literature that 12-22 failure is less than 13-23 over time (86).

Zachrisson introduced the bonded retainers with twisted stainless steel wires in 1977 (87). Bonded retainers have become more and more popular among patients (88), and the current shift is from removable retainers toward bonded retainers in different countries (89-94). The common use of flexible stainless steel twisted (three or more wires are twisted around each other) or multi-strand wire (several wires are twisted around a central wire) like 5-stranded or 7-stranded wires. The size varies from 0.016 to 0.022 in the maxilla. Braided or plain flexible square wires, glass-fibre reinforced and lately the CAD/CAM produced titanium wire have also been used (95). It is recommended using plain 0.016x0.016-inch or braided 0.016x0.022-inch stainless steel wires to increase torque control (96). The use of V-loop shape retainer instead of straight wire retainer has been used to facilitate interproximal cleaning. The results showed a slightly higher rate of bond failure without any clinically or statistically significance (97).

Various materials of light-cured composite resin, polyacid-modified resin composite (compomer) and resin-modified glass ionomer have been used in direct or indirect bonding technique. The placement of the retainer usually occurs directly after or before debonding. Some prefer to bond the retainer several weeks prior to debonding to assure stability of the retainer and the possibility to repair the retainer in case of bond failure when braces and arch wire still are in place.

Vacuum-formed retainer (VFR) was introduced in 1993 (98). This aligner was called Essix which is an acronym for S-six which stands for 'Sheridan's Simple System for Stabilising the Social Six' – the ESSIX-System was conceived initially to stabilise the six anterior teeth but, later on, extended to involve even molars. There are several different possibilities to also use it for achieving small tooth movements.

There is a different thickness, 0.75, 1.0 and 1,5 mm and different material. VFRs are made of Polyethylene, Polyurethane, and Polypropylene. Polyethylene is recommended for long-term wear (99). The problem with VFR and other removable retainers is that compliance reduces with time (100, 101). Some, like the Jensen retainer and the Hawley retainer, are designed to allow vertical tooth movements. They are even suitable for preventing transversal relapse.

The choice of retention device may depend on the initial malocclusion, expected growth, occlusal development, and the expected adherence. Bonded retainers seem to be popular as they effectively prevent tipping and rotation of the teeth (102, 103). They are rather independent of cooperation and can be used for long periods (65, 87, 104, 105), although there are few studies on real long-term use. Bonded retainers are, on the other hand, operative sensitive and retainer failures are common (86, 101, 106, 107) especially in the maxilla (106, 108). Hawley retainers, Jensen retainers, and VFRs allow prosthetic pontics for missing teeth in the aesthetic zone. Some appliances, such as positioners and spring retainers, are used rarely but can also be useful for minor tooth movements.

Figure 7. To the left, a retainer bonded to six teeth. To the right, a retainer bonded to four teeth

Figure 8. Vacuum-formed retainer 17-27

Figure 9. Jensen retainer

Figure 10. Hawley retainer

Figure 11. Positioner to the left and spring retainer to the right

Adherence

Patient adherence is very important when it comes to removable retainers. It appears that compliance with removable orthodontic appliances is suboptimal, with patients wearing appliances considerably less than stipulated and routinely overreporting the duration of wear (109). Many orthodontists believe that a lack of awareness of dental problems, a lack of motivation to cooperate, and personal problems are the main reasons for non-compliance (110). To increase adherence, giving information to the patient in different ways is important (109). Although there is insufficient evidence to allow clinicians to choose a single method, the results demonstrate the value of spending time with patients to illustrate the importance of adherence (111). The relationship between orthodontist and patient seems to play a key role in patient adherence (112). It is well-known that adherence reduces with time (101).

There is a difference between compliance and adherence, even though the terms have been used as synonyms. Adherence is an active choice of patients to follow through with the prescribed treatment while taking responsibility for their own well-being. Compliance is a passive behaviour in which a patient is following a list of instructions from the doctor. Different kinds of sensors have been used together with removable appliances to monitor and increase patients' compliance (112-115). The overall results are good, and an objective measurement of wear time allows a more realistic view of compliance by patient and orthodontist. Some of these studies showed knowing that wear time is recorded, does not necessarily increase the amount of time the patient wears removable appliances (113, 114).

Significance

In the maxilla, the removable retainers have been used routinely. The bonded retainers have become popular because they have good retention qualities and are not dependent on the patient's cooperation (89). However, there was a lack of scientific studies on maxillary bonded retainers (116, 117). Papers I and II were aimed to examine the effectiveness and durability of bonded retainers in maintaining the results both short-term and long-term after orthodontic treatment. The orthodontists want to know which kind of retention is more effective to use, removable or bonded retainer. Do they need to extend the bonded retainer to involve canines or is it enough to involve only four incisors in the maxilla? It has been a lack of knowledge in these areas and Paper III was mending to fill this gap with a randomised clinical trial (RCT) study design between three commonly used retention devices. Retainers have been used routinely in decays, but no scientific study has investigated what happens if no retainer is used in the maxilla. In previous studies with no retention in the mandible, interproximal reduction (IPR) was carried out (47, 71, 118, 119) with satisfying results. If the results are similar in the maxilla remains to be investigated. Paper IV was aimed to answer this question in a highly scientific manner with its RCT study design.

To add more to this framework, a one-year post-retention evaluation was carried out in Paper IV to find out what happens when we take out the retainer in the group with retention.

AIMS

Paper I

To investigate the amount and pattern of relapse of maxillary anterior teeth previously retained with a bonded retainer.

Paper II

To investigate the amount and pattern of changes of maxillary anterior teeth seven years post-retention, which previously were retained with a bonded retainer.

Paper III

To evaluate post-treatment changes in the irregularity of the maxillary, six anterior teeth and single tooth contact point discrepancy (CPD) of three different retention methods after two years in retention.

Paper IV

To evaluate whether retention is needed after orthodontic treatment for impacted maxillary canines and with moderate pre-treatment irregularity in the maxilla.

HYPOTHESES

Paper I

The bonded retainer in the maxilla is effective to stabilise teeth in position one year after removal.

Paper II

There are no major changes seven years after removal of the bonded retainer.

Paper III

There would be no difference in retention capacity between any of the three maxillary retention methods (bonded retainer 13-23, bonded retainer 12-22, and vacuum-formed retainer) during two years of retention.

Paper IV

No statistically or clinically significant difference will occur in the position of the maxillary anterior teeth of patients with and without retention, one-year post-treatment.

MATERIALS AND METHODS

Paper I and II

The study group originally consisted of 45 patients in Paper I and 27 patients on recall for Paper II. Recordings from study models before treatment (T1), at debonding (T2), one year after removal of the retainer (T3), and seven years post-retention (T4) were present. All patients had been treated with fixed edgewise appliances by the same orthodontist. The patients were selected from the Orthodontic Clinic in Mariestad, Sweden, when their maxillary bonded retainer was removed.

The wire used was 0.0195-inch Wildcat (GAC International Inc., Central Islip, NY). All six maxillary permanent anterior teeth had to be present before treatment and having irregularity. Spaced dentitions in the maxillary anterior teeth and treatments started as adults were excluded. Labiolingual displacements of the anatomic contact points from the mesial of the right canine through to the mesial of the left canine were measured with a digital calliper on the casts from T1, T2, T3, and T4, with 0.1 mm accuracy. CPD less than 0.5 mm were judged to be zero.

An Agfa DuoScan F40 (Agfa-Gevaert N.V., Mortsel, Belgium) scanner was used to scan the casts at 300 DPI (dots per inch) resolutions. All 45 x 3 casts were scanned in 300 DPI and then placed on the upper third part of the glass, with almost the same size of the scanned area. All anterior teeth were optimally in contact with the glass surface of the scanner to avoid distortions.

A free computer program, Scion Image, from Research Services Branch (RSB), National Institutes of Health (NIH), USA was used to mark points on the pictures of the scanned casts to measure rotation changes and intercanine distance. The rotations were measured as the angle between a line through the mesial and distal points on the incisal edge of the teeth and

the raphe line. The intercanine distance was measured between the cusp tips of the maxillary canines as shown in Figure 12.

The Little's irregularity index (LII) (120), which is the sum of five CPDs, and rotations of anterior teeth with the raphe line and intercanine distance, were calculated at T1, T2, T3, and T4 (Figure 13).

Figure 12. Showing the tooth angles on the right side to raphe line and intercanine distance

Figure 13. Little's irregularity index

Paper III

In Paper III, 90 patients were recruited to the study. All participants were recruited from patients with ongoing orthodontic treatment at the Orthodontic Clinic in Växjö, Public Dental Service, Region Kronoberg, Sweden. They were all treated by three experienced orthodontists. The inclusion criteria were adolescents treated with the fixed appliance in the maxilla or in both maxilla and mandible. The exclusion criteria were patients with syndromes, agenesis or extracted maxillary anterior teeth, or in need of orthognathic surgery.

Three months before the estimated removal of the fixed appliances, the patients were invited to take part in the trial. After gaining informed consent from the patient and their custodians, the patients were randomly allocated to one of the three retention groups as follow: A) bonded retainer 13-23, B) bonded retainer 12-22, and C) removable vacuum-formed retainer (VFR) covering the maxillary teeth including the second molars. The material in the bonded retainers was Penta-One 0.0195 (Masel, Carlsbad, California, USA) with bonding agent Transbond Supreme LV (TSLV-3M, Unitek, Monrovia, California), and in VFR (EssixTM, Erkodur, 1.5 mm 120ø, Erkodent® Erich Kopp GmbH, Pfalzgrafenweiler, Germany).

The retainers were bonded the same day directly after debonding. The VFRs were produced within one day after debonding. The patients followed a standard protocol for VFR-wear: 22–24 hours per day during the first four weeks, then every night. One year after debonding, the wearing time was reduced to every other night. Retention check-ups were performed one month, one year, and two years after insertion of the retainers.

The randomisation process was prepared by an independent person and carried out by three staff members not involved in the trial. The randomisation used blocks of 30. The randomisation notes were delivered in a sealed opaque envelope each. Every new participant picked an envelope and revealed the group assignment by opening the envelope. Recruitment went on until the total number of participants met the estimated sample size.

The primary outcomes were changes in single CPD and LII measured on digitalised three-dimensional study casts before and after two years in retention. The secondary outcomes were: changes in arch length defined as the sum of the distances between the mesial contact point of the first permanent molar and the central incisal contact point in the maxilla; changes in intercanine width, defined as the distance between the canines' cusp tips in the maxilla; changes in intermolar width, defined as the distance between the mesiobuccal cusp tips of the first permanent molars in the maxilla; maximum single tooth rotation of one of the six maxillary anterior teeth, defined as the angle between the line from distal to the mesial contact point and the sagittal plane; and overjet and overbite were also measured.

Data on all participants were evaluated on an intention to treat (ITT) basis. Consequently, all randomised patients remained in the allocated

group. Subsequently, patients lost in follow-up were included in the final analysis by assessing the group's maximum value for primary outcome change (irregularity of the maxillary six anterior teeth and single tooth discrepancy) and the secondary variables representing the change in arch length, intercanine width and the intermolar width, overjet, and overbite.

Measurements were made on digitalised 3D study casts for all the three retention groups before treatment (T0), at the end of active treatment/start of retention (T1), and the two-year follow-up (T2). Before assessment of measurements, the study casts were digitised with a stationary 3D scanner (D3, 3Shape, Copenhagen, Denmark). On the digital models, the measurement points were located using a validated computer program, the OnyxCeph3™ (121) (software (v3.2.142), Image Instruments, Chemnitz, Germany) with semi-automatic segmentation.

The measurement points were then manually adjusted in order to improve consistency. The measurement points for CPD were defined as the mesial and distal point of the broadest mesiodistal diameter of the tooth. Further, the CPD was measured as a projection on the occlusal plane, shown in Figure 14, and the flow chart of the patients, Figure 15.

Paper IV

In Paper IV, 63 adolescent patients were recruited to the study. All participants were recruited from patients with ongoing orthodontic treatment at the Orthodontic Clinic in Växjö, Public Dental Service, Region Kronoberg, Sweden. They were all treated by one experienced orthodontist. After gaining informed consent from the patient and their custodians, the patients were randomised to one of two groups, a non-retention group as study group (31 subjects) and a retention group with VFR as the control group (32 subjects). The randomisation process was prepared and carried out by an independent person not involved in the trial. The randomisation used blocks of 20 (10 + 10). Opaque envelopes contained 20 sealed notes each (ten notes signed retention, and ten notes signed non-retention). Every new participant in the trial took a note from the first envelope. When the first envelope was empty, the next envelope was opened, and so on, until the number of participants met the estimated sample size, see the flow chart in Figure 16.

Data on all participants were evaluated on an ITT basis. Consequently, all randomised patients remained in the allocated group. Subsequently, patients with discontinued observation or lost to follow-up were still in-

cluded in the final analysis by assessing the group's maximum value for change in the primary outcomes as well as for the secondary variables. The trial period lasted between the removal of the fixed orthodontic appliances (T1) and one year after debonding (T2). The measurement methods, primary and secondary outcomes were the same as Paper III.

Figure 14. Primary and secondary outcome measures in OnyxCeph3™

Figure 15. Flow chart three retention methods

Figure 16. Flow chart retention or no retention

Ethical considerations

In Paper I and II Ethical Committee of Västra Götaland, Sweden, classified them as quality control and thereby, no ethical approval was needed. In Paper III and IV, the Regional Ethical Research Board, Linköping, Sweden, approved the trials (Dnr 2013/130-131). The participants received the information that participation was of free will, and they could refuse participation or discontinue with the study at any time. The patients and their custodians signed a consent form.

STATISTICAL ANALYSIS

Sample size calculation

In Paper, III and IV the sample size calculations were assessed and based on a clinically relevant difference in LII of 3 mm and standard deviation (SD) 3 mm between the groups. The level of significance was set to 5 per cent and the power to 90 per cent. The calculation resulted in a sample size of 23 patients in each group. To compensate for dropouts, at least 30 patients were planned to be enrolled in each group.

Group comparisons

In all papers, arithmetic means and standard deviations (SD) were calculated at the group level for each variable.

In Paper I and II, paired t-tests were applied to test differences in CPD, rotations, and intercanine distance between T1, T2, T3, and T4. Pearson's product-moment correlation test was applied to test correlations between CPD and rotations at T1 and changes during treatment and the follow-up period. The data were analysed using the statistical package SAS ® v8.2 program (SAS Institute Inc, Cary, NC, USA). For all statistical analyses, the statistical significance level was set to 5 per cent.

In Paper III and IV, the statistical analysis was conducted using the programming language 'R' (v. 3.60) and (v. 4.0.2) (122). In Paper III, the outcome measures were tested for normality in distribution with histograms and Shapiro-Wilk test. Variance homogeneity was tested with Levene's test. Statistical significance was then tested with One-Way ANOVA followed by pairwise t-test for variables with a normal distribution. Variables with non-normal distribution were tested with the Kruskal–Wallis test, followed by Dunn's test. When p-values were calculated, Holm–Bonferroni correction was applied to compensate for multiple comparisons. Dif-

ferences with a P-value less than 5 per cent ($P < 0.05$) were considered statistically significant.

In Paper IV, the Shapiro–Wilk test was used for normality testing. Homogeneity of variance was tested with Levene’s modified test. Hypothesis testing was conducted with *t*-test for independent variables with a normal distribution. Independent variables that were not normally distributed were evaluated with the Mann–Whitney *U*-test. Correlations between post-treatment increase of irregularity and possible predictors were assessed with scatterplots and Spearman’s rank correlation coefficient.

Measurement error analysis

Paper I

The reproducibility of the measurements for rotations and intercanine distance was determined by double measurements of 45 scanned models from 15 patients at T1, T2, and T3. The error of the method was calculated using Dahlberg’s equation (123).

$$S_x = \sqrt{\frac{\sum D^2}{2N}}$$

Where *D* is the difference between repeated measurements and *N* is the number of measurements. The errors were 3.1 degrees for canines, 2.8 degrees for laterals, and 2.4 degrees for centrals. The error of measuring the intercanine distance was 1.1 mm.

Paper II

The measurement error was calculated from double measurements of 27 models (T4), using Dahlberg’s formula. The error for CPD measurements was 0.2 mm. The measurement errors for rotation were 3.1 degrees for canines, 2.8 degrees for laterals, and 2.4 degrees for centrals.

Paper III

The same observer conducted repeated segmentation and measurements on T1, and T2 models of 15 randomly selected cases after at least two weeks. The two-measurement series were compared with Bland–Altman method (124). All variables showed sufficient agreement and low bias. Further, paired *t*-tests could not reveal any statistically significant differences/bias between the two-measurement series. The absolute mean

measurement error for CPDs was 0.1 mm, for LII 0.2 mm, for overjet, overbite, arch length, intercanine and intermolar width 0.1 mm each, and 2.4 degrees for tooth rotations.

Paper IV

Forty-five randomly selected study casts were repeatedly measured on two separate occasions with at least two weeks' interval by the same examiner. A paired *t*-test revealed no significant mean differences between the two series of record occasions. The size of the method error was determined using Dahlberg's formula. The mean measurement error for the CPDs was 0.1 mm, for LII 0.2 mm, for intercanine and intermolar width 0.2 mm each, and 2.6 degrees for tooth rotations.

RESULTS

Paper I

Before treatment (T1), the mean irregularity index was 10.1 (range 3.0 – 29.9). The largest displacements were recorded between laterals and centrals followed by the displacement between laterals and canines. The smallest deviations were found between the centrals as shown in Figure 17.

After treatment (T2), the mean irregularity index was 0.7 (range 0.0 – 2.1). There was a significant difference in the index between T1 and T2 ($P<.0001$).

One-year post-retention (T3), the mean irregularity index was 1.4 (range 0 – 5.1). There was a significant difference in the index between T2 and T3 ($P<.0001$).

Figure 17. Contact point displacements before treatment (T1), after treatment (T2), and one-year after retention (T3)

Paper II

Results from the second study showed that there were no statistically significant differences between the change in mean CPDs for the contacts canines/laterals, laterals/centrals, or centrals/centrals, as shown in Figure 18. The mean irregularity index for 27 patients examined in the second study was 10.3 (range 3.7 – 29.9) at T1, 0.9 (range 0.0 – 2.1) at T2, 1.3 (range 0.0 – 3.5) at T3 and 2.0 (range 0.0 – 5.8) at T4. No correlations were found between the pre-treatment and post-retention irregularity T1/T3 and T1/T4. There was a significant association between the irregularity index at T3 and T4 ($R = 0.938$, $P < 0.0001$).

The irregularity index of the maxillary anterior teeth changed very little or not at all during the one-year post-retention. Further changes long-term resulted in an irregularity index of mean 2.0 mm (range 0.0 – 5.8). The contact relationship between the laterals and centrals seems to be the most critical. Forty rotated teeth in 21 patients were corrected more than 20 degrees. Mean relapse during the one-year post-retention was 6.7 degrees (range 0.0 – 14.7). Mean changes under seven years were 8.2 degrees (range 0.0 – 19.3)

Figure 18. Contact point displacement (CPD) before treatment (T1), after treatment (T2), one-year post-retention (T3), and 7-years post-retention (T4)

Fourteen cases out of 27 were stable one- and seven-years post-retention showing individual differences illustrated in Figure 19.

Irregularity Index 1 and 7 years post retention

Figure 19. Stable and non-stable cases one- and seven-years post-retention

Paper III

There were no significant differences in gender, age, irregularity, treatment duration, and treatment outcome between the groups see Table 1.

Table 1. Baseline demographic data considering the number of subjects, gender distribution, maximum contact point discrepancies (max CPD), maximum rotations of anterior teeth, extractions, bimaxillary treatment and treatment duration in months. P-values calculated with the Kruskal-Wallis test for continuous variables and Chi-square test for categorical variables.

Group	Pre-treatment number of patients and gender distribution	Pre- treatment age, years mean (SD)	Pre- treatment max CPD mean (SD)	max CPD (T1) mean (SD)	Max rotation T1-T0 mean (SD)	Number of patients who had extractions	Number of patients who had bimaxillary treatment	Treatment duration in months mean (SD)
A - Bonded retainer 13-23	30 (♀ 17; ♂ 13)	13.8 (1.5)	3.3 mm (2.0)	0.5 mm (0.3)	11.8° (8.0)	12	23	24.3 (10.4)
B - Bonded retainer 12-22	30 (♀ 20; ♂ 10)	14.0 (1.8)	3.3 mm (1.7)	0.4 mm (0.3)	14.1° (10.6)	11	25	22.3 (8.3)
C - Vacuum-formed retainer	30 (♀ 17; ♂ 13)	13.9 (1.9)	2.7 mm (1.2)	0.4 mm (0.2)	14.3° (9.5)	5	17	24.6 (12.9)
P value 3-group-comparison	0.659	0.893	0.451	0.797	0.520	0.108	0.056	0.852
Total population	90 (♀ 54; ♂ 36)	13.9 (1.7)	3.1 mm (1.7)	0.4 mm (0.3)	13.4° (9.4)	28	65	23.7 (10.6)

During the two years of retention, Little's irregularity index and maximum single tooth discrepancies increased slightly in all three groups without any statistically significant group differences. The null-hypothesis was thereby confirmed, as shown in Table 2 and Figure 20.

The group with bonded retainer 13-23 showed statistically significant less rotational changes during retention compared to the group with bonded retainer 12-22 ($p = 0.014$) and the group with VFR ($p = 0.036$) (Table 2). Further, the intercanine width increased in the group with VFR while it diminished in the group with bonded retainer 13-23 and remained unchanged in the group with bonded retainer 12-22. The difference in intercanine width was statistically significant between bonded retainer 13-23 and VFR ($p = 0.023$) (Table 2).

The intercanine width was smaller in Group A (bonded retainer 13-23), than in Group C (VFR) (0.5 mm), but clinically insignificant. Regarding overjet, overbite, intermolar width, and arch length, minor changes without any significant inter-group differences were found.

Table 2. Changes (T2-T1) during the retention period (T1= start of retention and T2= Two years of retention). Results on the intention to treat basis represented by means and 95% confidence interval (CI). Test conducted with Kruskal–Wallis test P^a for 3-group comparison followed by Dunn’s test P^b for between-group comparison. P-values adjusted for multiple comparisons with Holm–Bonferroni correction.

	Group A					Group B					Group C				
	Bonded retainer 13-23					Bonded retainer 12-22					Vacuum-formed retainer				
	(n=30)					(n=30)					(n=30)				
	3-group comparison P^a	Mean	95% CI	lower	upper	13-23 vs. 12-22	Mean	95% CI	lower	upper	12-22 vs. VFR	Mean	95% CI	lower	upper
Change T2-T1	Little irregularity index	0.134	0.3 mm	0.1	0.5	0.397	0.6 mm	0.4	0.8	0.500	1.0 mm	0.4	1.6	0.138	
	Arch length	0.239	0.1 mm	-0.1	0.3	0.283	-0.1 mm	-0.3	0.1	0.583	0.0 mm	-0.2	0.2	0.537	
	Intercanine width	0.019	-0.3 mm	-0.5	-0.1	0.066	0.0 mm	-0.4	0.4	0.593	0.2 mm	0.0	0.4	0.023	
	Intermolar width	0.775	-0.3 mm	-0.7	0.1	0.999	-0.4 mm	-0.8	0.0	0.999	-0.4 mm	-0.6	-0.2	0.898	
	Overjet	0.951	0.1 mm	-0.1	0.3	0.931	0.1 mm	-0.3	0.5	0.999	0.0 mm	-0.4	0.4	0.999	
	Overbite	0.938	0.2 mm	0.0	0.4	0.999	0.3 mm	0.1	0.5	0.945	0.3 mm	-0.1	0.7	0.999	
Maximum rotation	0.010	2.9°	1.7	4.1	0.014	5.2°	4.2	6.2	0.649	6.6°	3.9	9.3	0.036

Figure 20. Changes in LII during the two years follow-up

Paper IV

No significant differences in age and treatment duration were found between the groups or between genders. Surgical exposure was carried out in 15 patients in the retention group and 19 patients in the non-retention group see Table 3.

Table 3. Baseline demographic data, standard deviation (SD)

Group	Gender	<i>n</i>	Age, yrs mean (SD)	Impacted palatal canines, <i>n</i>	Impacted buccal canines, <i>n</i>
Retention	Female	24	13.1 (1.7)	17	10
	Male	8	12.1 (1.4)	6	2
	Total	32	12.8 (1.7)	23	12
No retention	Female	15	12.9 (1.1)	14	3
	Male	16	13.0 (1.4)	15	4
	Total	31	12.9 (1.2)	29	7
Both groups	Total	63	12.9 (1.5)	52	19

The difference in irregularity change between the retention and non-retention groups was statistically significant ($p < 0.0001$, 0.4 versus 1.3 mm) thereby the null-hypothesis was not confirmed, see Figure 21. The maximum increase in irregularity was 2.5 mm in the retention and 3.2 mm in the non-retention group ($p < 0.001$) (Table 4). Moreover, the mean maximum single contact point discrepancy was lower in the retention group compared to the non-retention group, but not significant (Table 4). Small but not statistically significant changes between the groups were found in arch length, intercanine and intermolar width. No significant correlations between post-treatment changes in irregularity and duration of treatment, pre-treatment contact point discrepancies or tooth derotations were detected, as shown in Figure 22, which follows the earlier studies (69). In the non-retention group, including the 10-week interim period, most changes occurred during the ten weeks, see Figure 23. In the retention group, 93.5 per cent had a LII less than 3 mm, and in the non-retention group, 80 per cent had a Little's irregularity index less than 3 mm after the one-year observation period.

Figure 21. The changes in the Little's irregularity index in the two groups between T1 and T2 presented as Tukey boxplots

Figure 22. Correlations between changes in irregularity and (A) duration of treatment ($\rho = 0.28$); (B) maximum CPD ($\rho = 0.15$) and (C) maximum derotation ($\rho = 0.15$)

Figure 23. Post-treatment changes in irregularity in non-retention group

Table 4. Mean changes in mm CPD during the retention period (T1= post-treatment, to T2= one-year follow-up) in the retention group and non-retention group. Results (ITT) represented by means and 95% confidence intervals (CI).

		Retention group (n=32)			←P→	Non-retention group (n=31)		
		Mean	95% CI			Mean	95% CI	
			lower	upper			lower	upper
Change T2-T1	Littles Index	0.4 mm	0.2	0.6	<.001	1.3 mm	0.9	1.7
	Arch length	0.0 mm	-0.2	0.2	.145	-0.3 mm	-0.5	-0.1
	Inter canine width	0.1 mm	-0.1	0.3	.279	0.4 mm	0.0	0.8
	Intermolar width	-0.1 mm	-0.3	0.1	.492	0.0 mm	-0.4	0.4
Maximum CPD T1		0.5 mm	0.3	0.7	.330	0.5 mm	0.3	0.7
Maximum CPD T2		0.7 mm	0.5	0.9	.002	1.1 mm	0.9	1.3
Maximum derotation T2-T1		4.7°	3.5	5.9	.034	6.4°	5.4	7.4

Additional follow-up

In the retention group the retention device was removed after one-year post-retention. It was minor and non-statistical changes after removal of the retainer the following year post-retention. The results were statistically significant, looking at total changes during these two years’ post-treatment. However, the LII under 3 mm was maintained with clinically good results as shown in Table 5 and Figure 24.

Table 5. Post-treatment changes in irregularity, arch length, inter canine width, and inter molar width.

N=31	0-1 year	1-2 years	0-2 years
LII–mean (SD) – min/max	0.4 mm (0.7) -0.5/2.5	0.4 mm (0.7) -0.8/2.3	0.9 mm (0.8) -0.5/2.8
Arch length – mean (SD)	0.0 mm (0.6)	0.0 mm (0.4)	-0.1 mm (0.7)
Inter canine width – mean (SD)	0.1 mm (0.7)	0.2 mm (0.6)	0.3 mm (1.1)
Inter molar width – mean (SD)	-0.1 mm (0.8)	0.0 mm (0.5)	-0.1 mm (1.1)

Figure 24. Post-treatment changes of irregularity in the group with retention. One-year in retention and one-year after removal of the retainer.

DISCUSSION

The main findings of this thesis were that bonded retainers showed good results in retention capability, short- and long-term. Most of the relapse happened during the first year after removal of the retention. The relapse continued long-term but in minor extent. Lateral incisors were more unstable compared to the central incisors and the canines were the most stable teeth. When comparing three different retention methods, all three retention methods showed equally effective retention capacity. In the study without retention, satisfactory clinical results one-year post-treatment were found, and retention does not appear always to be needed. Since most of the relapses in the non-retention group occurred during the 10-week post-treatment interim period, this was useful in identifying patients who might have a relapse immediately after treatment.

Paper I

The change from a mean irregularity index of 0.7 after treatment to 1.4 mm one year out of retention, can be regarded as a minor relapse compared to the corrections achieved from mean 10.1 mm during treatment. No correlations were observed between the severity of pre-treatment irregularity and the amount of relapse. This finding was contradictory to other studies' statement, "Pre-treatment irregularity affects relapse negatively" (65, 125). A possible explanation is that in earlier studies, they were using removable retainers and rotations were not excluded from CPD. It might be some differences in retention method when bonded retainers are used for two to four years.

There was, however, a significant positive correlation between the amount of correction of incisor rotation and the magnitude of relapse. Of 306 teeth with bonded retainers, there were a few bond failures (six teeth

in five patients) during the retention period and in accordance with the results. The failure rate of bonded retained teeth (2 per cent) is consistent with the findings of Zachrisson (87) and must be considered excellent because most of the studies with bond failure show much higher failure rate (86, 126).

Bonding failures may occur in cases when lower teeth interfere with the retainers. In cases with pointed lower canines, the technicians were informed to position the wire more cervically on the maxillary canine and the distal part of the maxillary lateral. In patients with short clinical crowns, the wire was placed more cervically.

By using an angle between raphe and six maxillary anterior teeth, it was distinguished between rotational changes and CPD changes. Subsequently, even if there was no broken CPD, a rotation existed. In other studies when a computer-generated arch form was used, they could only show contact point displacement when the contact was broken (65, 127). When two adjacent teeth were rotated outward, there was no CPD even though teeth were rotated.

The contact relationship between laterals and centrals showed the largest CPD at T1, which is following the earlier finding. Even the most severe rotations were found among the laterals. The number of severely rotated laterals and centrals were slightly higher than for the canines, which confirm the trend reflected in the CPD measurements before treatment start T1. The correction of a bodily displaced laterals includes selective root torque to minimise the relapse tendency.

Paper II

The 27 patients we could examine long term were in all aspects similar to the larger group in Paper I (initial irregularity, treatment, duration of retention). Most of the patients who showed minor irregularity one-year post-retention were more irregular at long-term follow-up. The irregularity index less than 3 mm decreased from 84 per cent in the first study to 70 per cent in this long-term study. There was a strong correlation between irregularity, one-year post-retention and long-term. However, as in the first study, we could not confirm the finding that pre-treatment irregularity is a significant risk factor for post-retention relapse (65).

Concerning corrected rotations, almost all relapse was seen one-year post-retention with very small further changes long-term. The Little's irregularity index is not always reflecting the aesthetic impression of the teeth; evenly distributed small CPDs are obviously better than one or two

major displaced contacts with the lateral/central contact often being the most critical. However, half of the group of 27 patients did not change at all, and they were stable during the whole post-retention period, see Figure 19.

Paper III

Based on clinical experience, hard contacts from mandibular canines causes fractures on the wire between canines and laterals in the maxilla. Many clinicians advocate using bonded retainers from 12-22 instead but there has not been any RCT on comparing cases with bonded retainers 12-22, 13-23 and VFR. This study is, to our knowledge, the first RCT on the two-year stability of the maxillary anterior teeth using fixed or removable retainers.

In this trial and from a clinical point of view, all three retention methods had a good capacity to retain the maxillary anterior teeth. There were no statistically significant differences in irregularity, and thus, the null hypothesis was accepted. This finding is in line with the results reported earlier who found no statistically significant difference between bonded retainers and VFR in the maxilla (101). In contrast, they found small differences in the mandible. The intercanine width was smaller in the bonded retainer group (13-23) than in the group with VFR. Even if statistically significant ($P=0.023$), the difference in intercanine distance was small (0.5 mm) and not clinically significant. It might be speculated that the reduced intercanine width in group A, could have been caused by the retainer that may have inhibited growth changes in the intercanine area. The slightly increased intercanine width in the VFR-group was opposed to the findings in an earlier randomised trial, which showed a decrease in maxillary intercanine width when using VFR covering the palate (118).

In the VFR-group, canines showed slightly more rotational changes than the other groups. Even though statistically significant, the changes were too small to have any clinical importance. On the other hand, the similarities between group (13-23) and group (12-22) on lack of rotational changes regarding canines and intercanine width, somehow confirm the theory that bonded retainer between 12-22 may be sufficient because of the stability of the canines (67). An interesting finding beyond the primary aim of this study was that fourteen patients (47 per cent) in the VFR-group with suspected poor adherence, also showed an increase in LII compared to the patients with suspected good adherence (119), see Fi-

figure 25. The differences within the VFR-group did however not influence the differences between the three retention groups.

Figure 25. LII in VFR-group between compliant and non-compliant patients

Paper IV

This unique trial, with neither retention nor IPR, has never been described before. This study showed satisfactory clinical results one-year post-treatment in the group without retention. Only in one study, they took out the arch wire for one month to measure relapse under this very short period before they put back the arch wire in place (128). Even though the average difference in LII, 0.4 versus 1.3 mm, was statistically significant, it is our opinion that this difference was not clinically significant since LII between 1 and 3 mm are scored as minimal irregularities (120). However, it cannot be overlooked that some individual patient may have been disturbed by an irregularity of 3 mm. Consequently, our initial hypothesis could be partly confirmed, and it has to be pointed out that the range of changes in the irregularity index was greater in the non-retention than in the retention group.

The challenge is to identify the patients with a higher risk for an increase in irregularity index beforehand. Since the parameters for this identification still are not entirely known, the use of the 10-week interim period in the non-retention group was useful in identifying those patients who might have a relapse immediately after treatment. Also, for ethical reasons, this interim method was justified to avoid major relapse or harm to patients. From a short-term perspective, this trial showed that retention with a removable vacuum-formed retainer and non-retention both were

successful in patients with impacted maxillary canines and moderate pre-treatment dental irregularities.

The results of the present trial are similar to trials that have investigated post-treatment changes of mandibular anterior teeth. Hence, these trials have reported stable results after IPR, and without any retention appliances (71, 118, 119). It can also be pointed out that in the group without retention, the largest irregularity changes occurred during the first ten weeks. These findings are in line with the results by Reitan who reported changes as early as the first day and a progressive relapse during the following 232 days until the supra crestal fibres were re-arranged (44). However, most of the patients with no retention, showed very good alignment one year after debonding as shown in Figure 26. Patient number 10 with no retention and only treatment in the maxilla one-year post-treatment. The results are very promising because patients without retention do not need to come to the clinic for controls and repairs to their retention. No retention when it is possible may have significant benefits in reduction of social costs, patient's costs, and environmental costs.

Figure 26. Patient number 10 with no retention treatment only in the maxilla, one-year post-treatment

Additional follow-up

In the retention group, the retention device was removed one-year post-retention. It was minor and non-statistical changes after removal of the retainer the following year post-retention. The results were statistically significant, looking at total changes during these two years' post-treatment. However, the LII was under 3 mm and clinically good results as shown in Figure 24 and Table 5. This observation confirms our know-

ledge that continuous changes occur after orthodontic post-treatment no matter if retention is present or not, especially in the maxilla (129). Other changes as intercanine distance, intermolar distance, and arch length were minor and not statistically and clinically significant. The relapse changes varied between individuals. Some treatment results were stable and some relapsed as illustrated in Figures 27-30.

Figure 27. Patient number 38 with retention. Tooth 22 is rotated pre-treatment T0, corrected at T1, stable at one-year post-treatment T2, and stable one-year post-retention T3.

Figure 28. Patient number 23 with retention. Tooth 12 is rotated pre-treatment T0, corrected at T1, but relapse at one-year post-treatment T2, and relapse stopped one-year post-retention T3.

Figure 29. Patient number 33 with retention. Lack of space for 23 at pre-treatment T0, aligned teeth at post-treatment T1, stable at one-year post-treatment T2, and one-year post-retention T3.

Figure 30. Patient number 24 with retention. Ectopic eruption of 13 and 23 and spacing at pre-treatment T0, aligned teeth at post-treatment T1. Spacing at one-year post-treatment T2 and increased spacing one-year post-retention T3.

Limitations

Paper I and II were case series without controls, and thereby, contributed to limited evidence. Both studies were completed at a single centre and patients treated by one operator. Another weakness with Paper II was the relatively small number of patients ($n=27$) of the original 45 patients. Thus, the dropout rate was high (40 per cent) since many patients had moved to other cities and did not want to travel to the clinic or it was not possible to locate their residence. We were not able to collect all the participants in the first study seven years post-retention, which might have influenced the results.

In Paper III, the results are short-term during two years of retention and a single centre. There is a need for long-term evaluation. Multicentre studies would add generalizability.

In Paper IV, the trial was a single-centre RCT, and one operator conducted the treatments. Therefore, operator-related errors might have influenced the results, but the single-centre design has the advantage of clear communication and less variance of trial conduct. There is a need for long-term evaluation of this study.

Strengths

Paper I, the first study in its kind, analysed and separated rotations from buccolingual movements to distinguish their effects on contact point displacement and irregularity.

Paper III compared three different retention methods in a randomised clinical trial. The method of using the 3D scanner gave higher precision than previous studies.

Paper IV is a unique RCT and the first of its kind in study design, questioning if we need retention after orthodontic treatment of impacted maxillary canines.

The advantages of using the RCT methodology in Paper III and IV, lead to minimising the selection bias as well as confounding variables which by the randomisation will be equally distributed to the groups (130).

The intention to treat (ITT) approach was used to evaluate every patient record, regardless of whether the treatment was successful or not (131). By using the ITT approach instead of per-protocol, over-optimistic estimates of the efficacy of an intervention by removal of unsuccessfully treated subjects or dropouts from the study were avoided.

Fortunately, we had only one dropout in Paper III and two dropouts in Paper IV. They received the highest negative values from their allocated group when measuring the results.

Generalizability

A randomised controlled trial design was undertaken in Paper III and IV. Efforts were made to reduce the risk of bias and confounders should be evenly distributed between groups because of the randomisation. The prospective design and normal treatment procedure in the clinic ensured that the results could be implemented in everyday work.

In addition, the intention to treat approach was used to evaluate every patient record, the consisted sample was in gender, age and conducted treatment typical for an orthodontic specialist clinic. As such, this sample is considered representative of adolescent orthodontic patients.

Future research

In Paper III and IV, the results are short-term. Long-term results of those studies may add valuable data to understand differences between short- and long-term changes and stability after orthodontic treatment between different retention methods and no retention.

Further, it can be important to evaluate which retention strategy is most cost-effective. Another important area is evidence-based clinical research on patients' perspective for not wearing retainers compared to patients using retention devices, likewise their perspective and experience between wearing different types of retentions.

CONCLUSIONS

Paper I and II

- Minor or no relapse in short-term follow-up (one year) was noted in the maxillary front after correction of irregularity and a two to four-year period of bonded retention. Further, small relapses occurred long-term, i.e. at mean seven years post-retention.
- There was a strong correlation between irregularity one- and seven-years post-retention. Stable cases one-year post-retention are stable in the long-term and cases with small changes one-year post-retention tend to deteriorate with time.
- There was a significant positive correlation between the amount of correction of incisor rotation and the magnitude of relapse.
- Laterals are more prone to relapse. If, after three years of retention, a decision is made to use permanent retention of the maxillary anterior teeth, a retainer bonded to only the incisors seems to be a relevant choice.

Paper III

- All three retention methods showed an equally effective retention capacity. Thus, a bonded retainer to the maxillary four incisors, a bonded retainer to the maxillary four incisors and canines, and a removable vacuum-formed retainer can all be recommended as retention methods in the maxilla.
- Results were slightly better within the VFR-group among those with better adherence than others.

Paper IV

- Changes between the retention and the non-retention group were statistically but not clinically significant, and since satisfactory clinical results one-year post-treatment were found in the non-retention group retention does not appear to be needed.
- Most of the relapses in the non-retention group occurred during the 10-week post-treatment interim period, and, thus, this period was useful in identifying patients who might have a relapse immediately after treatment.

Clinical implications

The contact point between laterals and centrals in the maxilla, is the most crucial contact point when it comes to relapse and canines are the most stable ones. Therefore, bonded retainer between 12-22 is enough to keep the alignment of the anterior teeth.

Most of the relapse happens during the first two months without retention and during the first year after removal of retainers in patients with retention. Stable cases one-year after removing the retainer, are stable even after seven years.

All three retention methods, i.e. bonded retainer 12-22, bonded retainer 13-23, and the vacuum-formed retainer can be recommended for retention of maxillary anterior teeth. However, those patients not adherent to wearing their vacuum-formed retainer showed more irregularity than adherent patients.

It may be possible not using retainers in special cases for orthodontic treatment of impacted maxillary canines. The observation period of 10 weeks may be useful in identifying patients who might have a relapse immediately after treatment.

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ABBREVIATIONS AND DEFINITIONS

12-22	Bonded retainer attached to each tooth from left lateral incisor to the right lateral incisor in the maxilla
13-23	Bonded retainer attached to each tooth from canine to canine in the maxilla
CAD/CAM	Computer-aided design/computer-aided manufacturing
CPD	Contact point displacement
Debond	Removing the braces, treatment is finished
IPR	Interproximal reduction of tooth width by stripping
ITT	Intention to treat
LII	Little's irregularity index
PDL	Periodontal ligament
RCT	Randomised controlled trial
TMD	Temporomandibular disorders
VFR	Vacuum-formed retainer

PAPERS I - IV

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