Stability of occlusion and anterior tooth alignment – the influence of retention in a long-term perspective

A doctoral thesis by
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2017

Series of dissertations submitted to the
Faculty of Dentistry, University of Oslo

ISBN 978-82-8327-031-0

Cover: Hanne Baadsgaard Utigard.
Print production: Reprosentralen, University of Oslo.

ACKNOWLEDGEMENTS

Firstly, I would like to thank the Faculty of Dentistry, University of Oslo for giving me the opportunity to carry out this PhD, and for providing funding and work facilities.

My sincere gratitude goes to my main supervisor Professor Vaska Vandevska-Radunovic. Thank you for sharing your scientific knowledge and for giving valuable advice on my work. I am very grateful for the time you have invested, and that you decided to «open the retention archives» for me. I would also like to thank you for our refreshing debates. Without discussion there is no progress.

I wish to thank my co-supervisor Associate Professor Marit Midtbø for constructive ideas regarding the project and for providing access to the Bergen sample. I am proud to say that I probably was the last person ever to do scientific work in the old faculty building in Bergen.

A profound thanks to Professor Leiv Sandvik for statistical advice and enjoyable conversations. Your guidance was as helpful as it was amusing, thanks to your contagious positive attitude.

I am thankful to the people at the Department of Orthodontics for making this PhD possible, and for the clinical and scientific education I have received the past years. I have learnt a great deal. To the staff who is working in the department on a daily basis: Your efforts are strongly appreciated. Without your continuous help with patient care and data collection, research like this would not be possible to conduct.

To my friends and fellow specialist candidates, who I meet far to seldom: I wish I had seen you more often. But in fear of getting carried away and making promises I can't keep – let's just say there's room for improvement!

I am highly appreciative to my co-workers with whom I have shared office; you have made our office a positive and inspiring work place. Work would not be as fun without you. Thank you all for your contributions, even the periodontists among you…

Last but not least, to my family whom I can always rely on: Thank you for having faith in me, and for your unsurpassed support along the way. And to my father, the realist of realists: I am grateful for being brought up in a safe and loving home filled with music, humor, curiosity and an appreciation of knowledge and independent thinking.

Oslo, November 2017

Ragnar Bjering

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PREFACE AND LIST OF PAPERS

The following papers (I-III) are submitted in fulfilment of the requirements for the degree Philosophiae Doctor (PhD) at the Faculty of Dentistry, University of Oslo. This thesis is based on original research carried out at the Institute of Clinical Dentistry, Faculty of Dentistry, University of Oslo and the Department of Clinical Dentistry, University of Bergen. In the present summary the papers will be referred to by their Roman numerals.

Paper I

Bjering R, Birkeland K, Vandevska-Radunovic V. Anterior tooth alignment: A comparison of orthodontic retention regimens 5 years posttreatment. Angle Orthod. 2015 May;85(3):353-9. doi: 10.2319/051414-349.1. Epub 2014 Aug 20. PubMed PMID: 25140669.

Paper II

Bjering R, Sandvik L, Midtbø M, Vandevska-Radunovic V. Stability of anterior tooth alignment 10 years out of retention. J Orofac Orthop. 2017 Jul;78(4):275-283. doi: 10.1007/s00056-017-0084-2. Epub 2017 Apr 13. PubMed PMID: 28409195.

Paper III

Bjering R, Vandevska-Radunovic V. Occlusal changes during a 10 year posttreatment period and the effect of fixed retention on anterior tooth alignment. Manuscript 2017 (Under review).

ABBREVIATIONS

ACS	Anterior component score (extracted from the PAR Index)
ICC	Intraclass correlation coefficient
ICON	Index of Complexity, Outcome and Need
IPR	Interproximal enamel reduction
LII	Little's Irregularity Index
OGS	Objective Grading System
OPG	Orthopantomogram
OTM	Orthodontic tooth movement
PAR	Peer Assessment Rating
SPSS	Statistical Package for Social Sciences
T0	Pretreatment
T1	Posttreatment
T3	3 years posttreatment
T5	5 years posttreatment
T10	10 years posttreatment
TPR	Thermoplastic retainer
UIB	University of Bergen
UIO	University of Oslo

INTRODUCTION

Rationale behind orthodontic treatment

Orthodontics is the branch of dentistry involving diagnostics and treatment of deviations in jaw position, occlusion and dental position. The aim of orthodontic treatment is to correct these deviations. Fundamental in orthodontics is the understanding of malocclusion, which can be defined as an appreciable deviation from ideal occlusion [1] - occlusion being the relation of the teeth when the jaws are closed. Malocclusion is not a disease, but an aberration of normal anatomy. Today's perception of malocclusion is largely influenced by Edward H. Angle's classification from 1899 [2]; a classification where "normal occlusion" in reality rather should be considered the ideal. There is a strong belief that neutral occlusion is the desired occlusion, both functionally and aesthetically. Deviation from a neutral occlusion is regarded as a compromise in function and/or appearance. This notion forms the rationale behind the orthodontist's perception of orthodontic treatment need.

Treatment need can be divided into objective and subjective need. An objective assessment of treatment need seeks to give an impartial appraisal of the need for orthodontic treatment. Since the first quantitative method for assessment of malocclusion was proposed in the 1950s [3], a great number of indices have been developed. In countries where orthodontic treatment is subsidised by third party funding, such indices are frequently used as eligibility criteria of reimbursement [4]. Although some of the indices assessing treatment need include aesthetic evaluations, the majority have prioritised occlusion and function as the most important criteria. However, other important aspects of more subjective nature such as facial aesthetics [5], social background and cultural or geographic origin [6] have reported to significantly influence a patient's perceived treatment need. Aesthetics has been reported as the most frequent motive for orthodontic treatment [5]. Even minor deviations may be of importance at an individual level [7]. The desire to correct the dental alignment is not new. The first written record of attempts to correct protruded or crowded teeth is some 3000 years old [8], and traces of orthodontic appliances date back to ancient Greece. In contrast, scientific literature regarding the influence of dental appearance on psychosocial well-being only goes a few decades back. Dissatisfaction with the dental appearance may impact social behaviour negatively [9]. Despite a poor correlation between normative need and patient's recognition of orthodontic treatment need [10], improved smile aesthetics have been reported to significantly increase quality of life in orthodontic patients [11].

Relapse and retention

When the active treatment phase is over and the appliances removed, orthodontic patients are in the short term susceptible to relapse. Relapse is often defined as a movement towards the initial malocclusion [12]. “True” relapse takes place in the first 8 months or so, during the time it takes for the interdental and dento-gingival fibres to remodel [13]. Forces from the gingival and supracrestal fibres tend to pull the teeth out of alignment, often back towards their original positions. Relapse may also be caused by soft tissue pressures if the teeth are placed in an inherently unstable position. It is essential that the occlusion is stabilised throughout this period, since unwanted tooth movement can take place within few weeks after appliance removal [14]. In the long term it is hard to distinguish relapse from normal physiologic changes in occlusion. While some authors have questioned whether growth-related changes could be considered as relapse [15], others have decided to include such changes in the term relapse [16].

Retention has been defined as “the holding of teeth following orthodontic treatment in the treated position for the period of time necessary for the maintenance of the result” [17]. The retention phase prevents relapse and other unwanted tooth movements. A retainer secures the position of the teeth and stabilises the occlusion and alignment while the periodontal fibres fully remodel and soft tissues adapt. This way the orthodontic control of the teeth is withdrawn gradually. Orthodontic retainers traditionally come in two forms, removable and fixed, and are custom-made for each patient.

Removable retainers can be removed by the patient, and are consequently dependent on patient compliance. A traditional removable retainer is made of an acrylic body covering parts of the palate, and is held in place with metal clasps and a labial bow. The “Hawley bite plate” is probably the most famous design, introduced by American Charles A. Hawley (1861-1929) in 1908 [18]. It is still widely used, although often in modified versions. The newer thermoplastic retainer (TPR) introduced in 1993 [19] has gained increasing popularity [20]. This retainer has a clear or transparent look. It is produced from a mould and therefore fits over the entire arch of teeth. It’s made of polypropylene or polyvinylchloride, typically 0.5-1.5 mm thick. Brand names commonly associated with this type of retainer include Essix® and Sta-Vac™. Fixed retainers are passive wires bonded to the lingual (or buccal) surfaces of a patient’s teeth. They are normally used in the maxillary or mandibular anterior region. In contrast to removable retainers, fixed retainers will serve their function as long as they remain attached and undamaged. The advantage of being compliant-free comes along with disadvantages such as impaired hygiene conditions and the risk of loosening.

Different types of wires can be used; both multistranded and solid wires are common choices. The most recent advances in fixed retainer manufacture utilises CAD/CAM technique to fabricate a custom-cut NiTi retainer wire (Memotain®) from a plain sheet of metal [21]. One of the first to use fixed retention was Victor H. Jackson (1850-1929). He believed the teeth should be held "absolutely firm", and described both palatal and buccal retainers in his text book from 1904 [22]. Over 100 years later we still use fixed retention of the very same principle, only more flexible wires which don't restrict the teeth from moving in a physiologic manner. Figure 1 shows a selection of different types of orthodontic retainers.

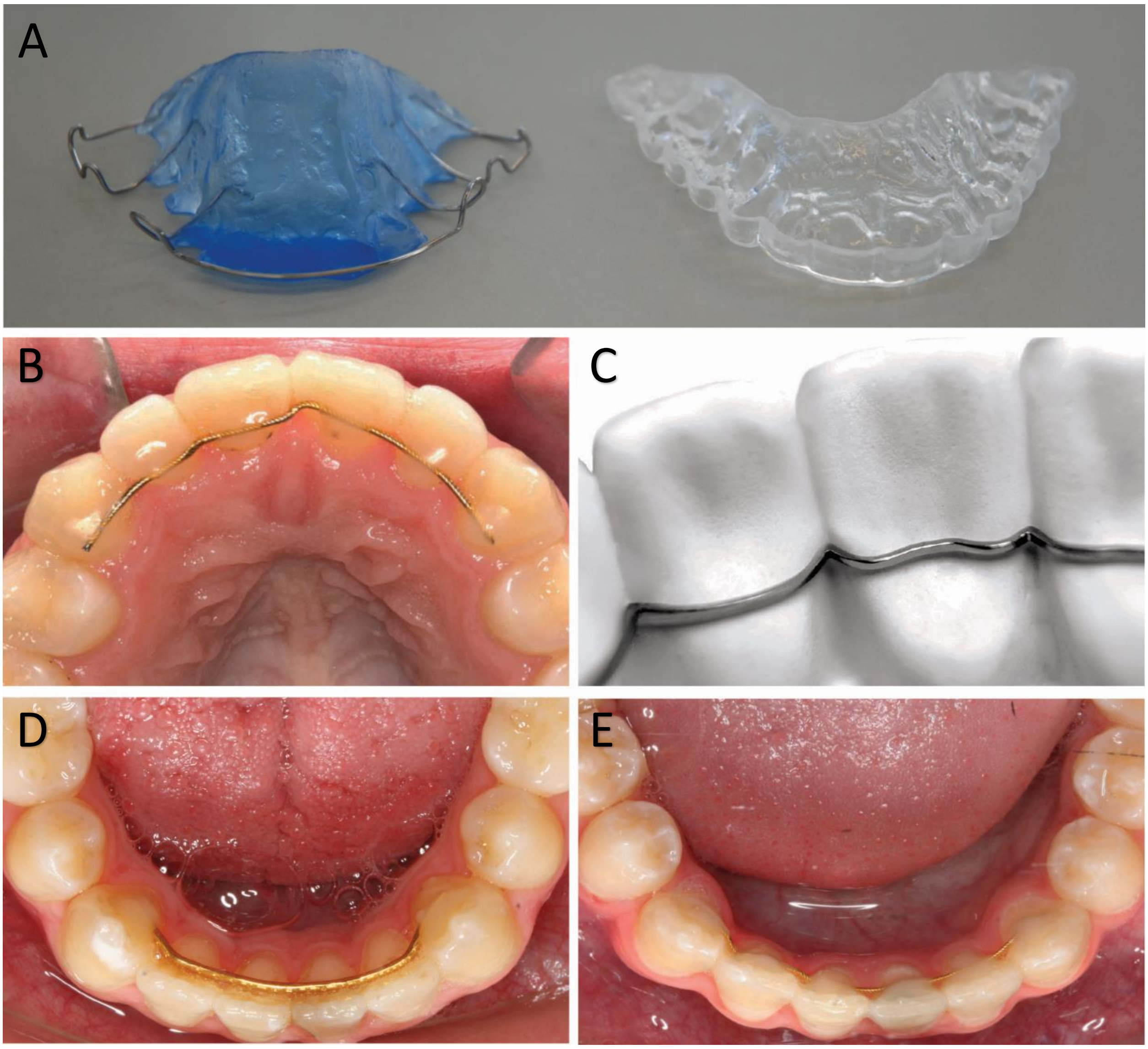

Figure 1. A selection of different types of orthodontic retainers: **A.** Removable maxillary retainers; Hawley retainer to the left, thermoplastic retainer to the right **B.** Fixed Penta Twist multistranded maxillary retainer, bonded to all six anterior teeth **C.** Memotain® custom-cut NiTi retainer fabricated using CAD/CAM technique **D.** Fixed mandibular Blue Elgiloy® retainer, bonded to the canines only **E.** Fixed Penta Twist multistranded mandibular retainer, bonded to all six anterior teeth.

Physiologic changes in occlusion and anterior alignment

The notion of viewing the occlusion as a static entity has for long been discarded. As growing biological beings both untreated individuals and orthodontic patients will inevitably be subject to changes in occlusion and dental alignment. Although tooth movement intentionally is restricted during the retention phase, it will not prevent all changes from happening. However, some adaptations can in fact be desirable, like settling. Settling takes place shortly after removal of the orthodontic appliance; it is characterised by improved interdigitation due to eruption of the molars and premolars to proper intermaxillary contact. The process is enabled by the tendency for the dentition to continuously adapt to the changing basis onto which it is attached [23].

As time progresses physiologic growth processes become of increasing importance to changes in the dentition. Several mechanisms are believed to play a role in the development of posttreatment or "late changes" in occlusion. Differential jaw growth will in most cases lead to a minor relative protrusion of the mandible compared to maxilla [24], accompanied by slight uprighting of the incisors seen both in adolescence [25], young adulthood [26] and late adulthood [27]. Overjet is reported to reduce both in late adolescence [28] and adulthood [29] as a result of this. Long-term changes in overbite seem to be of varying character, with some patients even displaying a decrease over time [30]. The growth of the mandible can also lead to altered soft tissue balance [31,32]. Change in muscular balance between the perioral musculature and the tongue may be a contributing factor for the increase in crowding, when the strength of the perioral musculature gradually exceeds the lingual pressure from the tongue [33,34].

The shape of the dental arches often changes with growth [35]. There is a general tendency to shortening of the arch lengths and arch depths, which leads to less available space in the anterior regions, particularly in the mandible. In untreated individuals, reports show a gradual reduction of arch length and arch perimeter from the mixed dentition to the early permanent dentition, as well as from adolescence to young adulthood [36-38]. The changes decrease with age, but are still present in the fifth and sixth decade of life [39]. Less available arch length may affect the alignment [40]. Furthermore, shortening of the mandibular intercanine distance will occur, and is believed to continue throughout life [41].

Increased mandibular crowding may also be associated with other factors such as facial morphology and growth direction. It has been showed by Björk [31,42] and Björk and Skieller [23] that rotation of the mandible influences the direction of tooth eruption. As the mandible is displaced forward, the upper incisors are believed to express a lingual directed pressure on the mandibular incisors. There are studies that both support [43] and reject [44] this theory. Others have highlighted the importance of vertical growth and concluded that both treated and untreated individuals with a larger amount of postadolescent vertical jaw growth will exhibit a larger increase in alignment irregularity due to lower incisor eruption [45]. The above mentioned physiologic changes may affect occlusion and alignment even in cases where retention is present [46]. However, the changes will be noticeably less in the retained region.

Stability of occlusion after orthodontic treatment

There are several ways of assessing stability of occlusion after orthodontic treatment. Often parameters such as arch length, arch perimeter, intercanine distance, overjet, overbite and incisor alignment are used as references, and changes over time in these variables compared between different time points [47]. Another way to assess stability of treatment is by using an orthodontic index. Indices allow for objective assessment of treatment outcome and easy comparison of cases with different malocclusions. While there has been introduced many indices that measure treatment need, the number of indices assessing treatment outcome is more limited. The most widely used indices for evaluation of treatment outcome are the Peer Assessment Rating (PAR) Index [48], the Index of Complexity, Outcome and Need (ICON) [49] and the Objective Grading System (OGS) [50]. Some of these indices are also capable of assessing the treatment outcome in the long term, such as the PAR Index.

It has been suggested that a good standard of treatment should result in a mean PAR score reduction of 70% or more [51]. Most studies report a PAR score improvement between 70% and 90% at posttreatment. However, as time passes the occlusion will to some degree deteriorate. For conventional orthodontic patients the PAR Index percentage improvement 5-10 years posttreatment has reported to be between 56% and 72% (Table 1) [52-56]. A slight additional decline in improvement scores has been reported for follow-up periods exceeding 10 years (Table 2) [57-61].

Table 1. Overview of studies using the PAR Index for assessing orthodontic treatment outcome 5-10 years posttreatment. Mean weighted PAR scores and percentage improvement reported.

Author(s)	Year	Sample size	Pre-treatment	Post-treatment	5-10 yr posttreat.	Follow-up period (yr)	Postretention period (yr)
Birkeland et al.	1997	224	28.7	6.0 79%	9.6 67%	7	5 yr
Berset et al.	2000	128	21.8	3.2 85%	6.1 72%	5	Mixed
Linklater et al.	2002	78	n/a	n/a 69%	n/a 56%	n/a	6.5 yr
de Freitas et al.*	2007	87	27.1	6.2 77%	10.6 61%	5	3.5 yr
Steinnes et al.	2017	67	27.2	6.7 75%	10.5 61%	9	Mixed

* For de Freitas et al. mean of the two groups in the study was calculated

Table 2. Overview of studies using the PAR Index for assessing orthodontic treatment outcome at least 10 years posttreatment. Mean weighted PAR scores and percentage improvement reported.

Author(s)	Year	Sample size	Pre-treatment	Post-treatment	At least 10 yr posttreat.	Follow-up period (yr)	Postretention period (yr)
Otuyemi & Jones	1995	50	26.6	4.3 83%	12.2 54%	11	10 yr
Al Yami et al.	1999	564	28.4	8.5 70%	14.6 49%	11	Appx. 10 yr
Woods	2000	65	25.5	3.0 88%	7.0 73%	11	At least 6.5 yr
Ormiston et al.*	2005	86	31.7	4.2 87%	12.1 62%	17	Appx. 14 yr
Lagerström et al.	2011	72	20.2	4.3 79%	9.4 54%	17	Mixed

* For Ormiston et al. mean of the two groups in the study was calculated

Stability of anterior alignment after orthodontic treatment

Whereas most patients tend to be unaware of their posterior occlusion, they are seldom oblivious to the anterior alignment. Complete long-term stability of the anterior alignment remains an obstacle yet to overcome, largely because it seems to be a battle against natural changes to the dentition. The instability is considered to be a multifactorial phenomenon. In orthodontic patients, relapse is one of the main causes. Tooth rotations for instance are especially vulnerable to relapse [62-64]. Eruption and presence of third molars have also been related to late mandibular crowding [65-67], although conflicting evidence exists. Other suggested possible etiological factors for lower anterior crowding include late mandibular growth, skeletal morphology and complex growth patterns. However, no particular type of skeletal morphology or specific growth pattern associated with an increase in lower arch crowding has been found [68].

Apart from use of retainers, other methods are occasionally used to enhance stability of incisor alignment. Overcorrection of rotations has proved successful and can limit the need for fixed retainers by allowing minor relapse to occur [69]. It is also important to preserve the arch form and avoid expansion of the lower intercanine distance. Moreover, increased stability has occasionally been reported in extraction cases [70-72]. Other possibilities to increase mandibular incisor stability include circumferential fibreotomy [73], interproximal enamel reduction (IPR) [74] and a combination of fibreotomy and IPR [75].

Stability of anterior alignment is often measured with Little's Irregularity Index (LII) (Figure 4). In this brief literature review focus has been directed to stability of anterior alignment measured by LII at least 5 years postretention after treatment with conventional fixed appliances. Since retainers are preventing tooth movement from taking place, the true answer to what degree of long-term stability one may expect can only be had several years after the retainer is removed. Due to differences in populations, treatment techniques, retention protocols and follow-up periods the cited articles will not be ideal for precise comparisons. Yet, the literature tables provide an overview of the main research on the subject to this date.

Historically, the mandibular incisor alignment has received much of the attention related to orthodontic relapse and long-term postretention stability. Despite its obvious relation to facial appearance, less focus has been directed to the maxillary alignment. A reason for this bias in research interest may be that stability of maxillary anterior alignment in general is perceived to exceed that of the mandible [39]. The past decade a growing number of reports have been published on stability of maxillary alignment. However, scientific reports are still outnumbered by corresponding research on mandibular alignment. A summary of the literature reporting stability of maxillary alignment at least five years postretention after treatment with conventional fixed appliances is given in Table 3 [76-84].

Mandibular anterior tooth alignment is known for being particularly unstable in the long term. It is now generally recognised that the tendency to late crowding is much the result of physiologic processes, which may take place regardless of orthodontic interventions. In untreated individuals with normal occlusion, Richardson found alignment changes to be the greatest between 13 and 18 years [85]. In a long-term follow-up of untreated occlusions, mandibular alignment increased significantly from adolescence to the fifth decade of life [86]. Mandibular irregularity has also been reported to increase during adulthood, although to a lesser extent [41,87]. Differences in lower incisor irregularity between treated and untreated individuals have been reported to be nonsignificant [45].

Assessments of mandibular anterior alignment in treated individuals 10 to 20 years postretention have concluded with increasing incisor irregularity and diminishing arch dimensions [88]. However, despite an unpredictable long-term response, acceptable anterior alignment can still be achieved [83]. Secondary mandibular crowding is only to a small degree associated with tooth widths [89]. Studies showing stability of mandibular alignment measured by LII at least five years postretention after orthodontic treatment with conventional fixed appliances are summarised in Table 4 [59,71,72,76-79,81,83,88,90-104].

Table 3. Stability of maxillary alignment measured by Little's Irregularity Index (LII) at least 5 years postretention after treatment with conventional fixed appliances. Mean values reported. Studies not reporting mean LII at follow-up were not included.

Author(s)	Year	n	Angle Class	Ex/Nonex	Follow-up period (yr)	Retention time (yr)	LII at pre-tx	LII at follow-up
Sadowsky et al.	1994	22	Mixed	Nonex	15	n/a	8.0	2.0
De La Cruz et al.	1995	45	Cl I	Ex	19	2.5	6.1	2.7
		42	Cl II, div 1	Ex	17	2.5	6.5	2.8
Vaden et al.	1997	36	Mixed	Ex	15	n/a	7.8	1.8
Ciger et al.	2005	18	Cl II, div 1	Nonex	6	1	5.9	3.4
Andrén et al.	2010	27	n/a	Mixed	10	2.9	10.3	2.0
Park et al.[a]	2010	51	Mixed	Mixed	16	3	n/a	1.6
		45	Mixed	Mixed	16	3	n/a	1.8
Quaglio et al.	2011	30	Cl I	Ex	9	1.2	8.6	1.8
		20	Cl II div. 1	Ex	10	1.3	11.1	2.1
		20	Cl II div. 1	Ex (max only)	10	1.1	9.7	1.4
Dyer et al.	2012	50	Mixed	Ex	23	2.5	6.8	2.1
Guirro et al.[b]	2015	19	Cl I	Nonex	8	n/a	7.8	2.0
		19	Cl II	Nonex	7	n/a	6.8	0.8
		30	Cl I	Ex	9	n/a	8.6	1.8
		35	Cl II	Ex	9	n/a	8.8	1.7

[a] For Park et al. top line represents adolescents, bottom line adults

[b] For Guirro et al. retention time for the total patient sample was appx. 3 years

Table 4. Stability of mandibular alignment measured by Little's Irregularity Index (LII) at least 5 years postretention after treatment with conventional fixed appliances. Mean values reported. Studies not reporting mean LII at follow-up were not included.

Author(s)	Year	n	Angle Class	Ex/Nonex	Follow-up period (yr)	Retention time (yr)	LII at pre-tx	LII at follow-up
Little et al.	1981	65	Mixed	Ex	15	2.0	7.3	4.6
Puneky et al.	1984	77	Mixed	Mixed	20	n/a	4.5	3.6
Glenn et al.	1987	28	Mixed	Nonex	12	4	2.9	2.2
Little et al.	1988	31	Mixed	Ex	28	2.0	7.4	6.0
Little et al.	1989	30	Mixed	Ex	17	1.9	2.5	3.8
Little et al.	1990	30	Mixed	Ex	15	2.0	4.1	4.4
McReynolds et al.	1991	46	Mixed	Mixed	16	> 2	4.9	3.8
Paquette et al.	1992	30	Cl II, div 1	Nonex	14	n/a	5.1	3.4
		33	Cl II, div 1	Ex	14	n/a	6.5	2.9
Luppanapornlarp & Johnston	1993	29	Cl II	Nonex	15	n/a	2.9	3.7
		33	Cl II	Ex	15	n/a	7.2	3.2
Sadowsky et al.	1994	22	Mixed	Nonex	15	8.4	5.2	2.4
Weiland et al.[a]	1994	40	Mixed	Mixed	n/a	n/a	4.8	4.1
De La Cruz et al.	1995	45	Cl I	Ex	19	2.5	8.1	4.0
		42	Cl II, div 1	Ex	17	2.5	4.8	4.4
Elms et al.	1996	42	Cl II, div 1	Nonex	9	2.1	4.4	2.0
Årtun et al.[b]	1996	41	Cl II, div 1	Nonex	n/a	n/a	2.8	3.6
		37	Cl II, div 1	Ex	n/a	n/a	5.3	4.1
Vaden et al.	1997	36	Mixed	Ex	15	n/a	4.7	2.6
Haruki et al.	1998	83	Mixed	Ex	16	2	8.1	3.7
Davis et al.	1998	72	Mixed	Mixed	20	n/a	4.3	2.9
Boley et al.	2003	32	Cl I	Ex	16	2.3	8.1	2.6
Ciger et al.	2005	18	Cl II, div 1	Nonex	6	1	3.7	5.0
Ormiston et al.	2005	86	Mixed	Mixed	17	3	4.8	3.5
Park et al.[c]	2010	51	Mixed	Mixed	16	3	n/a	1.5
		45	Mixed	Mixed	16	3	n/a	2.0
Dyer et al.	2012	50	Mixed	Ex	23	2.5	4.5	2.6
Myser et al.	2013	25	Mixed	Mixed	16	3	n/a	2.4
Franklin et al.	2013	114	Mixed	Mixed	18	6	5.3	2.3
Schutz-Fr. et al.	2017	64	Cl II	Mixed	12	2.8	4.6	4.3

For Puneky et al., McReynolds et al., Haruki et al., Davis et al., Ormiston et al. mean of the studied groups is reported

[a] For Weiland et al. mean postretention period was 10 years

[b] For Årtun et al. mean postretention period was 14 years

[e] For Park et al. top line represents adolescents, bottom line adults

Influence of retention on anterior tooth alignment

Not many years ago, the standard retention procedures often had a duration of 1-2 years. With time there has been a change of practice towards longer retention periods. Some orthodontists even advocate life-long retention [105]. Approaches to retention tend to vary between clinicians, but are also reported to differ significantly between countries [20,106-115]. Although a general increase in use of fixed retainers can be seen from these studies, there are several different approaches to retention with no apparent consensus on the topic. As a response to this, common retention guidelines have been requested [107].

Several types of retention have proved efficient in maintaining the treatment result, at least in the short term. This can explain the large variation found in retention protocols. Recent review articles have evaluated the evidence of the preventive effect of different retention protocols on anterior alignment [16,116,117]. As often with systematic reviews, it is concluded that much of the research on the topic is lacking in quality. Evidence from studies investigating whether TPRs should be worn full-time or part-time is of medium quality according to the GRADE quality rating; the remaining RCTs are of lower quality. The main conclusions are summed up below.

For both maxilla and the mandible, there is evidence that suggest no differences in relapse between part-time and full-time wear of Hawley retainers the first year posttreatment [118,119]. Also part-time wear of TPRs seems to perform on an equal level as full-time wear the first 6 and 12 months after debonding [120,121]. Several types of removable retainers have provided similar efficacy: A six month comparison of Hawley retainers and TPRs showed only slightly better mandibular irregularity scores for patients wearing TPRs [122]. In maxilla, no significant differences were found. However, there are a couple of articles that report that TPRs retain derotated teeth better than Hawley [123] and Begg retainers [124].

When comparing removable retainers to fixed retainers, small differences seem to separate them in the short term. Similar retentive capacity of TPRs and bonded retainers on mandibular anterior alignment 18 months posttreatment has been reported [125]. Nor at 3 years posttreatment were there any clinically significant differences between removable and fixed retainers [126]. At 7 years posttreatment, a TPR and a canine-to-canine retainer performed equally well in the maxilla, whilst in the mandible both a fixed retainer and IPR gave similar results on a clinical level [127].

Several types of fixed retainers can be used for maintaining the alignment. In the short term, both a multistranded 3-3 retainer bonded to each tooth, and a retainer bonded to the canines only can be effective in maintaining mandibular alignment [104,126]. But fixed mandibular retainers may be viable also in the long term, as much as 20 years posttreatment [128].

Because of the stringent inclusion criteria in systematic review reports, most of the high-level evidence we have are scientific studies with a rather short follow-up period. Consequently, there is a lack of evidence of the preventive effect of long-term retention. This also applies to retrospective research. As described in Table 3 and 4, the anterior alignment as measured by LII can vary substantially in orthodontic patients. Several of the more recent articles in Table 4 show acceptable stability of the anterior alignment, even after a modest retention period [81,83,102,103]. This leads us to suspect that long-term stability is not only a matter of retention. The advantages of prolonged retention in terms of improved alignment is yet not fully understood, and it is a paradox that duration of retention protocols increase despite this lack of knowledge. There is little information about preferred retention protocols in the literature, especially recommendations for long-term use. At the moment, no consensus is established. With some orthodontists advocating life-long retention, and retention surveys reporting an increase in use of fixed retention [20,107,111], it seems timely to address this issue. If the orthodontic community in the future is to give recommendations on a preferred type and duration of retention, more information is needed about the benefit of long-term over short-term retention.

AIMS OF THE STUDY

The lack of knowledge regarding the long-term effect of retention on anterior tooth alignment provided much of the motivation for the study. Further, the work would give information about long-term outcome of patients treated at the Department of Orthodontics, University of Oslo (UIO), and serve as a quality assurance of the teaching at the Department. The patient material from the Department of Clinical Dentistry, University of Bergen (UIB), provided a rare opportunity to evaluate long-term stability after what by today's standards is considered to be a short retention period. Broken down into specific objectives, the aims for paper I-III were:

1. To evaluate the treatment outcome in orthodontic patients 5 years posttreatment, and investigate differences in anterior tooth alignment between patients with different retention regimens.

   Objectives
   - Assess overall occlusion at 3 and 5 years posttreatment
   - Compare maxillary alignment between patients with a removable retainer and patients with a combination of removable and fixed retainer
   - Compare mandibular alignment between patients with fixed retention of varying duration

2. To assess the long-term treatment outcome in orthodontic patients after a short retention period, and investigate the influence of treatment-related factors on anterior alignment.

   Objectives
   - Assess the treatment outcome 10 years out of retention
   - Examine the long-term influence of treatment-related factors on postretention stability of maxillary and mandibular anterior alignment

3. To evaluate the treatment outcome 10 years posttreatment, investigate at what point during the follow-up period changes in occlusion and alignment occurred, and to examine the long-term effect of fixed retention.

   Objectives

   - Assess the long-term outcome in patients 10 years posttreatment
   - Investigate the stability of occlusal components during three subperiods: from posttreatment to 3 years posttreatment, from 3 to 5 years posttreatment and from 5 to 10 years posttreatment
   - To examine the effect of duration of fixed retention on anterior tooth alignment

MATERIAL AND METHODS

Subjects

Oslo sample

From 2003 patients who finished treatment at the university clinic at the Department of Orthodontics, University of Oslo, have been routinely summoned for posttreatment appointments following a fixed schedule (Table 5). Included in this retention archive are non-surgical patients age 20 or younger at beginning of treatment, presenting without agenesis, trauma or autotransplantations to the maxillary and mandibular anterior regions. Except for a few patients seeking treatment for minor irregularities, the patients in the Oslo retention archives are in group B and C of the Norwegian Orthodontic Treatment Index (NOTI) [129] and therefore qualifies for reimbursement for some of the treatment cost. Dental casts are taken of all patients at the 3-year, 5-year and 10-year follow-up appointments. Initially orthopantomograms (OPG) and lateral cephalograms were also taken, but this was discontinued in 2011 due to ethical and financial considerations. Since 2016 conventional study casts have been replaced by intraoral digital scanning.

Table 5. Schedule for patient recall after orthodontic treatment at the Department of Orthodontics, UIO. Study casts have now been replaced by intraoral scanning.

Time point	Records taken
Debonding (or within 6 weeks)	Clinical photos, study casts, ceph, OPG, intraoral x-rays of incisors
6 months	
1 year	
2 years	
3 years	Clinical photos, study casts
5 years	Clinical photos, study casts
10 years	Clinical photos, study casts

The patient sample in paper I consisted of patients having attended the 5-year follow-up as per 26/8 2011. Paper III was conducted on the basis of 125 subjects having attended the 10-year follow-up as per 22/3 2017 (Figure 2).

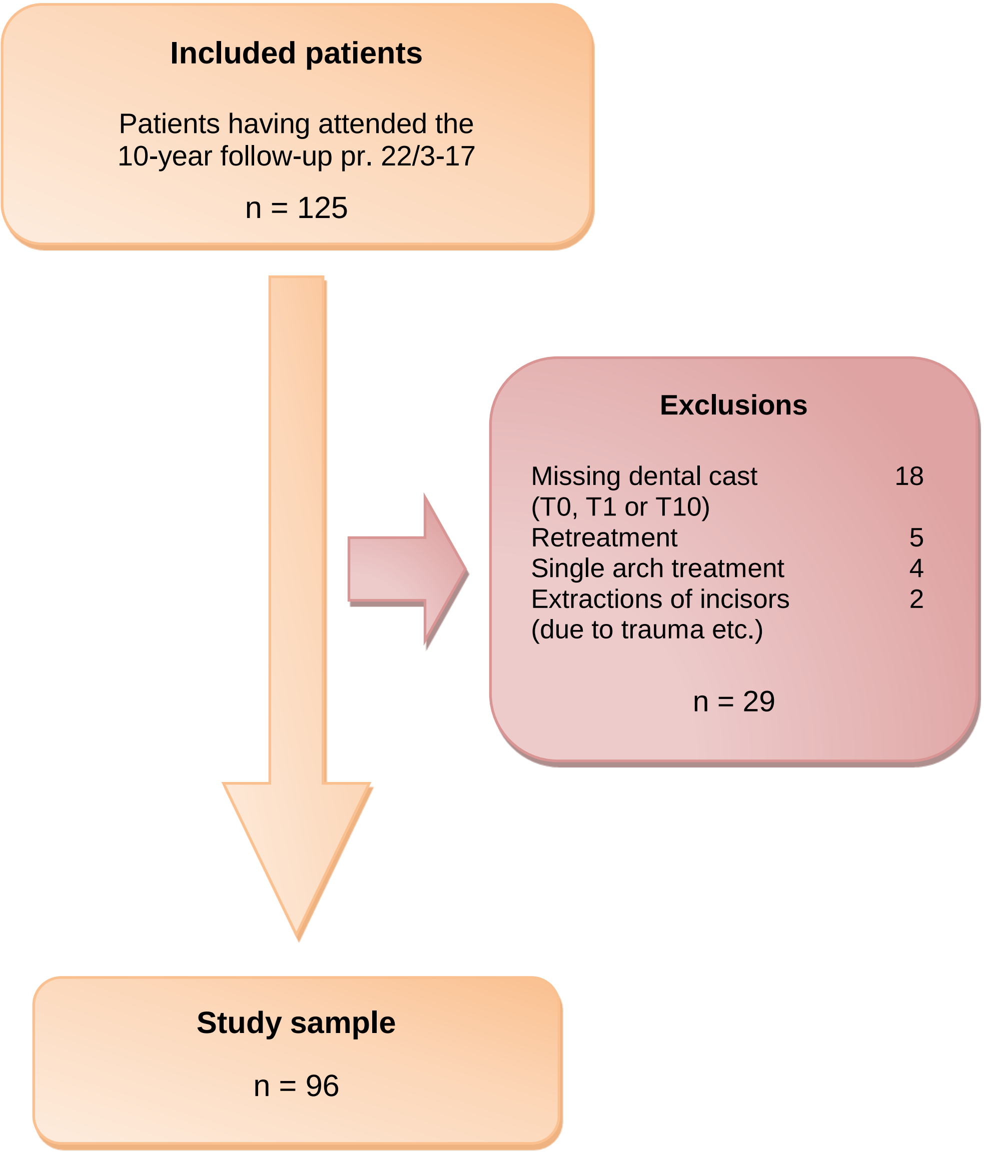

Figure 2. Flow-chart of patient inclusion and exclusion in paper III. T0 = pretreatment, T1 = posttreatment, T10 = 10 years posttreatment.

Bergen sample

The patients in the sample from the orthodontic clinic at the Department of Clinical Dentistry, UIB, had finished treatment between 1978 and 1990. At end of treatment they received a standardised retention regimen consisting of a Hawley appliance in the maxilla and a fixed 33-43 retainer in the mandible. Follow-up appointments were at approximately 2 and 12 years posttreatment. At the 2-year follow-up all retention was discontinued. Figure 3 shows patient inclusion and exclusion in paper II.

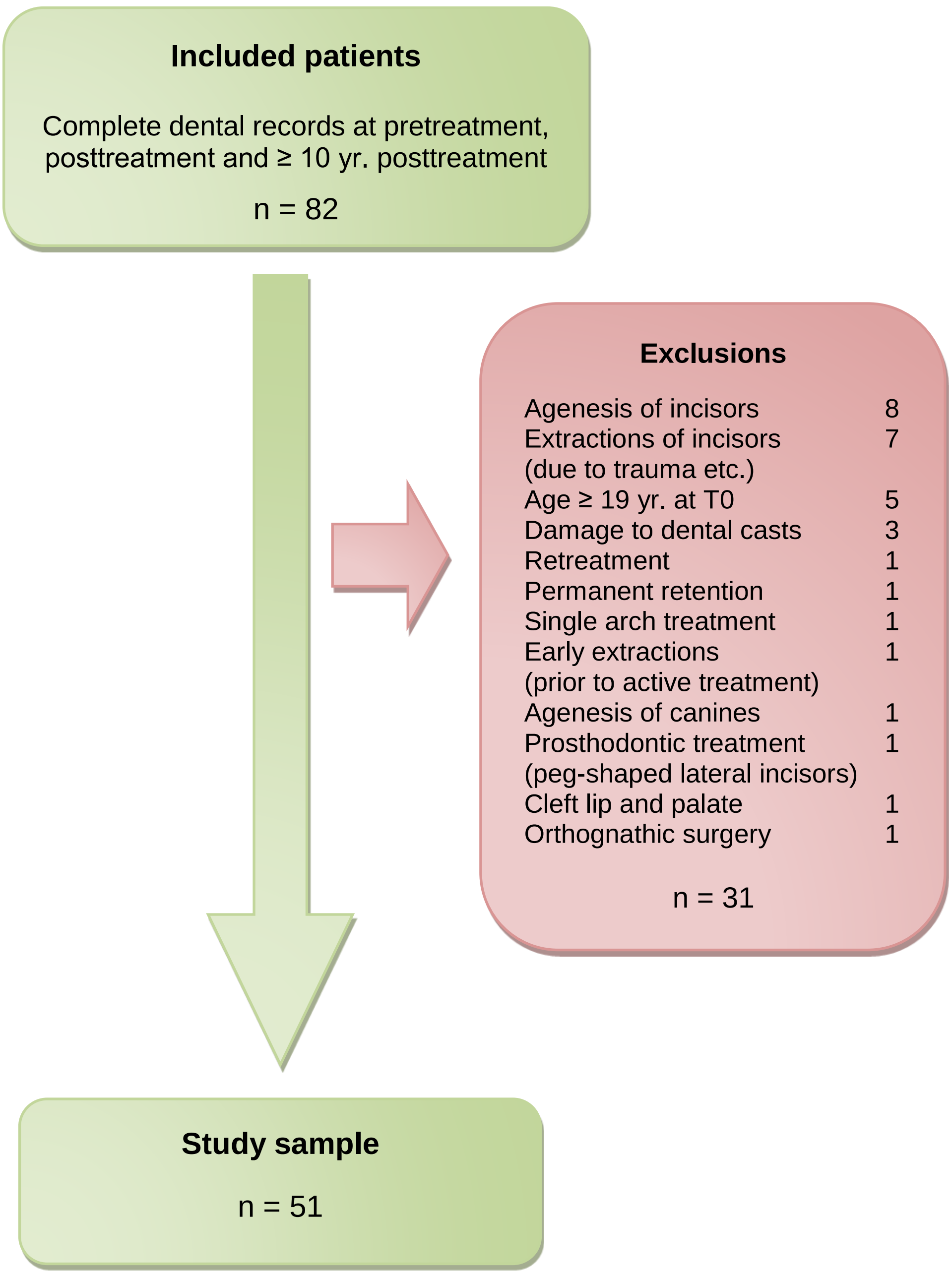

Figure 3. Flow-chart of patient inclusion and exclusion in paper II.

Assessment of occlusion

Peer Assessment Rating (PAR) Index

The Peer Assessment Rating (PAR) Index [48] was used to assess the general occlusion at various time points. The Index was used in all papers. Improvement in occlusion was measured by the PAR Index percentage method, as described in the guidelines for use of the PAR Index [130].

The PAR Index consists of five components, each assessing different traits of an individual's occlusion and alignment (Table 6). Scoring of the index is normally performed on dental casts. The score of each PAR component is weighted according to the degree of importance it was given in the index validation process. Scores for overjet, overbite and centreline discrepancy are weighted with a factor of 6, 2 and 4; anterior alignment and buccal occlusion are weighted by a factor of 1. The sum of the weighted scores constitute the total weighted PAR Index, which quantifies the degree of malocclusion and expresses the deviation from ideal occlusion. The higher the number, the larger the degree of malocclusion. Independent evaluation of the occlusal components is done using the unweighted scores.

An initial calibration session was performed where the main examiner was calibrated in using the PAR Index; 30 sets of study casts were assessed by both the untrained operator and an experienced examiner. The results were compared, and instructions given where needed before the casts were re-evaluated two weeks later.

The measurements were all done by the same person using a digital caliper ("Digital 6", Mauser, Germany) and a conventional ruler.

Table 6. PAR Index components and scoring.

PAR component	Assessment	Scoring	Weighting
Anterior [1]	Contact point displacement Impacted incisors/canines	0-4 5	x1
Posterior [2]	Sagittal occlusion Vertical occlusion Transverse occlusion	0-2 0-1 0-4	x1
Overjet	Overjet Anterior crossbite	0-4 0-4	x6
Overbite	Overbite Open bite	0-3 0-4	x2
Centreline	Deviation from dental midline	0-2	x4
Total		Unweighted PAR score	Weighted PAR score

[1] Measured from canine to canine, for both upper and lower arches, see Table 7 for details
[2] Measured from canine to last molar, for both right and left sides

Table 7. Scoring chart for the anterior component of the PAR Index. Scoring is per contact point displacement. For each jaw five measurements are made (canine to canine); the anterior component score (ACS) is defined as the sum of the five scorings.

Score	Contact point displacement measured in millimetres (mm)
0	0 - 1.0 mm
1	1.1 - 2.0 mm
2	2.1 - 4.0 mm
3	4.1 - 8.0 mm
4	> 8.0 mm
5	Impacted tooth

A tooth is regarded as impacted if it is not erupted and the space between the two adjacent teeth is ≤ 4 mm

Assessment of anterior tooth alignment

Anterior Component Score (ACS)

In paper I anterior tooth alignment was scored using ACS, the anterior component of the PAR Index. It was extracted from the total PAR score and analysed separately. In both arches, the anterior section from canine to canine was assessed. The ACS measures anterior irregularity like a nonparametric method (Table 7). For each contact point displacement a score of 0-4 is given according to the amount of discrepancy; 5 is scored in case of an impacted incisor/canine. The sum of scores gives the ACS.

Little's Irregularity Index (LII)

In paper II and III assessment of anterior alignment was done with Little's Irregularity Index (LII) [131]. LII is defined as the sum of the linear displacements of the anatomic contact points from canine to canine, measured in millimetres (Figure 4). Unlike the ACS, its score reflects the exact distance of the sum of the contact point displacements. The variable was measured to the closest 0.1 millimetre using a digital caliper ("Digital 6", Mauser, Germany).

In paper II and III, posttreatment change in anterior alignment measured by LII was used as dependent variable; i.e. the change observed from posttreatment till end of follow-up period. It was defined as follow-up value minus posttreatment value. Consequently, treatment change was defined as posttreatment value minus pretreatment value.

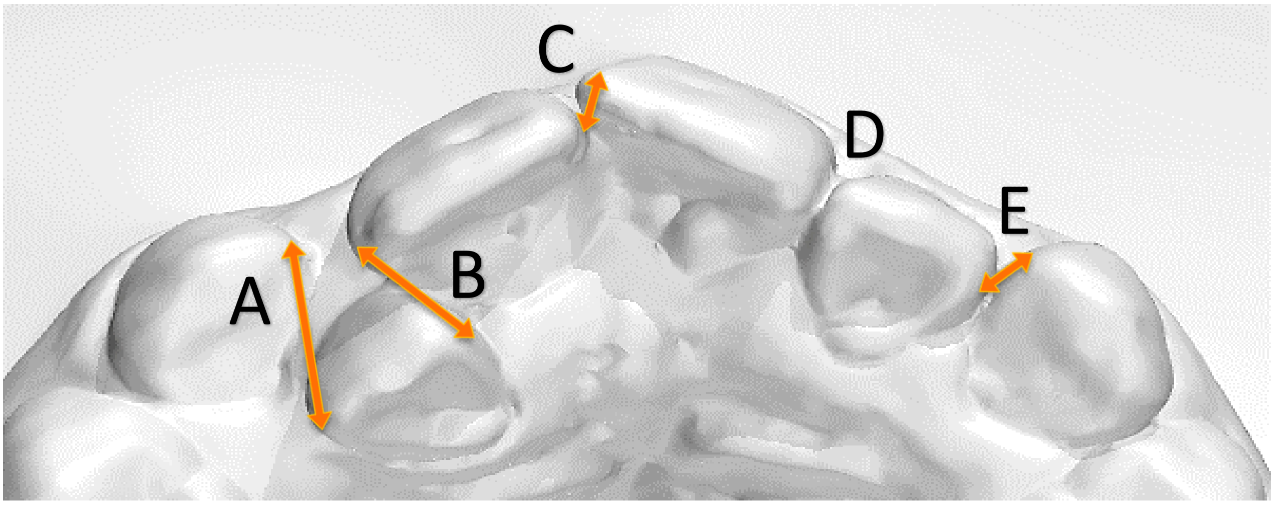

Figure 4. Anterior irregularity measured with Little's Irregularity Index (LII), defined as the sum of the contact point displacements A + B + C + D + E measured in millimetres.

Retainer status and supplementary registrations

In addition to the PAR Index and the LII, several other dental cast variables were registered. Both overjet, overbite, intercanine distances and canine and molar relations were recorded (Table 8). Further, the influence of gender, premolar extractions, treatment duration and posttreatment time was evaluated. Information about retention strategy was obtained from the patient files, and double checked with findings on the dental casts.

For dental cast variables with bilateral measurements, mean of the two recordings were used. If a measurement could not be recorded at one of the two sides (because the permanent tooth was not erupted) the valid contralateral measurement was kept. In case of unilateral premolar agenesis, molar occlusion was not registered at that side. Molar occlusion was not registered in patients with two upper or lower premolar extractions only. The variables were measured to the closest 0.1 millimetre using a digital caliper ("Digital 6", Mauser, Germany), except for overjet and overbite which were measured to the nearest 0.5 millimetre using a ruler.

Table 8. Dental cast measurements with definitions.

Measurement	Definition
Overjet	Distance parallel to the occlusal plane from the buccal surface of the most protruding maxillary incisor to the buccal surface of the corresponding lower incisor
Overbite	Maximum distance of the mandibular incisors overlapped by the maxillary central incisors
Canine relation *	Distance from the cusp tip of the maxillary canine to the distal contact point of the mandibular canine
Molar relation *	Deviation from a neutral occlusion, defined as occlusion of the mesiobuccal cusp of the upper first molar within the buccal groove of the lower first molar
Intercanine distance	Distance between the cusp tips of fully erupted teeth

* Distal occlusions were recorded as positive values, mesial occlusions as negative values

Cephalometric analysis

In paper III a cephalometric analysis was included. Pre- and posttreatment lateral cephalograms were available in digital form or as analogue (physical) x-ray films. The analogue cephalograms were scanned with a Canon Epson Expression 10000 XL scanner at 400 DPI and adjusted for the known magnification factor using the tracing software (Facad, Ilexis AB, Linköping, Sweden). Radiographs taken digitally were calibrated manually in Facad using a calibration stick visible on the radiographs. The x-rays had been taken on three different cephalostats. At Department of Orthodontics cephalograms were taken until 2008 on a Fuji cephalostat with 5.6% magnification. At Department of Radiology two cephalostats had been used, a Fuji cephalostat with 5.9% magnification (discontinued since 2008) and a Planmeca Promax Digital cephalostat with 13% magnification. Posttreatment radiographs were missing for six patients.

The retention subgroups were examined for overrepresentation of subjects with pretreatment skeletal characteristics and posttreatment dental positions outside the normal values (normal values corrected for Steiner's acceptable compromises) (Table 9). If required, the regression analyses were corrected accordingly.

Table 9. Cephalometric variables investigated for confounding when performing linear regression analyses to predict the influence of fixed retention on the outcome of maxillary and mandibular posttreatment change in Little's Irregularity Index (LII) 10 years posttreatment. The normal values for incisor position were adjusted for Steiner's acceptable compromises.

		Description
Skeletal variables	Mesial basal jaw relationship at T0	ANB < 1
	Distal basal jaw relationship at T0	ANB > 4
	Low mandibular plane angle at T0	ML/NSL < 29°
	High mandibular plane angle at T0	ML/NSL > 37°
Dental variables	Upper incisor protrusion at T1	Isb-NA > 2 mm above norm
	Upper incisor retrusion at T1	Isb-NA > 2 mm below norm
	Upper incisor proclination at T1	ILs/NA > 3° above norm
	Upper incisor retroclination at T1	ILs/NA > 3° below norm
	Lower incisor protrusion at T1	Iib-NB > 2 mm above norm
	Lower incisor retrusion at T1	Iib-NB > 2 mm below norm
	Lower incisor proclination at T1	ILi/NB > 3° above norm
	Lower incisor retroclination at T1	ILi/NB > 3° below norm

The tracings were oriented horizontally 7 degrees down from the sella-nasion line, and traced by the same operator. Skeletal characteristics and incisor position were measured before and after treatment (Figure 5). Reliability for the cephalometric analyses was tested by retracing 30 cephalograms after three weeks; intraclass correlation coefficient (ICC) were between 0.93 and 0.99.

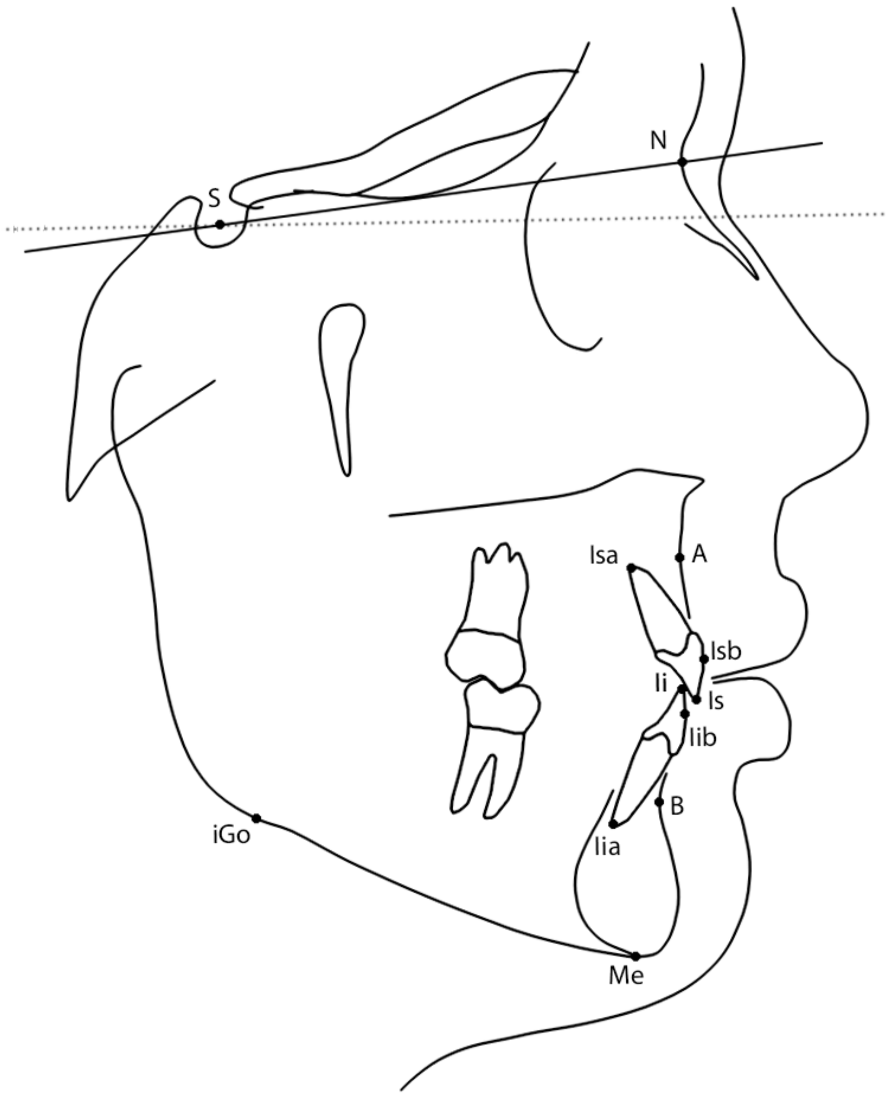

Figure 5. Landmarks used in pretreatment and posttreatment cephalometric analysis in paper III. The tracings were oriented horizontally 7 degrees down from the sella-nasion line. Isb and Iib represent the most anterior points of the labial surfaces of the maxillary and mandibular incisors.

Statistical analyses

The majority of the statistical analyses were performed with Statistical Package for Social Sciences (SPSS), versions 20.0-24.0 (SPSS Inc., Chicago, Illinois, USA). The post hoc power analyses in paper II/III and the sample size analysis in paper III were conducted using the software package G*Power (version 3.1.9.2; Franz Faul, Universität Kiel, Germany).

Statistical tests (Table 10) were applied under statistical guidance from a medical statistician (paper I and II) or competent personnel at the Norwegian Institute of Public Health (paper III). The different tests are described in detail in the separate papers. For the PAR calibration systematic measurement errors were assessed with a one-sample t-test and with reliability coefficient [132]. The t-tests showed a p-value > 0.05. The reliability coefficient was 0.86 before and 0.96 after calibration; 0.75 was used as lower limit for agreement. Occasional large differences in scoring between the trained and the untrained examiner, were discussed and corrected. Random errors were measured with ICC.

Table 10. Statistical tests used in the studies.

Statistical method	Paper I	Paper II	Paper III
Paired samples t-test	✓	✓	✓
Independent samples t-test	✓	✓	✓
Pearson correlation coeffecient		✓	✓
Intraclass correlation coefficient (ICC)	✓	✓	✓
Chi square test of independence	✓		✓
Fisher's exact test			✓
One-way analysis of variance (ANOVA) with Tukey post-hoc test	✓		
Linear multivariate regression analysis (forced entry)			✓
Linear multivariate regression analysis (backward variable selection)		✓	

SUMMARY OF RESULTS

The results of papers I-III are divided into topics and summarised in the three sections below.

Stability of occlusion

In paper I treatment outcome of 169 patients from the Department of Orthodontics, UIO, were assessed 3 and 5 years posttreatment using the PAR Index. The weighted PAR scores were 24.7 at T0, 2.9 at T1, 3.4 at T3 and 4.4 at T5. Orthodontic treatment led to 88.3% improvement of occlusion at posttreatment. The percentage dropped to 86.4% at 3 years posttreatment and 82.1% at 5 years posttreatment. In paper III excellent long-term stability 10 years posttreatment was found for 96 patients treated at UIO. Total PAR scores were 24.0 at T0, 2.6 at T1, 3.6 at T3, 4.5 at T5 and 5.1 at T10. PAR Index percentage improvement was 89.2% at T1, 85.0% at T3, 81.3% at T5 and 78.8% at T10. Occlusal parameters of the PAR Index were examined in three posttreatment subperiods. A gradual deterioration of occlusal components was seen, with small insignificant changes within each subperiod. When viewed over the entire 10-year posttreatment course the changes were significant, yet small.

Compared to the Oslo sample, the Bergen sample in paper III showed less favourable long-term results. Weighted PAR scores of 4.5 (73.1% improvement) at posttreatment and 8.3 (53.5% improvement) 10 years out of retention were still on par with existing research with an equivalent postretention follow-up period.

Stability of alignment

On average good stability of alignment was seen in the Oslo sample 5 and 10 years posttreatment. In both arches a small posttreatment deterioration was seen, increasing some with time. Of all the occlusal parameters, the anterior component was found to be most prone to relapse. Acceptable LII scores were also found for the Bergen sample, after a relatively short retention period of 1.8 years: 10 years out of retention the values were 2.8 in maxilla and 3.0 in the mandible. Premolar extractions were found to contribute to the long-term posttreatment stability of anterior tooth alignment. In general, there was a tendency towards greater stability of the maxillary alignment compared to the mandibular alignment.

The most striking finding was in paper II, namely that posttreatment increase in anterior irregularity was significantly correlated with the degree of treatment correction. The posttreatment changes were inversely correlated with the treatment changes, and increased with the amount of correction; Pearson correlation was -0.633 ($P < 0.001$) for maxilla and -0.303 ($P < 0.05$) for the mandible. The significant association in maxilla was confirmed in paper III. It was concluded that the need for retention will increase with the degree of alignment correction, particularly in maxilla.

Influence of retention

For both arches the influence of retention on anterior tooth alignment was compared between subgroups of patients with different retention protocols. In paper I stability of maxillary alignment, as measured by the ACS, was not influenced by choice of retention protocol. Use of a removable retainer proved to be equally efficient as dual retention in maintaining anterior alignment 3 and 5 years posttreatment. Paper III investigated the effect of retention 10 years posttreatment. Adjusted for corrections made during treatment, the findings showed that in patients wearing a removable retainer for three years the additional benefit of wearing a fixed retainer for 10 years was approximately 0.6 mm in terms of improvement in LII.

In the mandible, prolonged duration of fixed retention resulted in improved alignment. However, the improvement was not always of major clinical significance. Paper I showed that the alignment at 5 years posttreatment was slightly better for the group still using a fixed retainer compared to the group where the retainer was removed 3 years posttreatment. The results from paper III were that a 10-year fixed retention protocol gave moderately better alignment scores compared to a 3-year protocol (1.1 mm), and slightly better alignment compared to a 5-year protocol (0.7 mm).

DISCUSSION

Methodological considerations

The Oslo and Bergen retention archives formed the basis for this thesis. The study was approved by The Regional Committee for Medical and Health Research Ethics (Ref. No. 2010/3340a) and the Data Protection Official for Research (Ref. No. 29894). In retrospect, there are some methodological considerations that should be commented upon.

SUBJECTS

With research in general, there is always a risk of introducing bias. The advantage of prospective clinical trials is that they lower this risk by controlling important factors of the study, as for instance patient inclusion. In this thesis, all papers are longitudinal follow-up studies with a potential risk of bias. Even though the exclusion criteria were strict, inclusion of patients with diverse diagnoses is likely to have taken place as all malocclusions were accepted. The following allocation of patients into retention subgroups could have led to selection bias resulting in uneven distribution of malocclusions between the groups. However, relapse and physiologic posttreatment changes are expected to happen in all patients regardless of malocclusion. Also treatment modality may have differed between the groups, as the patients were treated by different operators. Nonetheless, all patients were treated with fixed appliances in both arches using conventional edgewise technique. The operators themselves were postgraduate students, yet under supervision by experienced orthodontists. It was therefore assumed that the treatment provided in general was of adequate quality and representative for the time it was conducted. Furthermore, in clinical studies on stability of alignment there is also the possibility that some subjects may have had additional time in fixed appliances without active tooth movement, which is essentially retention with brackets. Such conditions may be difficult to control even in RCTs.

Details of the retention protocol, like duration and type of retainer, was decisive of the assignment into subgroups. The type and duration of retention was not standardised. One might suspect that similar retention regimens were applied in similar situations. However, that was probably not the case. Like orthodontists in general the instructors are likely to have had opposing views on retention methods and prescribed their retention regimen of choice, with the result that different retention procedures could have been applied to similar clinical situations. The duration of the retention protocol was sometimes decided by the orthodontist, but most often a result of incidences like elective removal of the retainer or occasional debonds. Some patients were also advised to have the retainer removed because of hygiene reasons.

To make the patient samples as homogenous as possible various exclusion criteria were incorporated. For instance, retreated patients were excluded from the studies. While it obviously would do more harm to the overall results to include retreated patients, exclusion of such patients could decrease the representativeness of the results if the percentage of them was too high. The number of patients excluded because of retreatment was not particularly large, 1 patient in paper II and 5 in paper III.

Further, one can hypothesise that only the satisfied or the most organised and compliant patients attended the follow-up appointments. Such patients may also have been more compliant during treatment and retention. This kind of systematic distortion is known as response bias. On the contrary, one could also argue that the patients attending the long-term check-ups were the most dissatisfied patients, or the most anxious ones.

None of the studies incorporated a control material of untreated individuals, which may be considered to be a drawback by some. However, the patient samples were divided into subgroups which were then compared to each other, hereby acting as their own controls. It would have been interesting to compare the long-term posttreatment changes occurring in successfully treated orthodontic patients to the changes in age-matched untreated individuals, but that was outside the scope of this study.

METHODS

Assessment of occlusion

Introduced in 1992 [48], the PAR Index has become an established index within the orthodontic research community. It is internationally recognised and widely used. This makes for easy comparison with existing research. More importantly, the index has gone through a validation process where weightings were added, and it has proven inter-examiner reliability [48,133]. Whereas other indices such as the OGS are only intended to be used for posttreatment assessment [50], the PAR Index is applicable to both pre- and posttreatment dental casts. In a study from the US where the need for orthodontic treatment of 170 casts were rated by 15 orthodontists and their collective decision compared with the PAR value determined by a calibrated examiner, UK PAR score were found to be an excellent predictor of orthodontic treatment need [134].

One of the downsides to the PAR Index is that is doesn't incorporate other important facial traits like for instance aesthetics, as do other indices such as the ICON. Its focus is entirely on the occlusion, and it has been criticised for not giving a complete evaluation of the orthodontic treatment [135]. For example, the centreline assessment considers upper and lower midline in relation to each other, but not in relation to the facial midline. Other factors that may be influenced by orthodontic treatment such as apical root resorption, enamel decalcification, marginal bone loss and gingival complications are not addressed. While these factors undoubtedly are important and contribute to the treatment quality, it may be unwise to include too many aspects of orthodontic treatment into the same index as it may lose focus and detail of the separate parts in doing so. The aforementioned factors may be studied by applying additional appropriate methods. Other indices like the ICON was considered for this study. However, the ICON was rejected due to findings of lacking validity in both an American and a Dutch article [136,137]. Furthermore, there were signs that it had not gained widespread popularity within the research community.

While most of the components of the PAR Index are explicitly described in the guidelines, some of them are subject to judgment from the observer. Thus, lack of detailed objective descriptions may have allowed for observer bias in certain instances. The assessments of posterior sagittal occlusion and transverse cross bite tendency are examples of this. This issue was managed by being as consistent as possible during scoring. All measurements were performed by the same operator, and a calibration session was held prior to the data collection. Error of method was calculated for all papers, and was repeatedly found satisfactory. It should be underscored that the large majority of the components of the PAR Index have specific objective criteria which restrict the operator from subjective assessment. Therefore, any uncertainty in the measurements would be of minor influence to the total score.

Improvement of occlusion was measured by the PAR percentage improvement method. It was chosen over the less precise nomogram method for several reasons. By measuring the exact percentage improvement one gets a specific measurement of the treatment outcome, rather than a categorisation of the treatment outcome into one of the three categories "worse – no different", "improved" or "greatly improved". 25 years after the introduction of the PAR Index, the nomogram method also seemed somewhat outdated as it was fairly simple to achieve the "improved" status and, to a lesser degree, the "greatly improved" status.

All measurements were done manually on plaster models using a digital caliper and a conventional ruler. Neither the ruler nor the caliper were calibrated before use. In hindsight this would have been preferable. However, the caliper was reset at the start of every measuring session, as well as once or twice during a session. At the start of the project in 2011 digital study casts were not as common in orthodontics, and manual registrations were chosen for study cast analysis. Digital study casts became the new standard for patient records in 2015, after the data collection for paper I and II was finished. While it was an option to do the measurements for the third paper digitally, it would require time consuming digitalisation of the plaster models in the archive, as well as the need to adjust the method. To ensure coherence in the data collection, it was decided to continue with manual registrations.

Assessment of anterior tooth alignment

Anterior alignment was scored using two methods, the ACS and the LII. Initially, paper I was supposed to examine the general occlusion. Therefore, LII was not considered to be a necessary part of the methods. As the process with paper I developed, the attention was drawn towards the anterior alignment and the ACS was extracted from the total PAR Index as a measure of alignment. For reasons explained in detail below, ACS was replaced by LII in paper II and III to provide a more detailed depiction of the alignment status.

There are strong similarities between the ACS and the LII. They both measure contact point displacement in the anterior region, from canine to canine. However, the ACS is a less precise method compared to LII. Where the ACS uses a nonparametric approach to quantify anterior malalignment, LII measures contact point displacement in millimetres as a continuous variable, making it more sensitive to smaller deviations. There is evidence that patients are more aware of their anterior teeth than the rest of their occlusion [138]. A detailed method for measurement of the anterior alignment was therefore warranted. LII has the advantage over ACS by being intuitive and easy to understand, also by non-researchers. Moreover, LII is well established within the research community. While it has lately been criticised for being outdated and of low reproducibility for measuring contact-point displacement [139], it still remains a widely used index for quantifying anterior malalignment. It was the preferred method for measuring relapse in the latest Cochrane systematic review on retention procedures [116]. The concern addressed by Macauley et al. [139] that high correlation coefficients are misleading when assessing inter-examiner reliability will primarily potentially affect the interpretation of the results compared to peer research, since all LII measurements in the present research was conducted by the same operator. Though it was sometimes a challenge to keep the caliper steady in the transverse plane of space to get the correct measurement, error of the method as measured by ICC was satisfying for all papers. Still, it is likely that similar measurements will be performed on digital casts in the future and thereby increase precision [140,141].

A drawback of both the ACS and LII is their inability to detect all kinds of irregularity. For instance, teeth aligned in a zig-zag pattern will transcribe into a low irregularity score, despite the obvious malalignment. Such cases were however rare, if present at all. A different method that could have been used instead is a regular space analysis, often called tooth size arch length discrepancy (TSALD). This method would on the other hand have had other drawbacks, for example the decision of where to place the arch perimeter. Indices of anterior alignment are also limited in that they are incapable of expressing which teeth are out of alignment.

Retainer status and supplementary registrations

Clinicians base their treatment on information available before and during treatment. Therefore, our investigations regarding long-term changes in alignment were focused towards their associations with treatment-related factors such as correction in irregularity, intercanine distance, overjet, overbite etc. Retainer status was registered from the patient files. Because of the limited patient sample, it was not differentiated between different types of fixed or removable retainers. This is unlikely to have affected the results, as several articles report of similar retentive properties between the Hawley-type retainers and TPRs [117,122,142,143]. Only small, clinically insignificant differences in settling have been found between Hawley and Jensen retainers [144]. The distribution of Hawley/Jensen retainers and TPRs were appx. 50/50. Likewise, the distribution of mandibular retainers bonded to all anterior teeth and retainers bonded to the canines only was appx. 50/50. Stable long-term results have been reported with both types [104,145,146].

To get an impression of the malocclusions and to monitor the development of occlusion in absence of complete sets of radiographs, dental cast variables such as overjet, overbite and canine/molar occlusion were recorded. Canine and molar relationship was registered specifically for the purpose of measuring pretreatment sagittal deviation as well as sagittal movement during and after treatment. Although dental compensation was expected to make these measurements less accurate in expressing true sagittal deviation compared to a cephalometric analysis [23], the supplementary registrations were essential to describe the patient material.

Radiographic analysis

Because of ethical and financial considerations x-rays are not taken at retention check-ups at the Department of Orthodontics, UIO. With the increasing awareness of patient safety related to radiation exposure in clinical dentistry, it will be an ethical consideration whether it is justified for orthodontists to take radiographs at follow-up appointments. In Bergen, both OPGs and cephalograms were taken at all check-ups. Unfortunately, these records were often missing from the patient files. To not compromise the patient sample in paper II it was decided not to exclude patients with missing x-rays. For the x-ray analysis in paper III, it was determined that skeletal characteristics were best evaluated at pretreatment, since orthodontic treatment will seek to influence and correct tendencies deviating from normal, for instance by camouflage treatment of large overjets. Incisor positions on the other hand were evaluated at posttreatment, after correction of the malocclusion. Because radiographs from the 10-year follow-up were lacking, it was not possible to include posttreatment growth and change in incisor inclination in the statistical analyses. If posttreatment growth parameters had been obtainable they could potentially have strengthened the statistical analyses and improved the regression models. However, even if specific posttreatment cephalometric variables of influence to long-term stability had been found, they would most likely be difficult to implement in retention strategy decisions because of the difficulty to determine in what patients such growth would take place.

Statistical analysis

Most studies investigating posttreatment stability of alignment use the LII score at the long-term follow-up as dependent variable. Such an approach does not take into consideration the degree of irregularity present at posttreatment, nor does it incorporate into the analysis the amount of deterioration taking place throughout the posttreatment period. For the Bergen material it was quite evident that the alignment was not always treated to perfection; mean posttreatment LII values were 2.0 for maxilla and 1.5 for the mandible, compared to 0.5 for both arches in paper III. By using "posttreatment changes" as dependent variable, defined as the change in LII from posttreatment to the end of the follow-up, the level of finishing represented by the posttreatment value was taken into account. Consequently, "treatment changes" was defined as the posttreatment value minus the pretreatment value. Since relapse is believed to largely be a response to changes made during treatment, this way of defining the dependent variable seemed the most correct. In cases of perfect alignment with a posttreatment LII value close to zero, our method would score similar for "treatment changes" as for the pretreatment LII value. A supplementary Raghunathan, Rosenthal, & Rubin's test [147], not included in the published paper, was used to compare the maxillary correlation coefficient with the corresponding mandibular correlation in paper II. For the statistics on anterior alignment, we assumed that the alignment of maxilla and the mandible could be regarded as separate entities not influenced by each other.

The sample size analysis in paper III was based on the results from paper I and II, where a standard deviation of 9 was found for changes in the PAR Index. To account for potentially larger variations in the third paper a safety margin of approximately 25% was added, hence a standard deviation of 11 was used in the sample size analysis. The sample should be large enough to be able to detect an observed difference from pretreatment to 10 years posttreatment of 10 PAR points, an estimate based on what seemed reasonable from the data in paper I and II.

In spite of limited sample sizes for one subgroup in paper I and two subgroups in paper III, we chose parametric tests over nonparametric tests since parametric tests have higher sensitivity and greater power. Statistical power measured post hoc was satisfactory. All assumptions for the statistical tests were met. Use of nonparametric methods changed the results only marginally and did not alter the conclusions.

Study design

The present study was originally intended to be prospective. However, since the inclusion of patients were made after the outcomes of interest had taken place, it is per definition retrospective. It can be classified as an analytical observational study, or more precise a historic cohort study. Because of the study design the results of this study should be interpreted within its limits. There is no doubt that prospective studies are preferred over retrospective studies in terms of scientific evidence. However, long-term prospective studies can be difficult to complete because of cost and the risk of dropouts. Thus, retrospective studies may still be useful as interesting findings may emerge which can inspire future studies with a prospective design. The strengths of the study are the number of subjects, the comparison of multiple retention protocols and the long posttreatment periods in paper II and III.

Discussion of major findings

The value of orthodontic treatment has been questioned more than once. Orthodontic treatment has been criticised for only being of aesthetic benefit to the patients [148]. Recently, it has been claimed that the majority of orthodontic patients in Norway have little to no health benefit from the treatment [149]. In several countries, including Norway, considerable sums of money are spent on reimbursement after orthodontic care [149]. It is only reasonable that such substantial investments of funds should be justified to the authorities. One purpose of this thesis was to address some of these concerns by evaluating the long-term stability after orthodontic treatment with contemporary techniques currently taught at the University of Oslo. Secondly, it was to provide an understanding of the influence of retention on stability of maxillary and mandibular anterior alignment.

STABILITY OF OCCLUSION

The role of the orthodontist is not always an easy one. There is a fine balance between striving for perfection and at the same time managing expectations. A good orthodontic treatment result prerequisites a correct diagnosis, a sensible treatment plan and well executed treatment. After the active treatment phase, the posttreatment period is spent preventing relapse and growth changes from taking place. There are many stages during the treatment course where errors can be made, that in turn could affect the overall outcome years later.

According to The Swedish Council on Technology Assessment in Health Care, assessment of orthodontic treatment success should be undertaken at least five years posttreatment to be expedient [150]. In the three papers in this study, occlusal outcome was investigated 5, 10 and 12 years posttreatment. For the Oslo sample, the results were very good, surpassing those of peer research at both 5 and 10 years posttreatment. Results for the Bergen sample were mixed. While stability of the anterior alignment was acceptable, improvement in occlusion was only fair.

There may be several reasons to the observed divergence in long-term results between the Oslo and the Bergen materials. To begin with, the Oslo sample is a more recent sample treated in the 2000s, 20-30 years later than the Bergen sample. In that respect, a direct comparison between the two seems almost unfair. The posttreatment PAR score for the Bergen sample was higher than for the Oslo sample. Just from working with the study casts it was noticeable that the quality of treatment was higher in the Oslo sample. The precision and degree of finishing were at another level, which suggests that orthodontics has evolved during the last few decades despite the fact that techniques and principles have remained roughly unchanged. Further, the 60% extraction rate for the Bergen sample was higher compared to 40% for the Oslo material, and probably reflects the trend at the time. Moreover, retention periods were also substantially longer for the patients treated in Oslo. It seems reasonable to conclude that all these factors together have contributed to the differences in long-term outcome.

Compared to peer research, stability of occlusion was favourable for the Oslo sample (Table 11 and 12). Especially the results 10 years posttreatment stand out as notably better. There may be several reasons to this. Analogous studies differ some in terms of treatment modality, length of follow-up and degree of malocclusion. This may account for some of the differences. Also the skeletal characteristics of the patients could differ to some degree. However, the other patient samples are also from western countries, and substantial morphological differences from the Norwegian population is not expected. Favourable growth could also have affected the long-term results. Another possible explanation may be the use of retainers, as most of the earliest studies are on subjects with a short retention protocol. However, the impact of retention on occlusal stability has of late been questioned. Interestingly, a recent report concluded that presence of a retainer was not of great significance to overall stability of occlusion, its importance was more related to stability of the mandibular alignment [55]. Approximately half of the patient sample in paper III had quite long duration of retention. However, good long-term results have also been demonstrated with a moderate retention period; Woods et al. reported 73% PAR score improvement 6.5 years postretention after appx. 4 years of retention [61]. This could lead one to speculate that there are other factors besides retention that are just as important to the long-term outcome. From Table 12 it can look like treatment quality itself may be a strong causative factor for long-term success. The studies reporting the best occlusal scores at the long-term follow-up also had the lowest PAR scores at posttreatment. In fact, if the studies are rated from 1 to 7 according to the percentage improvement, the rating at pretreatment match with the rating at the

Table 11. Overview of studies using the PAR Index for assessing orthodontic treatment outcome 5-10 years posttreatment, including paper I. Mean weighted PAR scores and percentage improvement reported.

Author(s)	Year	Sample size	Pre-treatment	Post-treatment		5-10 yr posttreat.		Follow-up period (yr)	Postretention period (yr)
Birkeland et al.	1997	224	28.7	6.0	79%	9.6	67%	7	5 yr
Berset et al.	2000	128	21.8	3.2	85%	6.1	72%	5	Mixed
Linklater et al.	2002	78	n/a	n/a	69%	n/a	56%	n/a	6.5 yr
de Freitas et al.*	2007	87	27.1	6.2	77%	10.6	61%	5	3.5 yr
Paper I	2015	169	24.7	2.9	88%	4.4	82%	5	Mixed
Steinnes et al.	2017	67	27.2	6.7	75%	10.5	61%	9	Mixed

* For de Freitas et al. mean of the two groups in the study was calculated

Table 12. Overview of studies using the PAR Index for assessing orthodontic treatment outcome at least 10 years posttreatment, including paper II and III. Mean weighted PAR scores and percentage improvement reported.

Author(s)	Year	Sample size	Pre-treatment	Post-treatment		At least 10 yr posttreat.		Follow-up period (yr)	Postretention period (yr)
Otuyemi & Jones	1995	50	26.6	4.3	83%	12.2	54%	11	10 yr
Al Yami et al.	1999	564	28.4	8.5	70%	14.6	49%	11	Appx. 10 yr
Woods	2000	65	25.5	3.0	88%	7.0	73%	11	At least 6.5 yr
Ormiston et al.*	2005	86	31.7	4.2	87%	12.1	62%	17	Appx. 14 yr
Lagerström et al.	2011	72	20.2	4.3	79%	9.4	54%	17	Mixed
Paper II	2017	51	19.9	4.5	73%	8.3	54%	12	10 yr
Paper III	2017	96	24.0	2.6	89%	5.1	79%	10	Mixed

* For Ormiston et al. mean of the two groups in the study was calculated

follow-up. The same applies to Table 11. One can speculate that the provided treatment may be as important to the long-term success as the type of retention. Previous research has shown that the cases with the best finished occlusion tend to have better occlusion in the long-term, despite a small unfavourable relapse [56]. The low posttreatment PAR score in the present sample, noticeably lower than recent reports [55], indicate a high standard of treatment. Even though the treatment was executed by orthodontic graduates, it was always under close supervision by experienced clinicians. The instructors also approved the treatment plans, one of the most important steps in orthodontic treatment. Decisions regarding extractions were made by knowledgeable clinicians, and one may therefore assume that extractions were made in the appropriate cases. Because of the educational setting, one might also wonder if the attention to detail has been particularly great. In sum, all these different aspects of orthodontic treatment may provide some explanation for the good results seen for the Oslo material.

In essence, the results from the Oslo material suggest that properly treated orthodontic patients may experience a posttreatment course not dissimilar to that of untreated individuals. The minor reduction in intercanine distances and the insignificant increase in overjet and overbite found 10 years postretention is similar to changes seen in untreated individuals with normal occlusion [38]. The Oslo sample consisted of patients with all types of malocclusions. Mean pretreatment ANB was 4.1, which indicates a predominance of Cl I and Cl II malocclusions. This is probably representative for the Norwegian orthodontic patients. On average, corrections in overjet and overbite were not particularly large from a clinical perspective, and the results remained stable throughout the follow-up period. Intercanine distances were not altered during treatment. During the posttreatment period the values for molar and canine relationship showed a minor reduction. Given the length of the observation period, this was probably caused by differentiated sagittal jaw growth resulting in a slight relative protrusion of the mandible [24,151]. Furthermore, all PAR components showed a small, gradual deterioration during the 10 year posttreatment period, with no time period dominating in terms of posttreatment changes. There may be several explanations to this. Firstly, the retainers may simply have done their job – to prevent relapse in the most critical phase. In experimental studies relapse has shown to be the highest the first months after appliance removal. Also in humans high relapse rates have been found in the absence of retention. Later in the posttreatment course fewer of the patients in our sample still wore retainers. Arguably, their need for retainers probably also diminished with time.

STABILITY OF ANTERIOR ALIGNMENT

The main results point in the direction that mandibular alignment is more prone to posttreatment changes than maxillary alignment. Based on current knowledge, this observation was expected. Mean LII for the Oslo sample 5 years posttreatment was 1.1 for maxilla and 1.0 in the mandible. 10 years posttreatment the values were 1.4 for both arches. Values for the Bergen sample 10 years out of retention were 2.8 for maxilla and 3.0 for the mandible. Overall, these values are comparable to findings from other studies (Table 3 and 4). From Table 4 one can also discern a tendency towards lower irregularity scores in the later studies, which indicates that long-term postretention stability of anterior alignment has improved since the earliest reports using LII were published. It should be noted that many of the patients in the Oslo sample still wore fixed retainers at the 10-year follow-up, approximately 30% had retainer in maxilla and 50% had retainer in the mandible.

Based on the available records, the study investigated the role of several treatment-related factors on posttreatment deterioration of anterior alignment. Whilst the influence of retention was expected to be significant, there were other notable findings as well. One of the most interesting results in paper II was the correlation between treatment and posttreatment changes in LII, i.e. the relation between the degree of alignment correction and the subsequent relapse. Correlation was 0.6 for the maxilla and 0.3 for the mandible. A statistical difference between these correlations (P = 0.044) underscores the difference in expected predictability of postretention alignment. A coefficient of 0.6 for the maxilla should be regarded as quite strong for a clinical study, and is stronger than others have reported [63,64,152]. The weaker association for the mandible is in agreement with the current understanding of long-term stability, which in the mandible is affected by multiple factors and therefore believed to be somewhat unpredictable. However, the results are interesting in that they show at least some connection to the correction made during treatment. Evidence of the same relationships in the literature is scarce [97]. This may be attributed to the fact that few studies have used the same methodology as in the present study. Still, it seems accepted among many experienced clinicians that the pretreatment alignment to a great extent will be indicative of the relapse tendency. The pretreatment condition will by many clinicians be the most important factor of influence to their choice of retention strategy [112]. Experimental studies have shown that relapse rapidly occurs after tooth movement, and that the rate of relapse gradually decreases with time [153]. Animal studies in dogs and rabbits have found high correlation coefficients between tooth movement and relapse [154,155]. However, there are several reasons that a similar cause-and-effect relationship will be difficult to detect in humans.

Posttreatment changes in alignment are affected by multiple factors, not just the preceding correction made by the orthodontist. Because of the longer treatment period, periodontal fibres will start to remodel before the appliance is removed. The anterior teeth are also affected by forces from the tongue and lips, not to forget by the retainer which seeks to fixate the position of the teeth. To add to this, there is the influence of growth. All these factors bring us farther and farther away from an experimental situation where relapse in response to tooth movement may be studied undisturbed by external factors. Compared to today's longer retention periods, the situation in paper II where all retention was discontinued after 1.8 years is probably as close as one can get. The longer the retainer is kept, the more likely it is that a cause-and-effect relationship is disturbed, which after all is the intended purpose of retention.

It is well-known in statistics that a correlation does not infer causality. To assert that the findings establish a genuine cause-and-effect relationship, and not just some statistical coincidence, one may apply the suggested guideline of Sir Austin Bradford Hill (Table 13) [156]. The guideline is a probabilistic concept of causality, meant to be advisory and flexible. Although the criteria perhaps are normally used for more subtle epidemiological associations between cause and disease, they should also be applicable to concrete situations like this. An assessment of the criteria concludes that they do apply to the results in the present study, including what is commonly believed to be the key criteria: temporality, specificity, biological plausibility and coherence. It seems likely that a cause-and-effect relationship between orthodontic straightening of the alignment and the subsequent deterioration does exist. However, such a relationship may only last for a period of time, as the contribution of growth to changes in alignment is likely to exceed the influence of relapse as time progresses. Whatever the reasons for posttreatment changes, the findings indicate that a causal relationship is more likely to be present in maxilla. This idea is also supported by the fact that significant findings were present for maxilla in both paper II and III, although the strength of the associations differed. It should be underscored that stability of anterior tooth alignment shows great variability among orthodontic patients. For that reason, it should be kept in mind that the above mentioned results are average tendencies which may not be directly applicable at an individual level.

Table 13. Bradford-Hill criteria of causation.

Criteria	Meaning
Strength	Defined by size of the association, as measured by appropriate statistical tests. The stronger the association, the more likely it is that the relation is causal.
Consistency	The association is consistent when it is observed repeatedly by different persons, in different places, circumstances and times.
Specificity	When a single cause produces a specific effect. However, absence of specificity does not negate a causative effect, since they most often are multifactorial.
Temporality	The cause must always precede the effect in time.
Biological gradient	A dose-response relationship is strong evidence of a causal relationship, but no requirement. Other more complex associations may exist.
Biologic plausibility	The association should be biologically plausible with the existing knowledge. Still, occasionally those principles are not sufficient to explain new findings.
Coherence	The association should not seriously conflict with the generally known facts.
Experiment	It is possible to alter the condition (prevent or ameliorate) by an appropriate experimental regimen.
Analogy	In certain (life threatening) cases it can be fair to judge by analogy, and accept slighter but similiar evidence as in a previous case.

Another finding to influence anterior alignment was extractions. In paper II premolar extractions gave a small but significant contribution to postretention stability in the mandible. This effect was not seen in paper III. A plausible explanation to this may be the longer retention period in paper III, and that the effect of the mandibular fixed retainer exceeded the effect of premolar extractions. Several previous studies comparing extraction and non-extraction treatment have indicated a reduced tendency to postretention development of lower incisor crowding in extraction cases [70-72]. In the clinic, one will from time to time face the decision whether to extract teeth or not. From the results of paper II it appears that the clinical benefit of premolar extractions in terms of increased stability of alignment will be moderate to low. However, it should be kept in mind that the patients in the study were not borderline cases, and that the results therefore are not directly applicable to such patients. One must presume that some of the patients were clear-cut extraction cases and some were borderline patients. Thus, the differences between extraction and nonextraction therapy might indeed have been larger had all the patients in the study been borderline extraction patients.

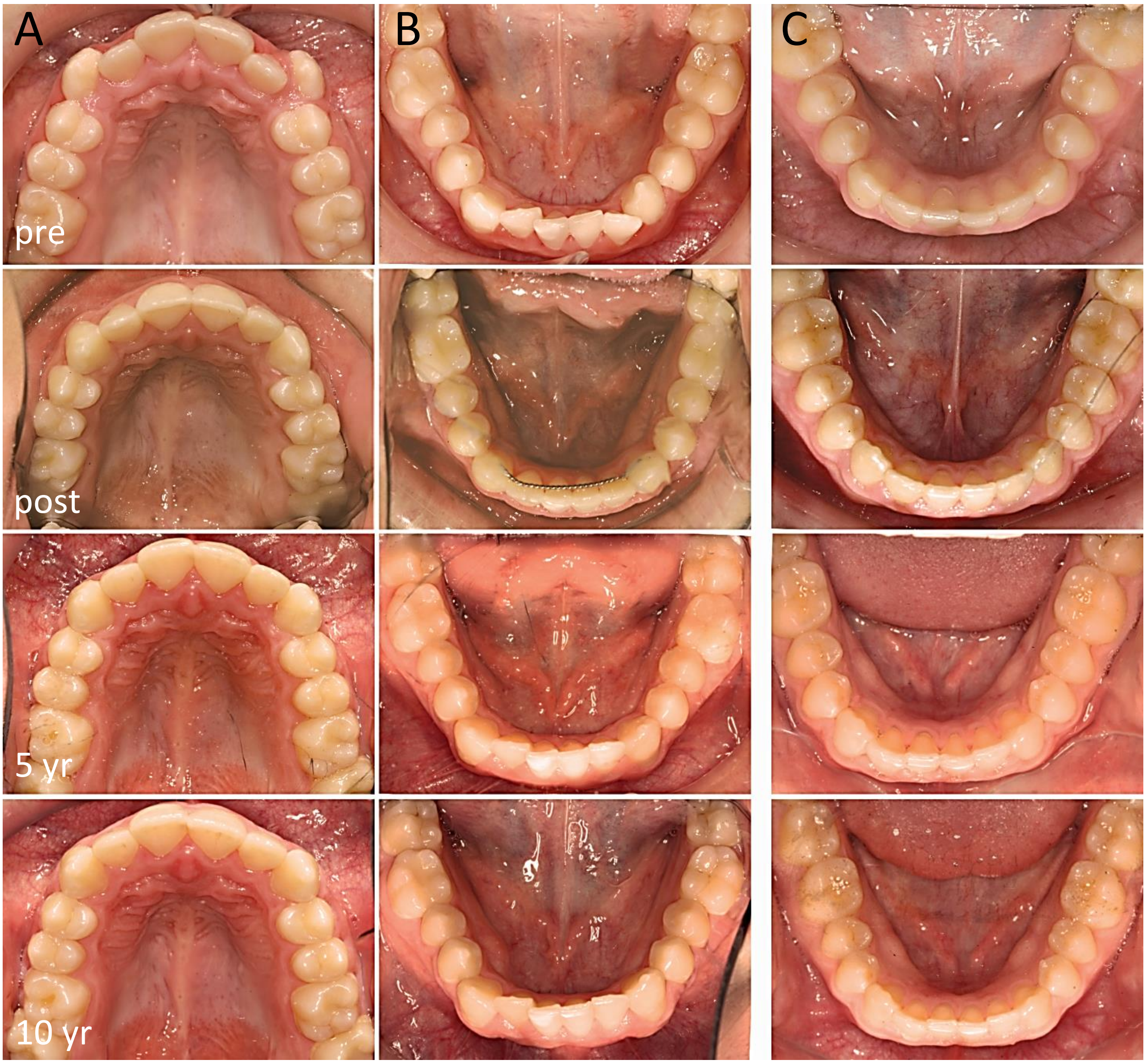

Figure 6. Examples of long-term stability of anterior tooth alignment for two patients. From top to bottom the pictures represent pretreatment, posttreatment, 5 years posttreatment and 10 years posttreatment. **A** and **B**: Stability of maxillary and mandibular alignment after nonextraction treatment of a patient with bimaxillary space deficiency. The patient got a removable retainer in the maxilla, and a fixed canine-to-canine retainer in the mandible; retention time was 3 years for both arches. Note the difference in stability between the two arches. **C**: Stability of mandibular anterior alignment in a patient with no pretreatment irregularity and no retainer. Note a small increase in irregularity with time.

INFLUENCE OF RETENTION

The orthodontic research community is in the process of comparing retention strategies. So far there is evidence that many types of retention devices are of equal efficacy in the short term. Whether it also applies in the long term remains inconclusive. Future research will help unveil this. Comparing studies on retention normally incorporates a great deal of uncertainty, particularly because of differences in pretreatment malocclusion, treatment techniques, treatment duration, study sample morphology etc. Despite these issues, a certain pattern regarding the nature of alignment stability has still emerged. The mandibular alignment consistently proves to be more unstable than the maxillary alignment. Overall conclusions from this study are in accordance with this pattern. All papers cohere and complement each other in that matter. The findings regarding retention need are a direct result of this inherent (in)stability of the dental arches. A clinician's choice of retention protocol is not only a matter of preventing relapse, but also to limit physiologic changes. Though it is obvious that total stability of an attained treatment result is not realistic to hope for in a long-term perspective, knowledge about general tendencies in growth and development is required when choosing retention protocol.

Maxilla

Comparisons of retention protocols for maxilla showed interesting results. Paper I concluded that in patients wearing a removable retainer for three years, no added benefit of fixed retainer wear for 3 or 5 years was found 5 years posttreatment. Paper III found that in patients wearing a removable retainer for three years, the added benefit of a fixed retainer for 10 years was minor in terms of improved anterior alignment 10 years posttreatment. The results indicate that on a clinical level, dual retention is unnecessary for up to 5 years posttreatment, and even up to 10 years in patients with mild to moderate pretreatment irregularity. Because of the increased relapse tendency for patients with high pretreatment irregularity, one should consider prolonged retention in such patients. It is likely that one could manage with just a fixed retainer, unless there are specific reasons to use dual retention. Other follow-up studies have concluded similarly, that different retention strategies perform equally favourable in the maxilla [127].

According to recent surveys of retention protocols, fixed retainers combined with removable retainers are the most common retention practice in Norway and Lithuania [106,112]. If dual retention on average only marginally outperforms a removable retainer in preserving anterior alignment 10 years posttreatment, there is potential to simplify the retention strategies for many orthodontic patients. Judging from patient opinions of retention appliances on social media, this would presumably be highly appreciated [157]. By doing this, one would reduce cost to both patients and the government, and at the same time reduce chair time in the clinic. One would also decrease the risk of potential side effects related to fixed retainers.

Mandible

Stability of the mandible was found to be lower than for maxilla. Consequently, this will influence the need for retention both in the medium and long term. Paper I concluded that at 5 years posttreatment, a 5-year fixed retention protocol gave slightly better alignment compared to a 3-year protocol. At 10 years posttreatment, paper III concluded that a 10-year fixed retention protocol gave moderately better alignment compared to a 3-year and 5-year protocol. Thus, longer duration of fixed retention improved the mandibular alignment, though to a moderate extent. The differences between the groups were in the range of 0.7 to 1.1 millimetres, however, with some uncertainty expressed in the confidence intervals which were appx. 1 mm wide. Although the insignificant results between the 3-and 5-year protocol subgroups at 10 years posttreatment would probably have been significant with larger group sizes, they would still have been of minor clinical consequences. Figure 6 shows a clinical example of the difference in stability of the maxillary and mandibular dental arches 10 years posttreatment, as well as stability of the mandibular alignment in a patient without retention.

Fixed retainers are used for maintenance of long-term results by a growing number of orthodontists [107,111]. In Norway, as in many countries, a fixed retainer is the most used retention appliance in the mandible [106,107,109]. The effectiveness of fixed retainers has been demonstrated; they are capable of maintaining the alignment without the patient's compliance [76,146]. The present study found that in cases with low to moderate pretreatment irregularity, there was a greater need for longer duration of retention in the mandible compared to maxilla. For longer retention periods in the mandible, a removable retainer will often be less suited. Arguably, chances are that patient compliance simply will be too challenging with a removable retainer. However, while not tested in this study, it cannot be ruled out that a removable retainer would also prove efficient in the mandible. Some clinicians use them with good results.

Other studies confirm that fixed retainers help preserve the mandibular alignment [55,145,146]. A recent study found years without retention to be a risk factor for lower incisor irregularity, indicating that longer retention times will result in better alignment [158]. Multistranded fixed retainers have shown to retain their mechanical properties 14 years posttreatment [159], so the potential is there for long-term use. Studies show that orthodontists in several countries tend to recommend that fixed retainers are kept for an indefinite period of time [20,107,108,112-115]. But uncertainty remains as to what the benefit will be of prolonged retention compared to short-term retention. Although longer retention periods seem to improve the mandibular alignment, they do not necessarily improve it by a great deal. The present study found only a small to moderate difference between the retention subgroups. Paper II showed acceptable alignment 12 years posttreatment after only a short retention period. Several other long-term follow-up studies up to 24 years posttreatment, also with quite short retention periods, have done the same [78,83]. It seems logical to assume that the longer the time since the removal of the orthodontic appliance, the more of the changes can be attributed to normal physiological development. That implies that the longer the retention is kept, the more you prevent developmental maturation processes from taking place rather than preventing relapse. Most of the posttreatment changes in the mentioned studies take place before the early 20s. A long-term follow-up of untreated individuals from 20 to 60 years of age concluded that the maxillary alignment was stable throughout the period and that LII for the mandible only deteriorated appx. 1 mm [41]. Based on these findings, one would consider the period from debonding to the age of 20 or thereabout to be the most crucial time to wear retainers. After the early 20s physiologic changes to the dentition progress at a slower rate, which should indicate a reduced need for retention. If you are not committed to wear a retainer for life, you would ask yourself when to remove it. There is not a straight-forward answer to this question. It would depend on several conditions like the malocclusion, the type of treatment, the motivation of the patient, the risk of side effects, the indications for treatment etc. It appears sensible from a clinical standpoint that one at some stage will reach a balance point where the potential disadvantages of prolonged retention start to outweigh the advantages. That stage may vary between patients. Moreover, it should be emphasised that the findings regarding duration of retention in this thesis are made on “average” adolescent patients with a general orthodontic treatment need. There are many special circumstances that may call for fixed retention for an indefinite period of time, such as instances of trauma to the anterior teeth, large diastemas, autotransplantations, anterior tongue thrust, periodontitis, extensive anterior space closures, expansion treatment, treatment of minor irregularities etc. One also has to recognise that removal of the retainer is ultimately a choice made by the patient.

Whether or not orthodontists should engage in permanent retention is almost a philosophical debate. One may ask oneself if it is reasonable to demand total stability of the dentition in a human body that so clearly ages in all other aspects. Some concerns may arise when permanent retention is applied. Firstly, it may raise the bar and create unrealistic expectations with the patient. If the patients get the impression that any changes to the dentition, whatsoever, indicate failure of treatment, the orthodontist will have a hard time living up to the expectations. In fact, engaging in permanent retention could make the patient more aware of minor alignment changes. By stretching the retention period well into adulthood, the orthodontist will also involve himself in the ageing process by indirectly assuming responsibility for the stability of the dentition. In turn, the patient may associate any unfortunate changes to the dentition with the orthodontist's work. There is also a risk that widespread use of fixed retention can make orthodontists believe that stability is mainly a matter of retention, and thus not fully acknowledge the importance of the treatment phase. In the US, there has been a shift towards use of TPRs and fixed retainers; fixed retainers being more commonly used after nonextraction treatments [20]. This may be an indication that nonextraction treatment is growing. Orthodontists who reported extracting less were more likely to tell their patients to wear the retainers at night for the rest of their lives.

Besides retention, there are other methods to improve stability of alignment. Quite established is the principle to leave the brackets on for a while after the desired treatment result is achieved. By applying finishing corrections as early as possible one will maximise the time the teeth are held in corrected positions. While it can be tempting in a busy practice to debond as soon as a proper occlusion is established, it may be unfortunate for the stability to end the treatment prematurely. Fibreotomy is one of the few methods recognised for having the potential of reducing relapse [75]. Perhaps this method could be used more in the clinic, for instance in cases where the irregularity is not generalised but instead located to one particular contact point deviation. Even better though would be to avoid severe tooth rotations in the first place, and facilitate tooth eruption in unrotated positions. Though not always feasible, this approach should be kept in mind since serial extractions could be indicated. New methods to inhibit orthodontic tooth movement (OTM) are continuously explored. Chemical methods, gene therapy and low-level laser treatment (LLLT) are relevant examples. At the moment, chemical methods have been most frequently investigated. Systemic or local administration of hormones [160], synthetic molecules [161] and different kinds of drugs [162-164] have shown potential to reduce OTM in animal models. Often the sources of impaired OTM themselves, these substances might prove useful in the posttreatment stabilisation phase. Gene therapy has been successful in inhibiting OTM in rat models by local overexpression of osteoprotegerin [165]. Furthermore, LLLT has effectively reduced rotational relapse in a study in dogs [166]. Conversely, LLLT can also accelerate tooth movement. Thus, there is still a way to go before precise control of its effects can be expected. The present knowledge of the preventive effect of these methods on OTM is primarily based on animal studies. However, if a method were to prove successful and safe in humans, it could potentially be used in the clinic to reduce relapse and long-term changes.

Risks of retention

Prolonged retention is not without risk [167,168]. Although fixed retainers have been reported to be compatible with long-term periodontal health [128], this is somewhat debated. A growing number of studies report on disadvantages of fixed retention in the form of compromised hygiene and a potential for side effects [168]. Increased values of plaque index, probing depth, bleeding on probing and gingival recessions have been found in orthodontic patients with fixed retainers compared to patients without fixed retainers [169,170]. However, it is not concluded that fixed retainers in the long term will lead to reduced marginal bone levels. As long as hygiene is maintained, fixed retainers are a viable option for tooth stabilisation. A recent article on the long-term effect of fixed retention on mandibular marginal bone levels as evaluated with cone beam computed tomography (CBCT), found no significant differences in patients wearing fixed retainers 10 years posttreatment compared to patients with a shorter (< 5 yr) retention period [171]. Compared to untreated controls, the orthodontic patients in general displayed a lower buccal bone margin in the anterior region. As the bone level was only measured at 10 years posttreatment, it is not known whether the bone levels for the patients and controls were comparable before treatment. Reassuringly, it was concluded that orthodontic retainers do not impose a risk for marginal bone loss. Although the study was missing measurements of hygiene parameters, it had other significant findings. Amongst other, it was found that protrusion of lower incisors and a high LII at pretreatment was positively correlated with reduced marginal bone level at the 10-year follow-up. Furthermore, retroclined lower incisors and low LII at posttreatment was negatively correlated with the marginal bone level. This indicates that pretreatment conditions such as incisor inclination and malalignment may be of importance to bone height in the long term, and that a good alignment gives the best foundation for optimal marginal bone level. Fixed retainer wear had lower impact on buccal bone levels 10 years posttreatment than did pretreatment inclination and irregularity. It seems preferable to avoid anterior irregularity not only because it predisposes to relapse, but evidently also because of its association with reduced marginal bone height. This information suggests beneficial consequences of making teeth erupt in their correct positions. Perhaps closer attention should be paid to the eruption of permanent teeth and serial extraction considered in severe space deficiency cases, rather than correcting the space deficiency after the arches have become overly crowded and the gingival fibres have formed. In the mentioned study appx. 70% of the patients were treated with bimaxillary extractions. This indicates a high degree of pretreatment irregularity which could explain the reduced bone level 10 years posttreatment.

Longer retention time also increases the risk of retainer deformation, a side effect with potentially severe outcomes. Unwanted tooth movement like torque changes has been reported [146,172]. If severe, torque changes can result in bone dehiscences where the teeth are pushed out of the alveolar ridge [173]. This may in turn lead to gingival recessions, compromising periodontal and dental health to a level where orthodontic retreatment and comprehensive periodontal surgery might be needed. Such alveolar bone defects will probably never heal completely. Gingival recessions may also be caused by excessive proclination [174], an outcome more likely to happen if the borders of nonextraction treatment are pushed beyond reasonable limits. Fortunately, unexpected complications of fixed retainers are relatively rare [175], with a reported incidence ranging from 0.1% to 5% [111,172]. Up to 50% of these may require retreatment [172]. It should also be mentioned that a protracted retention period increases costs related to regular check-ups and occasional debonds, expected to increase the financial burden on the patient [176].

Clinical implications and future perspectives

As covered in the introduction, there are many factors that contribute to long-term posttreatment changes. Some of them may be influenced by the orthodontist, such as the treatment plan, the treatment itself and the type and duration of retention. Other factors are beyond the control of the clinician, like jaw growth and physiologic shortening of the dental arches.

Novel techniques for tooth stabilisation are continuously explored. These new advances in orthodontic treatment and stability are certainly welcome. However, it does not refrain us from making the most of the methods we already have. Within the limits of the research design, the present study shows that excellent occlusal stability after conventional orthodontic treatment can be attained in the average patient, even in the long term. The importance of a good treatment plan and well executed orthodontic treatment should not be forgotten when aiming for the best long-term stability. Moreover, there were findings that prolonged retention may not be necessary to achieve a good long-term alignment, especially in the maxillary arch, where the results indicate that a single retainer could replace dual retention in many patients.

To assert that the good occlusal stability found in the present work is compatible with pleasing facial appearance, follow-up investigations focusing more on facial aesthetics and patient satisfaction are warranted, as these topics were not covered in the study. Treatment success from a patient's perspective should always be a high priority. The connection between alignment correction and subsequent relapse, a finding of potential clinical influence, should be tested for consistency by further investigations using the same methodology in new patient samples. Such studies should be done on patients with varying retention regimens, including short retention periods where the relation between movement and relapse is expected to be the greatest. Likewise, additional research is needed to further strengthen the evidence of the effect of long-term retention on stability of anterior tooth alignment. With time it should be possible to give general recommendations on duration of retention in orthodontic patients.

CONCLUSIONS

Based on the findings of the papers enclosed in the present thesis, the following conclusions were drawn regarding stability of orthodontic treatment and the influence of retention in the medium to long term:

Stability of occlusion

- Stability of occlusion as measured by PAR Index improvement was 79% 10 years posttreatment in patients treated at the Department of Orthodontics, University of Oslo.
- The results demonstrate that orthodontic treatment can be stable to a great extent, even in the long term. Compared to other studies using same methodology and with a correspondent follow-up period, the results from the present study were favourable.
- Occlusal parameters underwent gradual deterioration dispersed evenly throughout a 10 year posttreatment period. Small insignificant changes were seen within each subperiod. When viewed over the entire period the changes were significant, but of limited clinical importance.

Stability of anterior tooth alignment

- Anterior alignment was the occlusal component most prone to posttreatment changes. However, acceptable alignment was still found 10 years out of retention after only a short retention period.
- Long-term deterioration of maxillary anterior alignment showed a moderate to strong correlation with the amount of treatment correction. The need for maxillary retention was found to increase with the degree of alignment correction.
- Deterioration of mandibular anterior alignment showed a weaker correlation with the amount of treatment correction. Extraction of premolars reduced the degree of lower anterior irregularity 10 years out of retention.

Influence of retention on anterior tooth alignment

MAXILLA

- In patients wearing a removable retainer for three years, no added benefit of fixed retainer wear for 3 or 5 years was found 5 years posttreatment.
- In patients wearing a removable retainer for three years, the added benefit of a fixed retainer for 10 years was minor in terms of improved anterior alignment 10 years posttreatment.
- Dual retention in maxilla was found unnecessary in the average patient with mild/moderate crowding, both in the medium and long term.
- In patients with more severe alignment irregularity, prolonged retention should be considered.

MANDIBLE

- At 5 years posttreatment, a 5-year fixed retention protocol gave slightly better anterior alignment compared to a 3-year protocol.
- At 10 years posttreatment, a 10-year fixed retention protocol gave moderately better alignment compared to a 3-year protocol and slightly better alignment compared to a 5-year protocol.
- Longer duration of fixed retention improved the mandibular alignment, however to a moderate extent.

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