MALMÖ UNIVERSITY ODONTOLOGICAL DISSERTATIONS

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Linda Bokander Matilainen

Dental Crowding in Adolescents

Clinical Outcomes, Patient Perspectives, and Alveolar Bone Alterations in Fixed Appliance Treatment

DISSERTATION IN ODONTOLOGY

DENTAL CROWDING IN ADOLESCENTS

Clinical Outcomes, Patient Perspectives, and Alveolar Bone Alterations in Fixed Appliance Treatment

Dental Crowding in Adolescents

Clinical Outcomes, Patient Perspectives, and Alveolar Bone Alterations in Fixed Appliance Treatment

Thesis for Doctoral Degree (Ph.D.)

By Linda Bokander Matilainen

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LINDA BOKANDER MATILAINEN

DENTAL CROWDING IN ADOLESCENTS

Clinical Outcomes, Patient Perspectives and Alveolar Bone Alterations in Fixed Appliance Treatment

Malmö University
Faculty of Odontology

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To Olivia, Charlie, Arwid, and Fritte
With all my love, always

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LIST OF SCIENTIFIC PAPERS

This thesis is based on the following four CROWDIT (Crowded Displaced Teeth) studies:

I. Bokander Matilainen L, Johansson K, Wiaderny M, Brechter A, Petrén S, D'Anto V, Paulsson L. Treatment effects and treatment time in adolescents with crowded and displaced teeth treated with fixed appliance systems without extractions: a multi-centre randomised controlled trial. Orthod Craniofac Res. 2025;28(6):929–942. doi:10.1111/ocr.70005

II. Bokander Matilainen L, Johansson K, Petrén S, Brechter A, Wiaderny M, Michelotti A, Paulsson L. Oral health-related quality of life, experience and satisfaction in adolescents treated for dental crowding with self-ligating or conventional fixed appliances: a multicentre randomized controlled trial. Eur J Orthod. 2026; 48(4) doi:10.1093/ejo/cjag040

III. Bokander Matilainen L, Johansson K, Paulsson L, Christell H. Reliability and agreement of CBCT-based alveolar bone assessments for follow-up studies on adolescent orthodontic patients using multiplanar reconstruction and various CBCT units. Prog Orthod. 2026;27(1) doi:10.1186/s40510-026-00637-y

IV. Bokander Matilainen L, Johansson K, Christell H, Paulsson L. Alveolar bone level and fenestrations after non-extraction treatment of crowding in adolescents with self-ligating versus conventional brackets: a CBCT based randomised controlled trial. Revised manuscript will be submitted to Prog Orthod. October 2026.

Thesis at a glance

All studies in this thesis are based on the CROWDIT research project, a multicentre, two-arm parallel-group randomised controlled trial comparing passive self-ligating (Damon) and conventional (Victory) bracket systems in non-extraction treatment of 132 adolescents (12–17 years) recruited at four orthodontic clinics. Papers I–II include the whole sample, whereas Papers III and IV were based on a sample of participants recruited from three of the four clinics.

Aim	Sample	Materials	Outcomes	Main findings
Compare treatment effects and treatment time.	Analysed for main outcome: total sample.	Study models, cephalometric radiographs, dental records.	wPAR, LII, transverse width, incisor inclination, position, and treatment time.	PSLB group had more transverse expansion and the CB group had more incisor proclination post-alignment. NS intergroup differences at T2. Both groups had successful treatment outcomes.
Compare OHRQoL, treatment experience and satisfaction; and explore associations with satisfaction.	Analysed for main outcome: 132 (T0), 119 (T1), 120 (T2).	Questionnaires.	CPQ 11–14 score, patient experience and satisfaction questionnaires.	After a decline at T1, OHRQoL improved in both groups, with minor intergroup differences. Girls had worse baseline OHRQoL, at T2 the difference was NS. Motivation and satisfaction were high, regret about having started treatment was low.
Evaluate reliability and agreement of linear alveolar bone level measurements; fenestration detection agreement.	Three raters analysed 96 CBCTs from 48 participants.	CBCTs including incisors to the second premolars in both jaws.	Linear measurements: ICC, Dahlberg's error, Bland-Altman, SEM, MDC. Fenestrations: percentage agreement.	Intrarater reliability was moderate to excellent; interrater reliability ranged from poor to good. Agreement for fenestration detection was high (intrarater >81%, interrater >74%). Protocol is suitable when used by the same rater.
Assess and compare changes in alveolar bone level and occurrence of fenestrations.	Analysed for main outcome: 61 participants, 122 CBCTs.	CBCTs including incisors to the second premolars in both jaws.	ABL-CEJ (mm) and occurrence of fenestrations.	Intergroup differences were NS. ABL-CEJ distance increased while occurrence of fenestrations decreased. Bone loss was most pronounced buccally at mandibular anterior teeth.

Abbreviations: I–IV, Papers I–IV of the thesis; wPAR, weighted Peer Assessment Rating index; LII, Little's Irregularity Index; PSLB, passive self-ligating brackets; CB, conventional brackets; T0, pre-treatment (baseline); T1, post-alignment; T2, post-treatment; NS, non-significant; OHRQoL, oral health-related quality of life; CPQ 11–14, Child Perceptions Questionnaire 11–14; MPR, multiplanar reconstruction; ICC, intraclass correlation coefficient; SEM, standard error of measurement; MDC, minimal detectable change; ABL-CEJ, distance between the alveolar bone level and the cementoenamel junction.

ABBREVIATIONS

OHRQoL	Oral health-related quality of life
RCT	Randomised controlled trial
CB	Conventional bracket system
LII	Little's Irregularity Index
IOTN	Index of Orthodontic Treatment Need
DHC	Dental health component
AC	Aesthetic component
dPRO	Dental patient-reported outcome
dPROM	Dental patient-reported outcome measure
QoL	Quality of life
HRQoL	Health-related quality of life
CPQ	Child Perceptions Questionnaire
SLB	Self-ligating brackets
PSLB	Passive self-ligating bracket system
PDL	Periodontal ligament
RANKL	Receptor activator of nuclear factor kappa B ligand
OPG	Osteoprotegerin
CBCT	Cone-beam computed tomography
ABL-CEJ	Alveolar bone level to cementoenamel junction distance

MPR	Multiplanar reconstruction
CEJ	Cementoenamel junction
CROWDIT	Crowded Displaced Teeth
T0	Pre-treatment (baseline, before bond)
T1	Post-alignment (after completion of alignment)
T2	Post-treatment (after completion of treatment)
wPAR	weighted Peer Assessment Rating
OS	Oral symptoms
FL	Functional limitations
EW	Emotional well-being
SW	Social well-being
ICC	Intraclass correlation coefficient
SD	Standard deviation
ITT	Intention-to-treat
LOCF	Last observation carried forward
RSF16	Regression short form of the CPQ11–14 (16 items)
LoA	Limits of agreement
MD	Mean difference
SEM	Standard error of measurement
MDC_{95}	Minimal detectable change at the 95% confidence level
MCID	Minimal clinically important difference
ALADA	As low as diagnostically acceptable
ALADAIP	As low as diagnostically acceptable being indication-oriented and patient-specific

ABSTRACT

Crowding is among the most common reasons for orthodontic treatment. When space in the dental arch is insufficient, teeth may become rotated and overlapping, which can negatively affect oral health-related quality of life (OHRQoL). To address crowding, dental arch space can be gained by extracting teeth or expanding the dental arch using removable or fixed appliances.

A fixed appliance consists of small metal attachments called brackets, which are bonded to each tooth. Each bracket has a slot into which a metal archwire is placed. The most common bracket type is the conventional bracket, in which the archwire is held in the slot by an elastic or metal ligature. Another type is the passive self-ligating bracket, in which the archwire is held in the slot by a built-in mechanism, such as a sliding lid. The design gives the wire greater freedom of movement within the slot, especially at the beginning of treatment. This is claimed to result in gentler force, fewer side effects, and less need for extractions. However, the scientific support for these claims is limited. A 2021 Cochrane review found weak evidence comparing the two bracket types in children and adolescents, and no trial assessed patient satisfaction with treatment outcomes.

Orthodontic tooth movement alters root position within the alveolar bone, and movement beyond its boundary risks reducing alveolar bone support. This can be assessed with cone beam computed tomography (CBCT) which visualises the teeth and jaws in three dimensions. A standardised approach is required for measurements to be reliable.

This thesis is part of the research project CROWDIT (Crowded Displaced Teeth), which involves 132 children and adolescents (12–17 years) treated for crowding without extractions at four orthodontic specialist clinics in Sweden, using either a passive self-ligating or a conventional bracket appliance. Treatment results were assessed through indices and measurements, whereas patient perspectives

were analysed with the Child Perceptions Questionnaire, an instrument for oral health-related quality of life, and a questionnaire on expectations, motivation, and satisfaction. A measurement protocol for assessing alveolar bone on CBCT images was developed and evaluated for reliability and agreement.

Key results

During the alignment phase, arch space was gained through distinct expansion patterns. The increase in transverse arch width was greater in the passive self-ligating group, whereas the increase in proclination of incisors was greater in the conventional bracket group. At the end of treatment, both groups showed transverse expansion and incisor proclination to a similar extent, and both reached successful and comparable treatment results.

OHRQoL worsened in the oral symptoms and functional limitations domains in both groups during treatment, possibly due to the burdens of wearing the fixed appliance. After treatment, both groups reported improved OHRQoL beyond baseline levels. Patients were motivated, satisfied with their results, and did not regret having had treatment, which is consistent with the objective treatment outcomes being successful and similar in both groups. Girls reported poorer emotional well-being at baseline, suggesting girls experienced a greater burden from their malocclusion. Their OHRQoL improved more than boys during treatment, and by the end of treatment, no significant differences were observed.

The measurement protocol for assessment of the alveolar bone was reliable when used by the same rater (intrarater reliability), but less reliable between raters (interrater reliability). It was considered appropriate for follow-up assessments in similar samples and settings, when used by a single rater. A general reduction of alveolar bone support was observed, on average more pronounced buccally, possibly due to the expansion treatments of the dental arches. It was most extensive buccally at mandibular incisors, which were proclined during treatment. No significant intergroup difference was observed, which is in line with the observed comparable dental arch dimensions and treatment results.

The findings of this thesis, together with the other results from the CROWDIT project, suggest that the choice of appliance system may be primarily guided by patients' and clinicians' preference. However, treatment planning should consider potential adverse effects, and patients comparable to the individuals in this sample should be informed about a potential temporary decline in OHRQoL during treatment. Results from the planned long-term follow-up and health-economic analysis within CROWDIT may refine this conclusion.

POPULÄRVETENSKAPLIG SAMMANFATTNING

Trångställning är en vanlig anledning till tandregleringsbehandling. När det saknas plats i tandbågen blir tänderna ofta roterade och överlappar varandra. För att behandla trångställning behöver mer plats skapas i tandbågen, exempelvis genom att extrahera tänder eller genom att expandera tandbågen, då tänderna flyttas utåt med en avtagbar eller fast tandställning.

Fast tandställning består av små metallfästen, så kallade brackets, som limmas på varje tand. Varje bracket har ett spår i vilket en metallbåge placeras. Den vanligaste brackettypen är den konventionella, till vilken bågen fästs med en gummiligatur eller en metalligatur. En annan brackettyp är den passivt självligerande, som i stället fäster bågen med en inbyggd mekanism, exempelvis en lucka. När luckan är stängd har bågen ett visst spelrum i spåret. Detta påstås ge skonsammare krafter vid tandförflyttning, färre biverkningar och ett minskat behov av tandborttagning. Det vetenskapliga stödet för dessa påståenden är dock begränsat. Enligt en systematisk litteraturöversikt behövs fler studier med god kvalitet som jämför behandlingsutfall och patientnöjdhet mellan de två typerna av tandställning hos barn och ungdomar.

Om tänderna flyttas för långt och når utanför det tandbärande benets gränser, minskar tändernas benstöd. Konsekvenserna av detta är otillräckligt studerade. Benstödet kan undersökas och mätas med hjälp av cone-beam computed tomography (CBCT), en sorts röntgenundersökning som avbildar tänder och käkar i tre dimensioner. För att mätningarna ska bli tillförlitliga krävs ett standardiserat mätprotokoll.

Denna avhandling är en del av forskningsprojektet CROWDIT (Crowded Displaced Teeth), som omfattar 132 barn och ungdomar (12–17 år) vid fyra

specialistkliniker i ortodonti i Sverige. Deltagarna behandlades för trångställning utan tandextraktioner med antingen konventionell tandställning eller passivt självligerande tandställning. Behandlingsresultaten utvärderades med kliniska index samt olika mått på tändernas position och tandbågarnas dimensioner. Deltagarnas upplevelser undersöktes med frågeformulär om hur munhälsan påverkar livskvaliteten samt om förväntningar, motivation och nöjdhet med behandlingsresultaten. För att mäta det tandbärande benet på röntgenbilder utvecklades ett standardiserat mätprotokoll, vars tillförlitlighet undersöktes.

Huvudfynd

Båda gruppernas tandbågar expanderades under behandlingens första fas, den fas då tänderna linjeras upp, dels genom att tandbågen vidgades i sidled, dels genom att framtänderna tippades framåt. Efter den första behandlingsfasen hade den passivt självligerande gruppen bredare tandbågar i sidled, medan gruppen med konventionell tandställning hade mer framåttippade framtänder. Dessa skillnader i expansionsmönster kvarstod inte vid behandlingens slut. Båda grupperna uppvisade då lyckade och jämförbara behandlingsresultat.

Den munhälsorelaterade livskvaliteten försämrades i båda grupperna under behandlingen, främst avseende symptom och funktionella begränsningar. Detta förklaras troligen av att behandling med tandställning kan medföra exempelvis tuggsvårigheter och problem med att mat fastnar i tandställningen. Efter behandlingen var livskvaliteten bättre än före behandlingsstart. Patienterna var motiverade, nöjda med behandlingsresultatet och ångrade inte att de hade genomgått behandlingen. Flickor rapporterade sämre emotionellt välbefinnande än pojkar före behandlingsstart, vilket tyder på att de upplevde trångställningen som mer besvärande. Vid behandlingens slut påvisades inga könsskillnader.

Mätprotokollet visade god tillförlitlighet när samma bedömare upprepade mätningarna och bedöms vara lämpligt för uppföljande analyser i liknande patientgrupper när mätningarna utförs av samma bedömare. I båda grupperna sågs en likartad minskning av benstödet kring tänderna, framför allt på läppsidan av underkäkens framtänder.

Tillsammans med övriga resultat inom CROWDIT tyder våra resultat på att valet av tandställning kan baseras på patienters och behandlares preferenser. Patienter bör informeras om att den munhälsorelaterade livskvaliteten kan försämras tillfälligt under behandlingen. Den planerade långtidsuppföljningen och den hälsoekonomiska analysen inom CROWDIT kan ge ytterligare underlag för att värdera dessa resultat och kan komma att påverka denna slutsats.

INTRODUCTION

Crowded and displaced teeth

Dental crowding is one of the most common indications for orthodontic treatment. It occurs when there is insufficient space to accommodate all teeth in the dental arch, resulting in tooth rotations, displacements, and overlapping teeth (Figure 1).[1]

Figure 1. Illustration depicting a dental arch with crowding (left) and without crowding (right).

Crowding may be generalised or local within the dental arch.[2] When it occurs in the aesthetic zone in particular, it can adversely affect oral health-related quality of life (OHRQoL), most notably the emotional well-being and social well-being domains, and can also affect patients' self-esteem.[1,3,4] Of various malocclusion traits, anterior crowding has shown the strongest and most consistent association with poorer OHRQoL in adolescents.[5] Despite this, the evidence base for orthodontic treatment of crowding in children and adolescents is limited.[1]

As randomised controlled trials (RCTs) represent the highest level of evidence in intervention research, a Cochrane systematic review from 2021 assessed the effects of orthodontic intervention for crowded teeth in children and adolescents,

including only RCTs where at least 80% of the participants were 16 years or younger.[1] The review covered a broad range of treatment approaches, such as removable expansion appliances, removable eruption guidance appliances, extraction and non-extraction treatments, and comparisons between self-ligating (passive or active) and conventional bracket systems (CB).[1] Risk of bias was generally high or unclear in the included studies, and more research was warranted.

Aetiology

The aetiology of malocclusion is multifactorial, involving both genetic and environmental factors.[6] Genetic factors may influence, for example, tooth size, number, and morphology, arch dimensions, and eruption disturbances such as ectopic eruption and infraocclusion.[7] Environmental factors include premature tooth loss, with the subsequent mesial migration of adjacent teeth reducing arch space.[8,9]

Age-related changes, including late mandibular growth, mesial migration of the teeth, and continued reduction of the intercanine width, may further worsen crowding during adolescence and into adulthood. This is most pronounced in the mandible, where arch length commonly decreases with age.[2]

Diagnosis

Crowding can be diagnosed in several ways. Space analysis quantifies the deficiency by subtracting the summed mesiodistal widths of the teeth from the available arch circumference.[10] Categorical registration records crowding when the deficiency exceeds a predefined threshold,[11] and visual assessment has also been used.[4,12] Yet another approach is to measure contact point displacement, for example with Little's Irregularity Index (LII)[12], since dentitions with insufficient space for alignment tend to become irregular.

LII was proposed as a quantitative measure at a time when crowding was assessed primarily in subjective and non-quantitative terms.[12] It is a summary score of the linear horizontal displacements between the anatomical contact points of the six mandibular anterior teeth, measured in millimetres (mm) parallel to the occlusal plane.[10,12] Although originally described for the mandibular arch, it has been used to assess crowding in both the maxillary and mandibular dental arches.[13-15]

These different diagnostic approaches do not necessarily identify the same individuals,[4] which may partly contribute to the variation in reported prevalence.

Prevalence

The reported prevalence of crowding among European children and adolescents ranges from 42% to 57%,[1,16,17] whereas Swedish studies report prevalences of 26%–31%.[18,19] These differences may reflect variation in the age of the studied population, as well as in the methods used to assess and record crowding. For example, the figure of 26% represented the prevalence of crowding registered as a space discrepancy exceeding 2 mm, in schoolchildren examined at 7, 10, and 13 years of age[18], whereas at 11.5 years, the most frequent malocclusion trait in a Swedish adolescent sample was space discrepancy registered as contact point displacement exceeding 2 mm, with a prevalence of 31%.[19]

Orthodontic treatment need

In a survey of 5459 Swedish schoolchildren examined at 7, 10, and 13 years of age, the cumulative prevalence of some form of malocclusion was 73.8%, with crowding being the most frequent single finding at 26.3%.[18] More recent Swedish data are consistent, reporting malocclusion in 71% of 11.5-year-olds in a longitudinal cohort.[19] However, malocclusion does not necessarily equate to a need for orthodontic treatment. Treatment need can be objective (normative), as assessed by a clinician using indices such as the Index of Orthodontic Treatment Need (IOTN), or subjective, based on the patient's self-perceived need for treatment, which may be influenced by, for example, appearance.[20,21] These two perspectives do not always coincide.[22]

Objective treatment need

In Sweden, the indices used to assess objective orthodontic treatment need vary between regions.[23] Many are based on the four-grade priority index established by the Swedish Medical Board in collaboration with the Swedish Dental Society.[23-25] One of these is the IOTN, developed in the United Kingdom in 1989.[23,24] The IOTN comprises two components: the dental health component (DHC), which grades treatment need from 1 (no need) to 5 (very great need), according to morphological deviations of the occlusion, and the aesthetic component, which is a 10-point photographic scale reflecting perceived dental attractiveness.[24]

Applying the IOTN-DHC in the Swedish longitudinal cohort described above showed that 22% of the 11.5-year-olds had a severe or extreme need for treatment (grades 4–5), while 23.5% had a borderline need (grade 3).[19] In a cross-sectional

study of 12- and 13-year-olds in Sweden, IOTN-DHC assessments were available for 476 participants, of whom 37% had a severe or extreme treatment need (grades 4–5) and 27.5% had a borderline treatment need.[26]

Subjective treatment need

Subjective treatment need reflects how the individual experiences their malocclusion, which may differ considerably from the normative assessment. Malocclusion can have a negative impact on OHRQoL in adolescents, especially if the aesthetic zone is affected.[3,27] Among separate malocclusion traits, anterior crowding has shown the strongest and most consistent association with poorer OHRQoL.[5] Poorer OHRQoL has also been associated with bullying, low self-esteem, and psychological distress in adolescents.[28] An occlusal deviation that an orthodontist grades as minor may weigh heavily on the individual who lives with it, while another individual may not notice it at all.

A comprehensive understanding of a condition therefore requires insight into the patient's subjective experience,[29] which may be captured through dental patient-reported outcomes (dPROs). A dPRO is defined as:

> …any report of the status of a patient's oral health condition that comes directly from the patient, without interpretation of the patient's response by a clinician or anyone else.[29]

The instruments used to measure dPROs are called dental patient-reported outcome measures (dPROMs). They are typically questionnaires whose items are scored and combined into a numerical value representing the patient's experience.[29]

Despite their relevance, dPROs appear to be underused in orthodontic research. Among 315 RCTs of clinical interventions published between 2015 and 2021 in the top five orthodontic journals with the highest impact factors, about one in four reported a dPRO as a primary or secondary outcome.[30] OHRQoL was the most assessed dPRO.[30] Although the number of orthodontic RCTs has risen over time, quality of life was the topic of only 0.9% of the 1231 orthodontic RCTs published between 1968 and 2024, and 1.2% of those published between 2017 and 2024.[31] Therefore, patient-centred research is called for.[31]

Oral health-related quality of life

Well-being has been a subject of philosophical study since antiquity and has been approached from several theoretical perspectives. According to hedonism, well-being consists in pleasant experiences. According to subjectivism, nothing is good for a person unless they desire or endorse it. According to eudaimonism, well-being consists in flourishing, or fulfilment of human nature. Hybrid theories combining elements of these views are also common.[32]

Quality of life (QoL) *is one of the constructs* used to study the concept of well-being empirically in the sciences.[32] It has been described by the World Health Organization (WHO) as multidimensional, and defined as:

> …individuals' perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns.[33]

The philosophical theories address well-being in general, all things considered, and therefore offer little guidance on the areas of well-being that clinical research is concerned with.[32] Instead, well-being may be regarded as contextual, in the sense that its content is sensitive to who is asking, of whom, and under what circumstances.[32] For example, a person asked 'How are you?' by a friend is likely to answer differently than when asked the same question by a doctor, in which case the answer will probably concern health.[32] In the medical context, the relevant notion is health-related quality of life (HRQoL), which concerns the aspects of QoL affected by health and disease,[32,34,35] whereas QoL extends beyond the elements influenced by health to include, for example, experiences of living conditions, poverty, and leisure time.[34]

The instruments used to measure HRQoL depend on the purpose of the inquiry.[32,34] They may be generic, assessing overall health and everyday functioning, or developed for a particular condition or for specific circumstances, for example patients with vertebral fractures or caretakers of spouses with severe chronic illness.[32] Specific instruments are held to detect change more readily than generic ones,[32,35] though this has been disputed.[32]

Oral health contributes to HRQoL at a biological level (chewing, swallowing, and protection from infection) and at a social and psychological level (communication, self-esteem, self-expression, and facial aesthetics).[34] Sociodental indicators, measures of oral health based on the patient's

perspective,[36] were first advocated in the 1970s,[37,38] and research during the 1980s on the functional, social, and psychological consequences of oral conditions subsequently contributed to the development of OHRQoL as a construct.[34,36,37]

OHRQoL has been described as an integral part of general health and well-being.[36,37] It remains without a commonly accepted definition,[39] although definitions have been put forward, such as:

> …a multidimensional construct that includes a subjective evaluation of the individual's oral health, functional well-being, emotional well-being, expectations and satisfaction with care, and sense of self.[37]

In 2002, Jokovic and colleagues developed the Child Perceptions Questionnaire for 11–14-year-olds (CPQ11–14), as existing OHRQoL measures had been designed for adults.[40] It is a generic dPROM of OHRQoL and has been applied across a range of oral conditions, including caries, enamel defects, malocclusion, and craniofacial disorders.[41]

Expectations, motivation, and satisfaction with treatment outcome

Whereas orthodontists generally aim to achieve a functional, stable, and aesthetically pleasing occlusion, patients' expectations of treatment outcomes may vary considerably. Some young patients undergo treatment primarily at their parents' request, while others are highly motivated.[42]

According to a systematic review, satisfaction with orthodontic treatment is generally reported to be high among both patients and parents. It has been associated with patients' perceptions of the aesthetic outcome, the psychological benefits of treatment, and the quality of care, particularly interactions with the orthodontist and other dental staff. Understanding these factors and how they influence patient satisfaction is therefore important in clinical practice.[42]

To assess adolescents' expectations and experiences of orthodontic treatment, Feldmann and colleagues developed a questionnaire that covers treatment motivation, treatment expectations, pain and discomfort, and functional jaw impairment.[43] It was subsequently complemented with items capturing satisfaction with treatment outcome, quality of care and attention, and pain and discomfort, assessed retrospectively.[44]

Both the CPQ11–14 and the questionnaire by Feldmann et al., have since been used in several RCTs and observational studies.[30,45]

Orthodontic treatment

Treatment timing

The decision of whether and when to treat dental crowding depends on factors such as the severity of the malocclusion, the age of the patient, and the motivation of both the patient and the parents or caregivers. Minor crowding is common and is not considered a malocclusion requiring treatment[2]. Furthermore, crowding observed in the mixed dentition at around 8–9 years of age can be transient:[46]

Adequate anterior spacing in the primary dentition is essential because the permanent incisors are substantially larger than the primary incisors they replace. In the maxilla, the available space is generally sufficient to accommodate the erupting incisor, whereas, in the mandible it is more often insufficient, resulting in crowding.[46] Several mechanisms may contribute to resolving anterior crowding. The permanent incisors erupt along a labially inclined path, which increases arch circumference.[2,46] As the permanent canines erupt slightly buccally, intercanine width increases, particularly in the maxilla. In the mandible, the permanent canines may also move slightly distally into the primate space, where the arch is wider, thereby providing additional space for the incisors. Together with continued jaw growth, these changes may resolve anterior crowding seen during and after incisor eruption.[2,46,47] Posteriorly, the premolars are normally smaller than the primary molars they replace. This generates an average leeway space of about 3 mm in the maxilla and 5 mm in the mandible.[46] This space is normally taken up by mesial movement of the permanent molars, but can be preserved to relieve crowding.[46]

In children under 11 years of age with mild to moderate crowding, monitoring occlusal development may therefore be preferable to early intervention.[46,47] However, the potential for spontaneous space gain is unlikely to resolve severe crowding, which is therefore expected to persist into the permanent dentition.[46]

Moreover, the occlusion continues to change throughout life.[48] Gradual mesial migration of the teeth reduces arch dimensions, particularly in the mandible, so that anterior crowding may increase through adulthood.[48]

Treatment strategy

Management of dental arch space is sometimes indicated during the mixed dentition to facilitate the alignment of the permanent teeth. Space maintainers prevent mesial migration of the permanent molars and thereby preserve the

leeway space. Space can also be gained by reduction of tooth structure, for example by slicing the mesial surfaces of primary canines or molars. In addition, maxillary molars may be distalised with headgear or with appliances, in which coil or helical springs deliver the distalising force and an acrylic plate resting against the anterior palate provides anchorage.[46]

Interceptive serial extraction may be an alternative in cases of severe crowding, i.e., a dental arch space deficiency of approximately 8 mm or more per arch.[2,46] It is primarily considered for patients with a Class I occlusion and a normal overbite. The procedure ultimately leads to extraction of the first premolars and is often followed by fixed appliance treatment to achieve satisfactory occlusion and alignment.[2,46]

Space may also be created by sagittal arch expansion through proclination of the anterior teeth and distalisation of the posterior teeth, or by transverse expansion. Expansion can be performed as interceptive treatment during the mixed dentition,[49,50] or with fixed appliances in the permanent dentition.[2] In the permanent dentition, expansion may be used alone or in combination with interproximal reduction, which reduces the enamel width by approximately 0.1–0.2 mm per surface, or with tooth extraction.[2] Extractions often involve premolars, and occasionally a mandibular incisor. Alternatively, a tooth with a poor prognosis may be selected for extraction, such as a molar with extensive carious lesions, large restorations, or severe molar-incisor hypomineralisation.[2]

Treatment selection is multifaceted and depends on factors such as the severity of the space discrepancy, facial profile, skeletal relationships, tooth status, and patient cooperation. Extraction is an invasive procedure and a potentially distressing experience for the patient, which should also be considered during treatment planning. Children and adolescents undergoing orthodontically indicated premolar extractions report mild to moderate postoperative pain, peaking approximately two hours after the procedure and declining thereafter.[51]

Extraction or non-extraction

Given its irreversibility, the decision to extract teeth is among the more consequential choices in orthodontic treatment planning. It may be guided by space analysis. In a Class I molar relationship, an arch-length discrepancy of less than 4 mm seldom requires extraction, whereas a discrepancy of 5-9 mm can often be resolved through expansion, sometimes combined with molar

distalisation.[46] In contrast, a deficiency of 10 mm or more almost always necessitates extraction.[46]

The decision also depends on factors such as the facial profile and soft tissue characteristics, incisor protrusion and the amount of space that can realistically be gained through expansion or proclination.[46] Advancement of the incisors increases dental arch perimeter more than expansion in the canine region, which in turn creates more space than intermolar expansion.[52] However, excessive expansion across the canines, and incisor protrusion, increase the risk of mucogingival problems and relapse.[46] Excessive expansion may also lead to alveolar bone reduction[46], such as dehiscences and fenestrations. Therefore, even patients with an arch length discrepancy of less than 4 mm may be candidates for extraction treatment.[46] Studies have found similar soft tissue changes or only minor differences after both extraction and non-extraction treatment.[53-55] In summary, the decision of whether to extract teeth may be complex and cannot rest on a single criterion. Rather, it should be based on an individual assessment guided by the available evidence.

Fixed appliance treatment

The correction of tooth position dates back to a mechanical device described by Pierre Fauchard in the 18th century.[56] In the 20th century, Edward H. Angle laid the foundations of modern orthodontics. He classified occlusion, introduced prefabricated appliances, and organised the first educational orthodontic specialist programme.[57] He applied Fauchard's principles in his E-Arch, patented in 1899, which relied on heavy forces. The molars were banded and the other teeth were ligated to an expansion arch, so that crowding and irregularities could be relieved through expansion.[46,56] Angle's subsequent appliances established a mechanism of engaging a wire in an attachment fixed to each individual tooth. In the Ribbon Arch, every tooth was banded and a gold archwire was held in a vertical slot on each band. In the following Edgewise appliance, the slot was horizontal, and the wires were rectangular. This design became the standard for later fixed appliance therapy.[46] Angle became a well known advocate for non-extraction treatment. Charles H. Tweed was initially a pupil of Angle, who became his mentor and with whom he worked closely.[58] However, Tweed's own treatment results were discouraging. Following Angle's death, Tweed studied both his own successful cases and his failures and concluded that stable treatment results required adequate anchorage and tooth extractions. He then selected some of his previously unsuccessful cases, extracted the four first premolars in each

patient, and retreated them free of charge. The results were controversial when presented in 1940, at a time when non-extraction remained the professional norm, but Tweed's work led to a marked subsequent increase in extraction treatment.[58] Extraction rates later declined again.[59] Around the turn of the millennium, advocates of the Damon bracket system strongly promoted non-extraction treatment, based on the principle of arch expansion that Angle had advocated a hundred years earlier,[56,59] although the claims lacked scientific support. The history of the extraction debate thus illustrates the importance of individualised, evidence-based treatment planning, rather than following general treatment philosophies that lack scientific support.[59]

Types of fixed appliances

To apply force and guide the movement of teeth, a buccally fixed appliance may be used. These consist of brackets bonded to the teeth and archwires of varying cross-sectional geometric shapes, dimensions, and alloys, with different properties (flexibility, rigidity) that, taken together, affect tooth position, tip, torque, arch form, and final treatment outcome.

Throughout the mid-twentieth century, the edgewise and Begg appliances were among several systems used in parallel in clinical practice. The Begg appliance, developed in 1933 from an inverted ribbon arch design, was the first orthodontic system to employ a single round stainless-steel archwire.[46,60] The systems differed in shape and dimension of the bracket slot and wires that could be engaged, and the torque required for each tooth had to be added by the clinician through bending of the wire,[61] or by auxiliary springs.[60] Contemporary straight-wire appliances, introduced by Andrews in the 1970s,[62] incorporate built-in tip, torque, and in-out compensation within the brackets. The specific combination of these features is referred to as the appliance prescription.[46]

Fixed appliances may be categorised as conventional and self-ligating brackets (SLB) of active or passive type, referring to the mechanisms of passively or actively maintaining the archwires within the slots (Figure 2).

With CB, the archwire is ligated to each bracket with an elastomeric or stainless-steel ligature. SLB, on the other hand, have an inbuilt mechanism to ligate the wires. Active self-ligating brackets secure the archwire using an active clip, such as a spring clip, whereas passive self-ligating brackets (PSLBs), such as Damon brackets, employ a slide that allows free play between the archwire and the bracket slot. This was presumed to allow sliding mechanics with less friction,

particularly during the early stages of treatment when smaller diameter archwires are used.[63]

A systematic review on orthodontic treatment of children with crowded teeth, only including RCTs, compared among other things, self-ligating brackets (SLB) with conventional brackets (CB) and identified five trials.[1] These involved extraction and non-extraction treatment, ceramic brackets, active and passive self-ligating brackets. Three of the trials had a high or unclear risk of bias due to unclear randomisation methods, allocation concealment, unreported dropouts and, in one case, the removal of participants to balance group sizes.[1] In addition, there is an inherent risk of bias because the orthodontic intervention cannot be blinded, which is a well-recognised difficulty in this field of research.

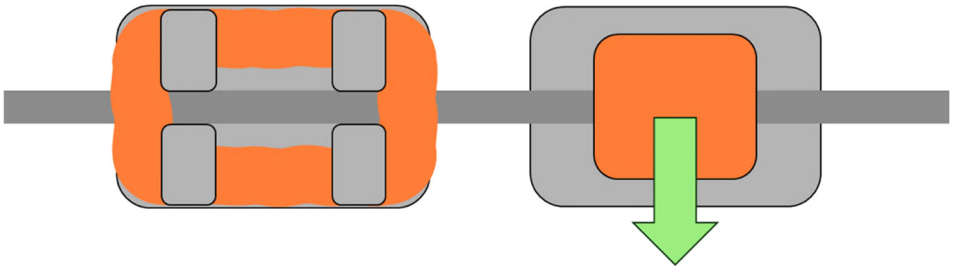

Figure 2. Illustration of a conventional bracket with an elastomeric ligature (left) and a self-ligating bracket with an integrated slide (right).

Self-ligating brackets

SLB brackets have been developed since the 1930s, beginning with the Russell Lock attachment[64]. Since then, a large number of designs have been developed. The Ormco Edgelok bracket, introduced in 1972, was the first design manufactured in large quantities, followed by the SPEED in 1980 and the Damon SL in 1996.[65] Despite continued development and design over the following decades, SLB remained a marginal part of overall orthodontics until the Damon2 and In-Ovation designs arrived in 2000s. This was followed by production of bracket types from a range of manufacturers bringing out designs of their own.[66]

The Damon System

Dwight Damon, known for developing the Damon system which comprise passive self-ligating brackets combined with broad archwires[63], initially advocated non-extraction treatments for most patients, asserting that sufficient

space could be created through arch expansion. This stance generated significant interest and considerable debate, with critics questioning the scientific support.[56,59]

The philosophy of the Damon system is to enable orthodontic treatment with low-forces and low friction. This was claimed to allow individual tooth movement and to guide the teeth into position through a balance of forces between the tongue, the cheeks, and the periodontium, resulting in good treatment outcomes, shorter treatment times, and less discomfort for patients.[63, 67] The Damon system nowadays claims to generate good treatment outcomes in crowded cases through arch expansion with less need for extractions[68]:

> The Damon System is an innovative combination of passive self-ligating brackets, high-tech archwires, and minimally invasive treatment protocols that work together as a low-friction, low-force system. The end result is clinically proven performance that includes faster treatment time, fewer appointments, improved patient comfort, exceptional results, and wider arch development with fewer extractions as well as less reliance on RPEs or surgery.[68]

However, there is limited support for these claims.

Tooth movement and bone remodelling

Force application leads to instantaneous displacement of the tooth within its socket, narrowing the periodontal ligament (PDL) space on the pressure side and stretching the PDL on the tension side.[46]

On the pressure side, the tissue response depends on the magnitude of the force. A light force compresses but does not occlude blood vessels, producing a chemically altered ischaemic environment.[46] The optimal force has been described as the lightest force producing a maximum or near maximum response, and it varies depending on the type of tooth movement.[46,69]

Within seconds of force application, fluid is redistributed within the PDL, and on the pressure side, the fluid is forced into the bone canaliculi, generating shear stress on osteocytes. This stimulates osteoclast differentiation and bone resorption, while compression also temporarily increases osteoblast apoptosis.[70]

In parallel, vascular compression creates hypoxia, which leads to the expression of vascular endothelial growth factor, receptor activator of nuclear factor kappa B ligand (RANKL), prostaglandins and inflammatory cytokines in PDL

fibroblasts and osteoblasts.[70] These cells, together with vasoactive neuropeptides released from distorted nerve endings, and the recruitment of immune cells such as leukocytes, monocytes, and macrophages, are involved in the onset of the acute inflammatory response. Prostaglandins further increase RANKL and decrease osteoprotegerin (OPG), favouring osteoclast differentiation.[70]

In anoxic areas, cell necrosis creates the 'hyalinised zone', a sterile necrotic area that appears glass-like under a light microscope.[2] Because the blood vessels have degenerated, osteoclast precursor cells cannot reach the area, and without osteoclasts, the tooth movement halts.[2] The necrotic tissue must be broken down and removed.[46] In hyalinised areas, undermining resorption is initiated from the adjacent bone marrow spaces, takes more time, and increases the risk of adverse effects such as increased pain, root resorption, loss of anchorage, and uncontrolled movement.[46] Once phagocytic cells have removed the hyalinised tissue, tooth movement resumes.[2] In areas without hyalinisation, osteoclasts instead differentiate and start frontal resorption in the direction of movement, which may continue as long as the force is present but not excessive.[2] Some undermining resorption occurs even with recommended force levels, since variation in root and alveolar bone morphology causes differences in local force distribution during orthodontic treatment.[6]

On the tension side, fluid flows from the canaliculi towards the PDL, activating osteocytes and promoting osteoblast differentiation and bone deposition.[70] Blood vessels dilate and blood flow increases.[46] Interleukin-10 increases OPG and suppresses RANKL expression, inhibiting osteoclast differentiation, while osteocyte signalling and TGF-β promote osteoblast differentiation and bone deposition.[70]

With or through alveolar bone?

Two main concepts have been proposed to explain orthodontic tooth movement, one suggesting that teeth move through bone, and the other that they move with bone.[71] The 'with-bone' theory has been particularly appealing to supporters of arch expansion.[71] The prevailing view, however, is that teeth move through bone, although movement with bone might be possible to some extent in growing individuals.[71] Roots can thus be moved beyond the boundaries of the alveolar bone, even in young patients, resulting in bony defects such as reduction of the alveolar bone margin and fenestrations[71] (circumscribed defects exposing the tooth root surface)[72], as illustrated in Figure 3. Such defects may nonetheless recover, as new bone formation has been observed when the root moves back

towards its original position. One explanation for this is the PDL–periosteum sandwich hypothesis, a thought experiment recently proposed by Huang.[71] As long as the periosteum and PDL remain as a bilayer over an exposed root, the root may regain bone coverage if moved back into the bone, as tension between the two layers is proposed to promote new bone formation.[71]

Adverse effects

Like other forms of treatment, orthodontic treatment can result in adverse effects. One of these is external root resorption, a potential side effect of cellular activity during removal of hyalinised tissue.[2] It primarily affects maxillary incisors, and anterior teeth more often than posterior teeth,[73] and the choice of bracket system does not seem to influence it.[74] Pain and discomfort are expected, especially in the first few days after appliance placement or after placement of a 0.019×0.025-inch stainless steel archwire,[75] although the pain is transient.[2] Enamel demineralisation, such as white spot lesions, is a more lasting concern, resulting from plaque accumulation around the brackets.[2] Plaque accumulation at the gingival margin can also cause gingival inflammation in patients who are not capable of, or do not prioritise, proper oral hygiene.[2] Gingival recessions, with related dentine hypersensitivity and impaired aesthetics, are another adverse effect associated with orthodontic treatment,[76,77] particularly in patients whose crowded anterior teeth have been aligned and proclined.[2] However, the aetiology appears to be multifactorial and owing to heterogeneity between studies, findings are inconsistent.[76,78] In these patients, there is also a risk of moving teeth outside the alveolar process, causing marginal bone loss and fenestrations (Figure 3).[72,79] Although such defects can occur naturally,[80] increased marginal bone loss has been observed on both labial and lingual surfaces following orthodontic tooth movement,[81,82] and has been reported to be more pronounced buccally and lingually than proximally.[82,83] Post-treatment recovery of such defects has been described,[84] although persistence has also been observed.[85] Furthermore, adolescents have been suggested to exhibit greater bone remodelling capacity than adults, who appear to experience more pronounced bone loss.[86]

Figure 3. Illustration of the buccal alveolar bone in the mandibular anterior region, showing fenestrations and a reduced marginal bone level.

Several factors are associated with treatment-related alveolar bone loss, such as pretreatment alveolar bone thickness,[87] patient age and sagittal facial pattern, extraction treatment, the use of miniscrews,[88] and the severity of crowding.[87-89] Findings across studies are, however, not entirely consistent,[90] and the evidence on treatment-related alveolar bone loss remains limited.[91] Well-designed studies with long observation periods are needed.[91] One aim of this thesis was to assess alveolar bone changes following orthodontic treatment comparing two types of fixed appliances.

Cone beam computed tomography

Assessing alveolar bone changes following orthodontic treatment requires imaging that can depict the thin buccal and lingual bone surrounding the roots. Conventional two-dimensional radiography is limited in this respect, as anatomical structures are superimposed and particularly in intraoral radiographs, the field of view is restricted, which may prevent a given diagnostic question from being answered.[92] Cone-beam computed tomography (CBCT) provides a three-dimensional volume of a given dentomaxillofacial region from a series of two-dimensional projections,[93] and has been used, among many other indications, to quantify treatment-related changes in bone support.[94] The CBCT x-ray source and detector rotate around the patient on opposite sides. Patient structures and

their densities are rendered into discrete values represented by cubic voxels (volume elements, the three-dimensional equivalent of a two-dimensional pixel), each carrying a single grey value, and all combined into a regular voxel grid.[93] The voxel sizes are usually within the range of 0.08–0.3 mm, and set the theoretical boundary for the smallest detail that can be visualised (the spatial resolution).[93]

Many variables affect the spatial resolution, which is not constant throughout the volume but typically decreases from the centre towards the periphery.[93] Images may also appear grainy as the wide detector area intercepts scattered radiation from patient tissue, which registers as noise. In addition, high-density materials such as crowns or retainers give rise to beam-hardening artefacts that may obscure the region of interest.[93,95] Moreover, tissues that attenuate the beam to a similar degree cannot be separated, however fine the voxel grid.[93]

Furthermore, patient motion during exposure is inevitable, and the risk increases with increased exposure time and with younger patients.[96] Movement exceeding the tiny voxel size will result in error propagation in the reconstruction process, resulting in motion blur. Devices such as chin rests or head straps limit head movement but cannot eliminate small motions.[93]

Consequently, resolution figures derived from stationary phantoms do not reflect these in vivo limitations, and the resolution available in a patient scan therefore falls short of what the voxel size alone would suggest. Image quality therefore affects the ability to identify structures and influences both the reliability and validity of measurements.

CBCT assessment of alveolar bone

The CBCT image can be reformatted in several ways, such as three-dimensional rendering or multiplanar reconstruction (MPR). The latter displays the volume in three perpendicular planes: coronal, sagittal, and axial plane (Figure 4).

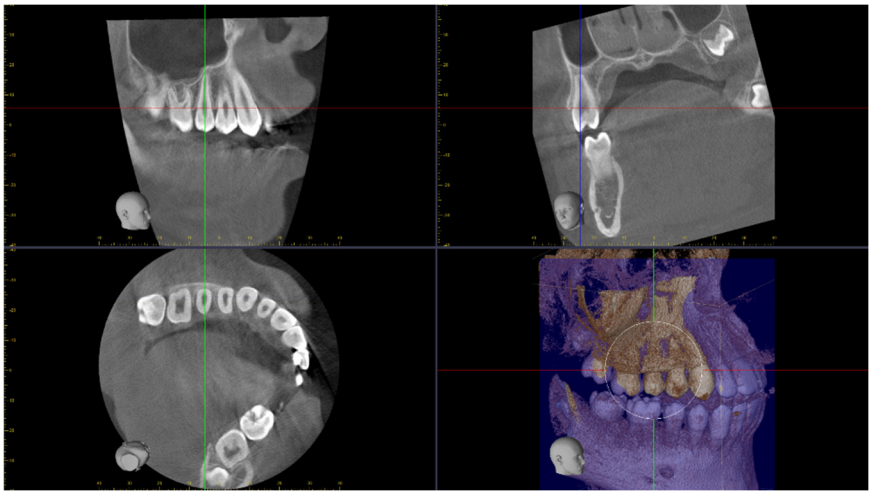

Figure 4. Multiplanar reconstruction of a CBCT volume showing the sagittal (upper left), coronal (upper right), and axial (lower left) planes, with a three-dimensional volume rendering (lower right).

Radiographic assessment of the alveolar bone often concerns two dimensions: the vertical position of the marginal bone level in relation to a landmark, such as the cemento-enamel junction (CEJ);[97] and the width of the bone plates covering the roots at different levels of the root.[98]

In the anterior maxilla, the bone layer covering the roots is commonly less than 0.5 mm thick.[93] The minimum mandibular bone width required for visibility was 0.173 mm buccally and 0.356 mm lingually (without motion artefact) using a 0.125 mm voxel size.[99] This is at the limit of what can be depicted, and several factors further reduce achievable resolution below what voxel dimensions suggest, as previously described. The absence of a visible bony layer therefore does not establish that bone is absent in vivo, and fenestrations and dehiscences may consequently be reported where none exist.[72,93]

Reliability and agreement in measurement

All measurements involve some degree of error, and an observed change can only be considered real if it exceeds the error of the method used to detect it.[100] For alveolar bone measurements on CBCT, reported reliability and agreement estimates vary with study design, ranging from phantom- or skull-based studies,[101] sometimes using artificial markings,[102] to studies using preselected images.[103] Such designs may produce estimates that are not directly transferable to clinical practice, as they exclude sources of variation such as patient movement

during image acquisition and bone remodelling during orthodontic treatment. Furthermore, in follow-up studies, the same anatomical landmarks must be identified on images acquired at different time points. Between these, changes such as tooth movement, and attrition and abrasion of crown landmarks, may complicate the measurements.

As reliability depends on the conditions under which it is assessed, intra- and interrater reliability and agreement should be reported, also when measurements are performed within clinical trials, according to the Guidelines for Reporting Reliability and Agreement Studies (GRRAS).[104]

Rationale for the thesis

As described above, knowledge gaps remain for several outcomes of orthodontic treatment of crowding. The 2021 Cochrane review on crowded teeth in children and adolescents suggested outcomes for future research that are clinically useful and relevant for patients, for example: change in irregularity, irregularity at different time points, change in angulation, time to alignment, and adverse effects.[1] Although assessing dPROs is essential for understanding both the condition and its treatment,[29] no RCT reporting on dPROs such as self-esteem or patient satisfaction was identified in the systematic review.[1]

AIMS

The overall aim was to assess and compare clinical outcomes, patient perspectives, and alveolar bone alterations throughout non-extraction treatment with either a PSLB or a CB system in adolescents with dental crowding and displaced teeth.

Specific aims:

- **Paper I:** The primary aim was to assess and compare occlusal treatment outcome between the treatment groups; the secondary aims were to assess and compare alignment, lateral expansion, incisor inclination and position, and treatment time.
- **Paper II:** The primary aim was to assess and compare OHRQoL between the treatment groups, between boys and girls, and within the total sample. The secondary aims were to assess and compare treatment motivation, expectations, and satisfaction with treatment outcomes between the treatment groups and within the total sample; and to explore factors associated with satisfaction.
- **Paper III:** The aim was to evaluate the reliability and agreement of linear marginal bone level measurements at incisors, canines, and premolars, and the agreement in detecting fenestrations using an MPR-based protocol applied to CBCT volumes acquired from different units in adolescent orthodontic patients.
- **Paper IV:** The aim was to compare alveolar bone level and the occurrence of fenestrations between the treatment groups and in the total sample.

HYPOTHESIS

- **Paper I:** We hypothesised that treatment outcome and treatment time would not differ between the two appliance systems.
- **Paper II:** OHRQoL was expected to deteriorate at the onset of treatment as a result of pain and impaired oral function, with less deterioration in the PSLB group, given earlier reports of lower pain levels with PSLB brackets, and to improve beyond baseline by the end of treatment in both groups.
- **Paper III:** We hypothesised that the reliability and agreement of alveolar bone measurements using the MPR-based protocol for follow-up assessment would be suitable for the intended application of linear alveolar bone measurements and fenestration assessment, but lower than in previous studies conducted under controlled conditions, such as in phantoms, ex vivo human specimens, markers, and preselected images.
- **Paper IV:** Given the previously reported lack of statistically significant intergroup differences in occlusal outcomes, we hypothesised that alveolar bone outcomes would not differ between the groups. Because both bracket systems address crowding through expansion and incisor proclination, we further hypothesised that alveolar bone changes would be observed predominantly at buccal surfaces.

MATERIALS AND METHODS

Study design

This thesis is based on the CROWDIT (Crowded Displaced Teeth) research project, a multicentre, two-arm, parallel-group, randomised controlled trial with a 1:1 allocation ratio, evaluating outcomes of non-extraction fixed appliance treatment in adolescents with crowded and displaced teeth (ClinicalTrials.gov NCT05664282).

Papers I, II, and IV follow the CROWDIT randomised design. Paper III is a methodological reliability and agreement study using in vivo data.

Participants and settings

Adolescents with dental crowding and tooth displacement were recruited consecutively at four specialist orthodontic clinics in Malmö, Helsingborg, Falun and Östersund: one university specialist clinic, one private specialist clinic, and two public specialist clinics.

Papers I and II are based on the full trial population, whereas Paper III and Paper IV are based on samples with participants recruited at the three clinics that had access to CBCT equipment of sufficient quality.

Eligibility criteria

Inclusion criteria:

Age 12–17 years at treatment initiation; crowded and displaced teeth in one or both arches; sagittal relationship within ± one cusp deviation from a normal

sagittal relation; overbite ≥ 0 mm; normal transverse relation, or minor transverse dental discrepancy; treatment needs 3, 4, or 5 according to the IOTN-DHC.[105]

Exclusion criteria:

Treatment plan including extractions or surgical procedures; need for auxiliary appliances such as a transpalatal bar or Quad Helix; rheumatoid arthritis; missing permanent teeth; impacted teeth; previous orthodontic treatment; ongoing sucking habits; previous trauma to teeth or jaws with subjective, clinical, or radiographic findings; periapical pathology; probing depth of ≥ 5 mm at central incisors or first molars with a calibrated probe, screened at ≥ 4 sites per tooth; visible plaque Grade 3 (Silness-Löe)[106]; communication difficulties.

Enrolment and consent

Consecutive eligible adolescents awaiting fixed appliance treatment, who had been assessed by an orthodontist and approved for publicly funded comprehensive orthodontic care, were given verbal and written information about the trial, together with their guardians, and invited to participate. Assent and written informed consent were obtained before randomisation.

Randomisation and allocation

The allocation sequence was computer-generated by a statistician, and participants were assigned in a 1:1 ratio to either CB (Victory APC Plus™) or PSLB (DamonQ™) using permuted blocks of 10 stratified by sex. Sealed, opaque, sequentially numbered envelopes labelled "girl" or "boy" were prepared for each clinic.

After assent and written informed consent had been obtained, a staff member not otherwise involved in the trial opened the next envelope in sequence for the participant's sex. A clinical examination, medical history, and baseline registrations were then completed, after which treatment commenced according to the trial protocol.

Interventions

The treatment goals were to achieve a bilateral Class I relationship, normal vertical and transverse relationships, and aligned teeth. The treatment protocols were developed based on manufacturers' recommendations at the time of CROWDIT initiation.

Treatment protocol

All participants received routine oral hygiene instructions and professional tooth cleaning. The buccal surfaces were etched with 35% phosphoric acid and bonded under dry conditions. Where indicated, bite disarticulation was placed. Interproximal reduction was allowed during treatment.

Passive self-ligating brackets

The PSLB group received the Damon Q™ bracket (0.022-inch variable torque; Ormco Corporation, Orange, CA, USA), bonded with Greengloo™. For levelling and alignment, the Damon arch form was used with the following archwire sequence: 0.014-inch (or 0.013-inch) CuNiTi, 0.018-inch CuNiTi, and 0.014×0.025-inch (or 0.018×0.025-inch) CuNiTi.

Control intervals were 8–10 weeks.

Conventional brackets

The CB group received the Victory Low Profile™ bracket and APC Plus™ adhesive (0.022-inch MBT standard torque; 3M™, St Paul, MN, USA). For levelling and alignment, the 3M™ OrthoForm™ III (Ovoid) arch form was used with the following archwire sequence: 0.016-inch (preceded, where needed, by 0.012-inch or 0.014-inch) HANT, and 0.019×0.025-inch (and/or 0.014×0.025-inch) HANT.

Control intervals were ≥ 6 weeks.

Completion of treatment (both groups)

A 0.019×0.025-inch stainless steel archwire of ovoid form was used to finish the treatments (Figure 5). Progression to the next wire in the sequence required that the archwire could be seated passively in all slots.

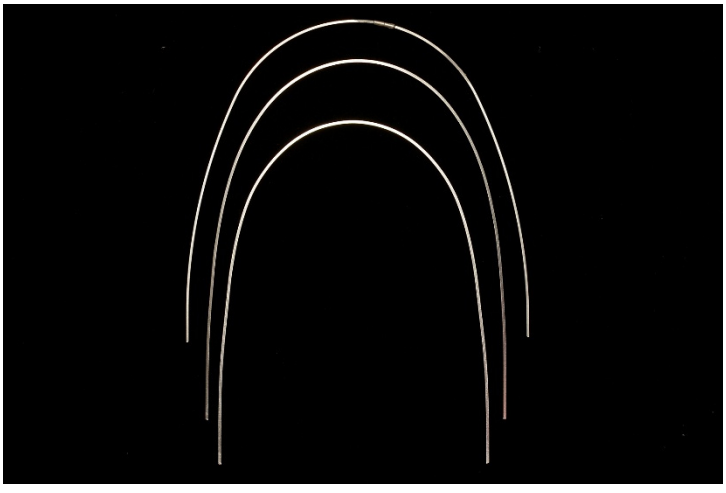

Figure 5. Comparison of the archwire forms used. The outermost archwire is the Damon archwire form, which was identical for the maxillary and mandibular arches. The two inner archwires are the OrthoForm III Ovoid archwire forms: the maxillary form (middle) and the mandibular form (innermost). Photo by Hans Herrlander.

Data collection

Overview and time points

Study models, clinical examinations and cephalometric radiographs were obtained at pre-treatment (T0; baseline), post-alignment (T1; defined as the insertion of the first 0.019×0.025-inch stainless steel archwire), and post-treatment (T2; after debond). CBCT examinations were performed at T0 and T2. Questionnaires were completed at T0 and T1 before any treatment was performed at the corresponding appointment, so that responses would not be influenced by the procedures, and at T2, two to three months after debonding (Figure 6).

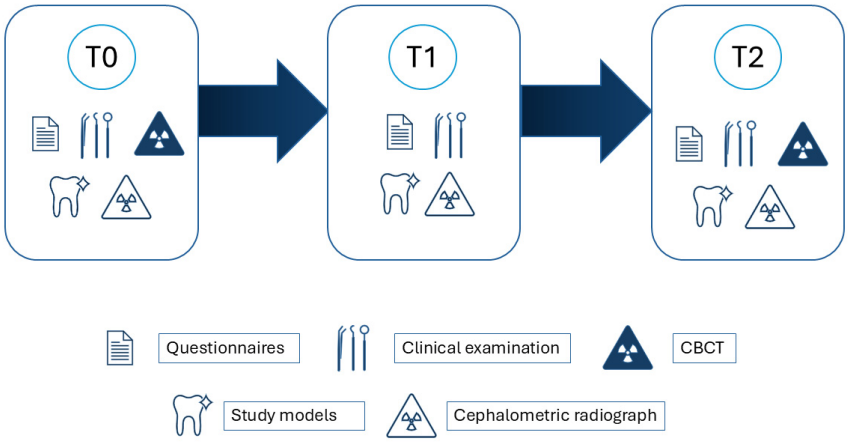

Figure 6. Data collection at each time point: baseline (T0), post-alignment (T1), and post-treatment (T2). Questionnaires were completed at all three time points (T2 for questionnaires was approximately 2–3 months after debonding); study models, clinical examinations, and cephalometric radiographs were obtained at T0, T1, and T2; and CBCT scans were acquired at T0 and T2.

Study casts and digital models

Study casts were digitised into three-dimensional models at Ortolab, Czestochowa, Poland, and analysed using O3DM, OrthoLab, DDP-Ortho software (version 2.6.2021-2.14.2023) for the baseline analysis and Paper I outcomes.

Lateral cephalograms

Cephalometric radiographs were acquired on the imaging units available at each clinic: Veraviewepocs 3D F40 (J. Morita Corp., Kyoto, Japan), Planmeca 3D Mid (Planmeca Oy, Helsinki, Finland), Planmeca ProMax 2D (Planmeca Oy, Helsinki, Finland), and Orthoceph OC100D (GE Healthcare, Tuusula, Finland). Tracing and analysis were performed in Facad (Ilexis AB, Linköping, Sweden) on coded material by an orthodontist with four years' experience.

CBCT

Prior to initiation, objective image quality assessment was conducted with the SEDENTEX CT Quality Control Phantom (Leeds Test Objects Ltd, Boroughbridge, UK) to establish dose-optimised protocols for each CBCT unit

in accordance with the ALADA principle.[92] CBCT examinations of both jaws were performed at T0 and T2 on five units representing four models at three clinics (A–C; Table 1). Acquisition parameters for each unit are presented in Table 1.

Table 1. CBCT equipment, acquisition parameters and distribution of CBCT examinations

	Clinic	CBCT machine	CBCT (n) in paper III	CBCT (n) in paper IV	Voltage (kV)	Tube current (mA)	Exposure time (s)	Rotation (°)	FOV (cm)	Voxel (µm)
T0	A	3D Accuitomo®170	9	9	80	3/6	17.5	360	8×8	160
	A	Veraviewepocs®	14	17	80/90	3/5	9.3/9.4	180	8×8	125
	B	i-CAT® 9140	20	27	120	5	4	360	8×16	300
	C	3D Accuitomo®170	5	8	80	3	17.5	360	8×8	160
T2	A	Veraviewepocs®	23	26	80/90	2/3/5	9.3/9.4	180	8×8	125
	B	i-CAT® 9140	7	10	120	5	4	360	8×16	300
	B	ProMax® 3D Mid	13	17	90	5/6	12	200	8×8	200
	C	3D Accuitomo®170	5	8	80	3	17.5	360	8×8	160

Abbreviations: Clinic, radiology clinic; CBCT, cone-beam computed tomography; n, number of CBCT examinations acquired; kV, kilovolt; mA, milliampere; s, seconds; FOV, field of view; cm, centimetres; µm, micrometres, T0, baseline; T2, post-treatment. Software: i-Dixel® (J. Morita Corp., Kyoto, Japan) for clinics A and C; Romexis® (Planmeca Oy, Helsinki, Finland) for clinic B.

Baseline analysis

Space discrepancy: was assessed on study casts with a digital calliper (Mitutoyo, Japan). It was calculated as the available arch length, measured in segments from the mesial contact points of the central incisors to the distal contact points of the lateral incisors, and from there to the mesial contact points of the first molars, minus the sum of the mesiodistal widths of the teeth (Figure 7, green lines, blue arrow). Digitised 3D study models were used to assess overjet and overbite in mm, IOTN-DHC[105], and sagittal and transverse relationships, based on the method of Björk[11]. Cephalometric analysis was performed on lateral cephalometric radiographs.

Time points in the thesis summary

This thesis summary uses three time points: T0 (baseline), T1 (post-alignment), and T2 (post-treatment), consistent with Papers I and II. Papers III and IV include only two time points, baseline and post-treatment, labelled T0 and T1 in those papers. For consistency, post-treatment is referred to as T2 throughout this thesis summary.

Outcomes

Objective outcomes

On study models

Peer Assessment Rating Index: Occlusal outcome was assessed using the weighted Peer Assessment Rating index (wPAR) which assigns numerical scores to defined occlusal traits recorded before and after treatment.[107,108] In the weighted version, the traits judged most clinically relevant are given greater weight.[108] Following the thresholds proposed by Richmond et al.[107,108], a reduction of at least 30% indicates an 'improved' result, and a reduction of at least 22 points corresponds to a 'greatly improved' result. wPAR was analysed as scores at T0 and T2, score reduction, and percentage reduction.

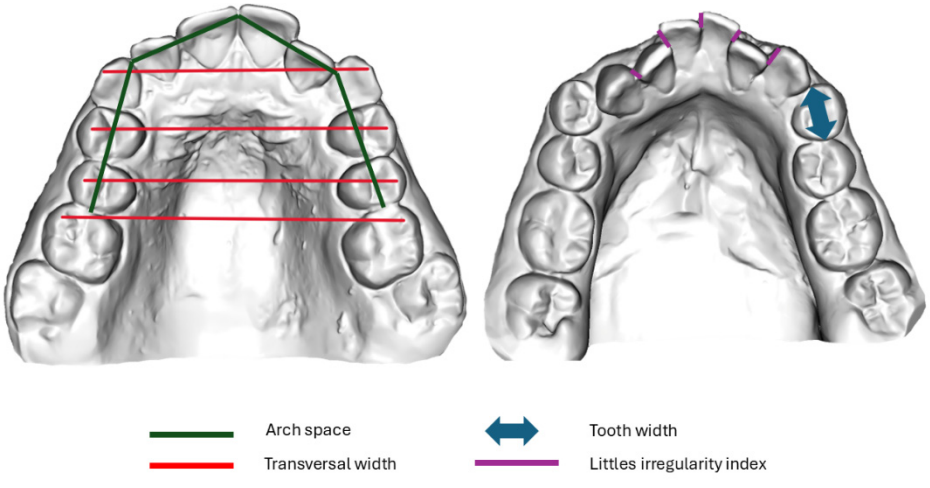

Figure 7. Measurements performed on the 3D digital study models. Left (maxillary dental arch): arch space (green) and transverse widths (red). Right (mandibular dental arch): Little's Irregularity Index (purple) and tooth width (blue).

Little's irregularity index: the sum of linear displacements of anatomical contact points from canine to canine, recorded in both arches on digital models at T0 and T2, and analysed as LII reduction.[12]

Transverse width: change in arch width (mm) during the alignment phase (T0–T1), the post-alignment phase (T1–T2) and total treatment (T0–T2), measured in

both jaws between the cusp tips of the canines, the buccal cusp tips of the first and second premolars, and the mesiobuccal cusp tip of the first molars (Figure 7, red lines). Where attrition or abrasion had worn a cusp, the measurement point was placed at the centre of the affected surface.[109]

On cephalometric radiographs

Cephalometric analysis: all variables in Table 2 were assessed at each time point and as changes over T0–T1, T1–T2 and T0–T2; except the sagittal (ANB, SNA, SNB) and vertical (ML/NL) jaw relationships, which were recorded at baseline to describe the sample. All variables are illustrated in Figure 8 and Figure 9.

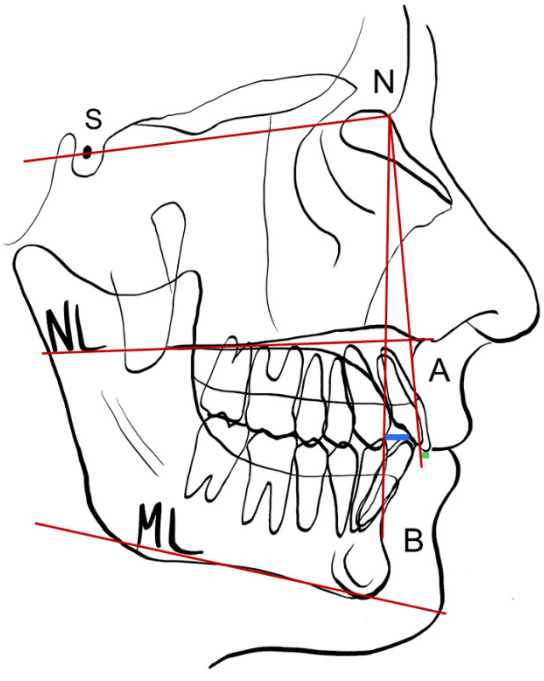

Figure 8. Skeletal relationship and incisor position: ANB (°), SNA (°), SNB (°), ML/NL (°); upper incisor to NA (mm; green line) and lower incisor to NB (mm; blue line).

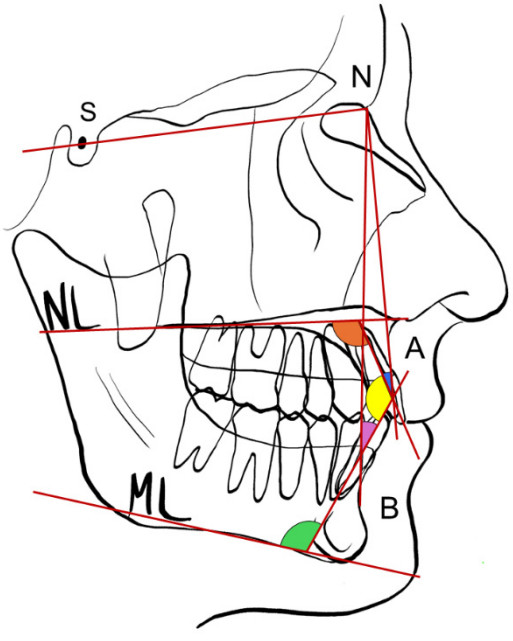

Figure 9. Incisor inclination: ILs/NL (°; orange), upper incisor to NA (°; blue), ILi/ML (°; green), lower incisor to NB (°; pink), interincisal angle (°; yellow).

Table 2. Cephalometric outcomes and their definitions

ANB (°) anteroposterior relationship between the maxilla and mandible
SNA (°) anteroposterior position of the maxilla relative to the cranial base
SNB (°) anteroposterior position of the mandible relative to the cranial base
ML/NL (°) maxillary-mandibular plane angle
ILs/NL (°) upper incisor inclination relative to the maxillary base
Upper incisor to NA (°) inclination
Upper incisor to NA (mm) position
ILi/ML (°) lower incisor inclination relative to the mandibular base
Lower incisor to NB (°) inclination
Lower incisor to NB (mm) position
Interincisal angle (°) angle between the long axes of the upper and lower in cisors

Clinical records

Treatment time: calculated in months from T0 to T1 and from T0 to T2.

On cone-beam computed tomography

ABL-CEJ (mm): the distance from the cementoenamel junction to the marginal alveolar bone crest, measured buccally and palatally/lingually on all teeth from the incisors to the second premolars in both jaws, according to the MPR-based measurement protocol (Figure 10). ABL-CEJ was assessed at T0 and T2 and as the change from T0 to T2.

Fenestrations: defined as circumscribed bony defects exposing the root surface without involving the alveolar bone crest, and registered when their vertical extent exceeded 2.2 mm. The occurrence of fenestrations was assessed at T0 and T2.

Reliability and agreement: the MPR-based measurement protocol (Figure 10) was evaluated for alveolar bone level measurements and fenestration detection, using CBCT volumes acquired at T0 and T2 (Table 3).

Table 3. Measures used to evaluate the reliability and agreement of the CBCT measurement protocol

Measure	Expresses	Applied to
ICC[110,111]	Relative reliability	Bone level, intra- and interrater
Dahlberg's random error[112]	Random error	Bone level, intra- and interrater
Bland-Altman plots[113].	Systematic and random error	Bone level, intrarater
SEM[100]	Absolute reliability	Bone level, intrarater
MDC_{95}[100]	Minimal detectable change	Bone level, intrarater
Percentage agreement	Agreement:	Fenestrations, intra- and interrater

ICC, intraclass correlation coefficient; SEM, standard error of measurement; MDC_{95}, minimal detectable change at the 95% confidence level.

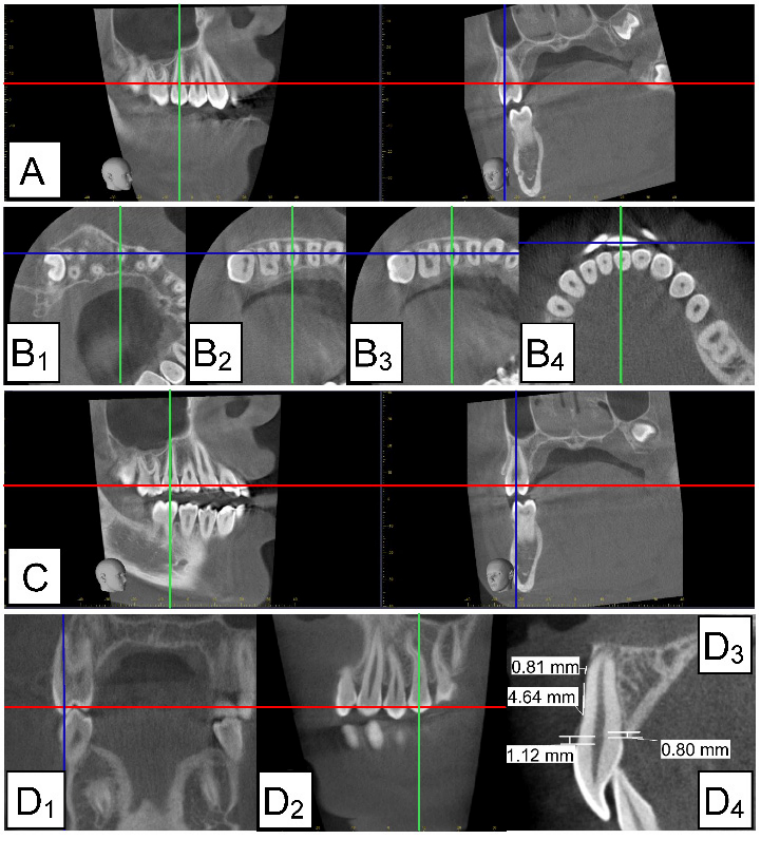

Figure 10. Measurement protocol. Primary setting: reference lines were aligned from the incisal edge, canine cusp tip, or buccal cusp tip of premolars to the root apex (A). For multirooted teeth, the line extended from the buccal cusp tip to the buccal root apex. In the axial stack, the sagittal reference line was positioned to intersect mid-buccal and mid-palatal/lingual aspects of the root. This orientation was adjusted at several levels along the length of the root, starting at the apex, with final positioning approximately 2 mm below the CEJ (B1–B3). For incisors, orientation was based on the incisal edge at the level of the dentinoenamel junction (B4). Final adjustments: In the sagittal and coronal stacks, axial reference lines were aligned with the long axis of the tooth. The long axis was defined as passing through the mid-incisal edge (incisors), cusp tip (canines), buccal cusp tip (two-rooted premolars), or mid central groove (single-rooted premolars), at the level of the dentinoenamel junction, and extending to the apical point of the root (C). For multirooted teeth, the buccal root was selected (D1). Curved root segments were ignored (D2). Measurements: In the sagittal stack, marker lines were placed at the CEJ and the alveolar bone crest, with positions verified by scrolling through the axial stack. Measurements were performed using the ruler function (D3). Fenestrations: following linear measurements, the tooth was assessed for the presence of fenestrations (> 2.2 mm in vertical dimension) by scrolling through all planes (D4). Text reproduced and figure adapted from Bokander Matilainen et al., 2026 [114] licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

Dental patient-reported outcomes

Oral health-related quality of life

OHRQoL was assessed with a modified Child Perceptions Questionnaire for 11 to 14-year-olds (CPQ11–14)[115], originally developed by Jokovic et al.[40] The CPQ11–14 has been translated into numerous languages, including Swedish,[116,117] and has been applied to children and adolescents with orthodontic treatment need.[27,115] The questionnaire comprises two global ratings of overall oral health and 37 items across four domains: oral symptoms (OS; six items), functional limitations (FL; nine items), emotional well-being (EW; nine items) and social well-being (SW; thirteen items). The items are scored as follows: 'never' (0), 'once or twice' (1), 'sometimes' (2), 'often' (3) and 'every day or almost every day' (4). Higher scores indicate poorer OHRQoL. A 'not applicable' option was included in the modified version.[115] CPQ11–14 was completed at T0, T1, and T2, and analysed as the baseline score and as the change from T0 to T1 and from T0 to T2. The questionnaire was completed independently at the clinic without parental assistance, although clinical staff were available to answer questions if needed.

Motivation, expectations, quality of care and attention, pain and discomfort, and satisfaction with treatment outcome

Questionnaires adapted from Feldmann et al.[43,44] were used to assess motivation, expectations, quality of care and attention, pain and discomfort, and satisfaction with treatment outcome. They also included items on teasing and oral hygiene. These questionnaires are hereafter referred to as 'Feldmann's questionnaires'. Each item was rated on a ten-box end-anchored scale. Before use, the adapted versions were piloted on ten adolescents not participating in the study, which led to minor clarifications in wording. Feldmann's questionnaires were administered at T0, T1, and T2 in time-point-specific versions and analysed as scores at each time point.

An overview of the outcomes assessed in each paper is presented in Table 4.

Table 4. Overview of outcome variables assessed in Papers I–IV

	Paper			
Outcome	I	II	III	IV
wPAR	✓			
LII	✓			
Dental arch width	✓			
Incisor inclination and position	✓			
Treatment time	✓			
OHRQoL		✓		
Motivation, expectations, experience, satisfaction		✓		
Reliability and agreement of the MPR based measurement protocol			✓	
Alveolar bone level and fenestrations				✓

Abbreviations: wPAR, weighted Peer Assessment Rating; LII, Little's Irregularity Index; OHRQoL, oral health-related quality of life; MPR, multiplanar reconstruction.

Outcome assessment

- **Paper I:** All study casts and digital models were analysed by one rater (LBM). Cephalometric measurements were made by an independent orthodontist with four years' experience, who was otherwise not involved in the CROWDIT project.
- **Paper II:** The questionnaires were self-reported and data entry was performed by one person (LBM). The clinical and occlusal variables reported alongside the questionnaire outcomes were assessed as described for Paper I.
- **Paper III:** The three raters (KJ, HC, LBM), all co-authors, were calibrated on a set of CBCT scans not included in the study. All three assessed marginal bone levels for the interrater assessment, and two (HC and LBM) registered fenestrations. The least experienced rater (LBM) repeated all measurements and registrations after a minimum of four weeks for intrarater assessment, on the assumption that more experienced raters would achieve equal or higher reliability.
- **Paper IV:** One rater (LBM) trained in the protocol and whose inter- and intrarater reliability had been evaluated (in Paper III), assessed all marginal bone levels and fenestrations. Study casts, digital models, and cephalometric radiographs were assessed as described for Paper I.

Blinding

Given the visible differences between the two appliance systems, neither the participants nor the treating orthodontists could be blinded to the allocation. Blinding was applied at the assessment stage: all material and data were pseudonymised before evaluation, so that assessors were unaware of group allocation. However, the time point could not be blinded.

Method error

In Paper I and for objective treatment outcomes in Paper II, intra- and interrater reliability was assessed using the intraclass correlation coefficient (ICC; two-way mixed effects model, absolute agreement, single measurement) for cephalometric measurements, alignment, space discrepancy, wPAR ratings, and 3D model measurements. Paper III provides the reliability and agreement evaluation of the method used in Paper IV (see Statistical analyses Paper IV below). ICC values below 0.50 were considered to indicate poor reliability, 0.50–0.75 moderate, 0.75–0.90 good, and above 0.90 excellent reliability.[111]

Sample size

Enrolment was halted at 132 participants because of the COVID-19 pandemic and concurrent changes to the regulations regarding eligibility for free orthodontic care in a region that included two participating clinics.

- **Paper I:** 65 participants per group, 130 in total, were needed to detect a mean difference of 2.5 PAR points, assuming standard deviations of 4.27 and 5.56,[118] two-sided t-test, 80% power, and $\alpha = 0.05$.
- **Paper II**: no formal sample size calculation was possible for the OHRQoL outcome, as no prior data existed for this population and instrument when CROWDIT began. All enrolled participants were therefore included, and the results may serve as a basis for estimating sample size in future studies.
- **Paper III:** a sample of 48 participants was required to estimate an ICC of 0.80 with three raters, a 95% CI width of 0.20 and 80% probability.[119]
- **Paper IV:** 23 patients per group were required to detect a 1 mm difference in buccal ABL-CEJ at the mandibular central incisor, based on standard deviations from previous non-extraction studies (PSLB: 1.06 mm[120]; CB: 1.26 mm[121]), a two-sided t-test, at 80% power, and $\alpha = 0.05$.

Statistical analyses

All analyses were performed in IBM SPSS Statistics for Windows (versions 28.0.1.1 to 31.0.1.0, Armonk, USA), in consultation with a statistician.

Descriptive statistics comprised means with standard deviations (SD), medians, ranges, and frequencies with percentages, as appropriate. Normality was assessed with the Shapiro–Wilk test and Q-Q plots. Effect sizes were expressed as Cohen's d for parametric tests and as r ($Z/\sqrt{N}$) for non-parametric tests.[100] All tests were two-sided.

Paper I

Intragroup changes were assessed with paired samples t-tests and intergroup differences with independent-samples t-tests. Two-way ANOVA was used to control for the effect of clinic on the comparison between appliance systems, with residuals tested for normality. Interaction effects were managed by stratifying the data by clinic and by conducting a one-way ANOVA within each. Where Levene's test for equality of variances was significant, adjusted t-test results were used and a $\log_{10}$-transformed variable vas used for the ANOVA; where normality was not met, or Levene's test remained significant after transformed data, a Mann–Whitney U exact test was applied per clinic. wPAR outcomes were analysed by intention-to-treat (ITT) with last observation carried forward (LOCF), complemented by per protocol analyses, which were also used for the secondary outcomes. Statistical significance was set at $P < 0.05$.

Paper II

Given the ordinal, non-normally distributed data, intragroup differences were assessed with the Wilcoxon signed-rank test and intergroup differences with the Mann–Whitney U test. Exploratory correlations were examined with Spearman's rank correlation, following Feldmann et al.[44]. Baseline demographics and clinical characteristics were also compared with the independent-samples t-test, Mann-Whitney U test, and the chi-square (χ^2) test for continuous, ordinal and categorical variables, respectively. The effect size, r, was interpreted according to Cohen[122]. Statistical significance was set at $P < 0.05$, except in the exploratory analyses, where Bonferroni-adjusted thresholds ($P < 0.0011$–0.0015) were applied.

For both CPQ11–14 and Feldmann's questionnaires, missing item responses were imputed using the item median. Two sensitivity analyses were conducted. As a printing error had omitted two CPQ11–14 items, the first used the short-

form regression version (RSF16), which does not include either of the omitted items and correlates strongly with the full version.[123] The second was restricted to complete questionnaires to assess the influence of imputation.

Paper III

The reliability of linear alveolar bone level measurements was quantified with ICCs (two way random-effects model, absolute agreement, single measurement/rater, with 95% CI).[110,111] Each measurement site (buccal and palatal/lingual surfaces of the second premolars, canines, and central incisors in the first and third quadrants) was evaluated separately at T0 and T2. ICCs were also calculated for pooled measurements by surface (buccal; palatal/lingual) for comparison with previous research, and for all sites pooled per CBCT unit for descriptive purposes.

Intrarater agreement was assessed with Bland–Altman plots[113] for pooled buccal and pooled palatal/lingual measurements in each jaw at T0 and T2, and systematic error was tested with paired-samples t-tests per site and time point. The influence of outliers on the limits of agreement (LoA) was assessed in a sensitivity analysis excluding observations exceeding 3 SD.

Random error was quantified with Dahlberg's formula[112] for each measurement site, tooth, and time point, for both intra- and interrater assessments, and for pooled buccal and palatal/lingual measurement sites at each time point for comparison with previous research. The standard error of measurement (SEM) was derived from the mean square error of the intrarater ICC ANOVA[100] for each site, tooth, and time point, and the corresponding minimal detectable change (MDC_{95}) was calculated for each site and tooth. Agreement in fenestration detection was expressed as intra and interrater percentage agreement. Statistical significance was set at $P < 0.05$.

Paper IV

As some variables deviated from normality, non-parametric methods were applied. All comparisons were made at tooth surface level, with one observation per patient per test.

Intergroup differences in ABL-CEJ change were evaluated with the Mann–Whitney U test (exact test), and the occurrence of fenestrations at T2 with Pearson's chi-square test (or Fisher's exact test). Changes from T0 to T2 in the total sample were examined with the Wilcoxon signed-rank test for ABL-CEJ

and McNemar's test was used to compare the occurrence of fenestrations at T0 and T2. As a sensitivity analysis, post-treatment ABL-CEJ was compared between treatment groups with ANCOVA, adjusting for baseline ABL-CEJ, voxel size and either transverse arch width (premolars and canines) or incisor inclination and position (incisors), after assumptions had been assessed. The significance level was set at $P < 0.05$; a Bonferroni-corrected threshold of $P < 0.00125$ was applied to ABL-CEJ outcomes. For descriptive purposes, transitions of surfaces within or between ABL-CEJ and fenestration categories from T0 to T2 were assessed. The categories for ABL-CEJ distances were <2 mm, 2–<4 mm, 4–<6 mm, 6–<8 mm, or ≥8 mm, and each category divided by the presence or absence of fenestrations (FEN/no FEN).

Ethical approval

The CROWDIT project was approved by the Regional Ethical Review Board in Lund (Dnr 2014/647, 30 October 2014) and by the radiation protection committees at Skåne University Hospital (No. SSFo2014-051, 19 November 2014), the County of Dalarna (10 February 2015), and Region Jämtland Härjedalen (Dnr RS/1084/2016, 31 May 2016). The study was conducted in accordance with the Declaration of Helsinki.[124]

RESULTS

Participants and study flow

Recruitment took place from 2016 to 2020. Of 185 adolescents assessed for eligibility, 132 were randomised to treatment: 70 to CB and 62 to PSLB.

Treatment outcomes and treatment time

Baseline demographic, clinical, and cephalometric characteristics were comparable between the groups (Table 5). Seven of the 132 randomised participants were lost to follow-up (Figure 11).

Peer Assessment Rating index and alignment

In both groups, the mean reduction in wPAR, the primary outcome, exceeded 22 points, a threshold for ‘greatly improved’. The score reductions from T0 to T2 were −24.07 (SD 12.12) wPAR points in the CB group and −22.11 (SD 11.18) in the PSLB group, corresponding to approximately a 78% and 74% reduction, respectively. The mean intergroup difference (MD) in score reduction was −1.96 wPAR points (95% CI −5.99 to 2.07), and no statistically significant intergroup difference was observed.

Similarly, alignment assessed with LII showed no significant intergroup difference, with comparable upper and lower LII reductions in both groups (CB upper/lower: −9.02 (SD 3.68)/−5.95 (SD 2.72); PSLB upper/lower: −8.44 (SD 3.07)/−5.29 (SD 2.92)).

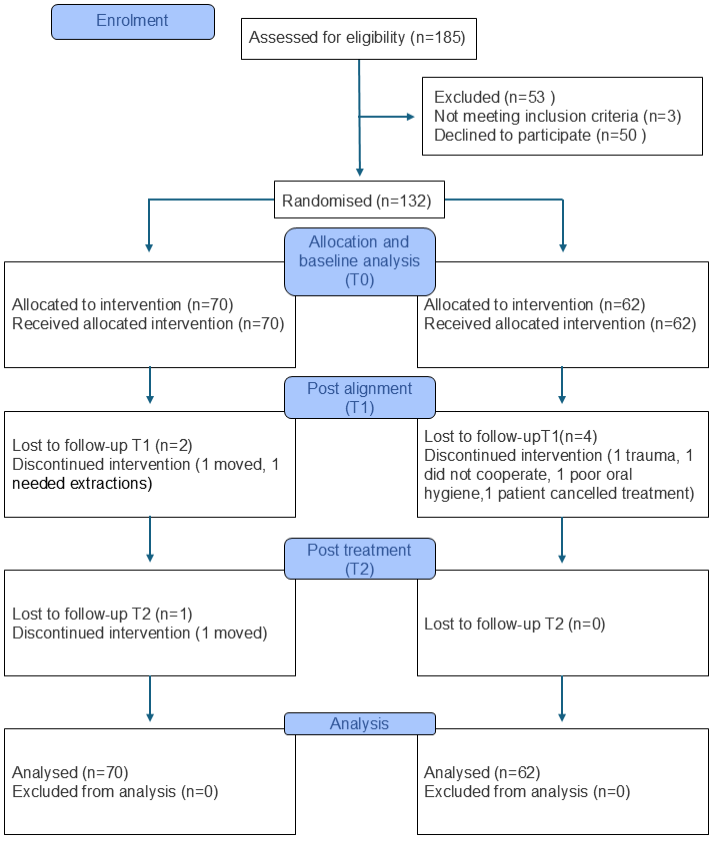

Figure 11. CONSORT 2025 flow diagram showing the progress of participants through the phases of the trial (Paper I). Abbreviations: CB, conventional bracket system; PSLB, passive self-ligating bracket system; n, number of patients. Adapted from Hopewell et al. [125] licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

Dental arch expansion and incisor inclination

Distinct expansion patterns were observed during alignment. Mean differences (MD) are expressed as CB minus PSLB. The PSLB group showed greater lateral expansion than the CB group between the maxillary canines (MD −1.35 mm; 95% CI: −2.05 to −0.66) and first premolars (MD −1.21 mm, 95% CI: −1.76 to −0.66); and between mandibular first (MD −0.75 mm, 95% CI −1.37 to −0.12) and second premolars (MD −0.76 mm, 95% CI: −1.39 to −0.13) (Figure 12).

In contrast, the CB group showed greater mandibular incisor proclination than the PSLB group, both relative to the NB line (MD 2.28°; 95% CI: 0.45 to 4.10) and to the mandibular plane (MD 2.23°; 95% CI: 0.42 to 4.03) (Figure 13). The

change in interincisal angle also decreased more in the CB group (MD −4.97° (95% CI −8.57 to −1.36).

No statistically significant intergroup differences in changes in dental arch width or incisor inclination were observed from T0 to T2.

Table 5. Baseline demographic, clinical and cephalometric characteristics per treatment group and for the total sample (n = 132)

Variable	CB	PSLB	Total sample
Age in years (SD)	14.61 (1.45)	14.73 (1.48)	14.67 (1.46)
Sex girls/boys (n)	39/31	34/28	73/59
IOTN-DHC grade 3/4/5 (n)	14/56/0	18/43/1	32/99/1
Overjet, mean in mm (SD)	3.59 (1.60)	3.58 (1.84)	3.58 (1.71)
Overbite, mean in mm (SD)	3.35 (1.62)	3.90 (1.88)	3.61 (1.76)
Class I/II/III (n)	48/21/1	39/23/0	87/44/1
Transverse relationship: Normal/crossbite/scissor bite/crossbite and scissor bite (n)	25/39/6/0	32/25/4/1	57/64/10/1
Space discrepancy upper jaw in mm (SD)	−3.17 (2.90)	−2.61 (2.34)	−2.91 (2.66)
Space discrepancy lower jaw in mm (SD)	−2.79 (2.30)	−2.02 (2.32)	−2.43 (2.33)
Maxillary transversal width, mean in mm (SD)			
13–23 cusp tips	34.07 (2.61)	33.71 (2.90)	33.90 (2.75)
14–24 buccal cusp tips	39.66 (2.68)	39.76 (2.34)	39.71 (2.52)
15–25 buccal cusp tips	44.92 (2.97)	45.05 (2.82)	44.98 (2.89)
16–26 mesiobuccal cusp tips	50.59 (2.99)	50.24 (2.97)	50.43 (2.98)
Mandibular transversal width in mm (SD)			
33–43 cusp tips	25.69 (2.33)	26.16 (1.88)	25.90 (2.14)
34–44 buccal cusp tips	32.90 (2.46)	33.38 (2.55)	33.12 (2.51)
35–45 buccal cusp tips	38.20 (2.93)	38.73 (2.63)	38.45 (2.79)
36–46 mesiobuccal cusp tips	44.40 (2.91)	44.29 (3.07)	44.35 (2.98)
Cephalometric analysis			
ANB, ° (SD)	2.57 (2.23)	2.74 (2.24)	2.65 (2.23)
SNA, ° (SD)	81.65 (3.87)	81.74 (3.13)	81.69 (3.52)
SNB, ° (SD)	79.08 (3.90)	79.01 (3.22)	79.04 (3.58)
ML/NL, ° (SD)	24.41 (5.91)	23.88 (5.31)	24.16 (5.62)
Upper incisor to NA, ° (SD)	21.51 (7.03)	19.27 (9.86)	20.46 (8.51)
Lower incisor to NB, ° (SD)	23.59 (7.24)	22.01 (6.96)	22.84 (7.13)
Upper incisor to NA, mm (SD)	4.44 (2.64)	3.47 (3.53)	3.98 (3.12)
Lower incisor to NB, mm (SD)	4.02 (2.70)	3.37 (2.47)	3.71 (2.60)
ILs/NL, ° (SD)	109.52 (6.71)	107.70 (9.33)	108.67 (8.07)
ILi/ML, ° (SD)	93.74 (7.47)	92.43 (7.47)	93.13 (7.47)
Interincisal angle, ° (SD)	132.33 (10.99)	135.99 (14.22)	134.05 (12.69)

Values are presented as mean (SD) for continuous variables and as frequencies (n) for categorical variables. Abbreviations: CB, conventional brackets; PSLB, passive self-ligating brackets; SD, standard deviation; IOTN, Index of Orthodontic Treatment Need; DHC, dental health component; ML/NL, angle between the mandibular line and the nasal line; ILs/NL, angle between the long axis of the upper incisor to nasal line; ILi/ML, angle between the long axis of the lower incisor to the mandibular line.

Within-group changes

Within both groups, all changes from T0-T1 and T0-T2 were statistically significant (P <0.001), with the exceptions of lateral expansion between the maxillary canines in the CB group (T1-T0 mean 0.01 mm, SD 1.80; T2-T0 mean 0.41 mm, SD 1.90), and between the mandibular first molars in both groups (CB: T1-T0 mean -0.19 mm, SD 1.24; T2-T0 mean 0.06 mm, SD 1.65; PSLB: T1-T0 mean 0.27 mm, SD 1.43; T2-T0 mean -0.14 mm, SD 2.54).

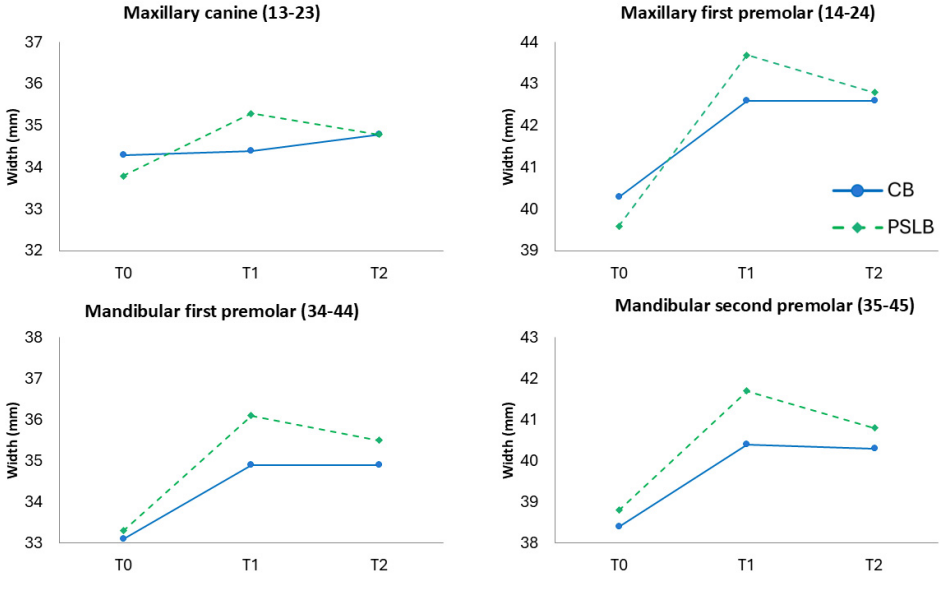

Figure 12. Transverse widths (mm) at baseline (T0), post-alignment (T1) and post-treatment (T2) for conventional (CB) and passive self-ligating bracket (PSLB) groups, measured between maxillary canines and first premolars and between the mandibular first and second premolars. The intergroup differences at T1 were statistically significant (P <0.05).

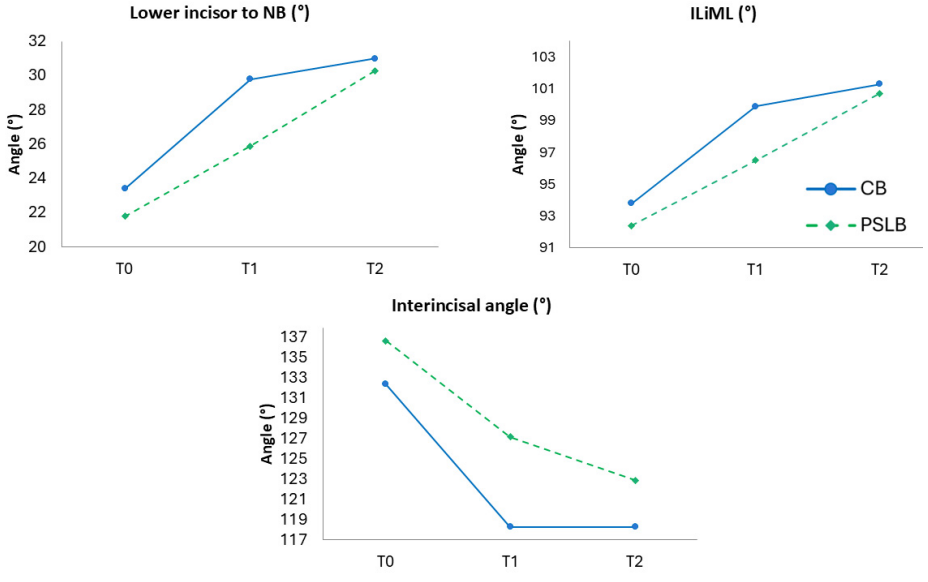

Figure 13. Incisor inclination (°) at baseline (T0), post-alignment (T1) and post- treatment (T2) for CB and PSLB at lower incisor to the NB line (upper left), lower incisor to the mandibular plane (upper right), and between upper and lower incisors (bottom). The intergroup differences at T1 were statistically significant (*P* <0.05).

Treatment time

Time to alignment was 12.12 (SD 4.98) months in the CB group and 13.63 (SD 5.59) months in the PSLB group (total sample 12.81, SD 5.30), with no significant intergroup difference (MD –1.51 months, 95% CI –3.42 to 0.40, *P* = 0.121).

Total treatment time was 21.74 (SD 7.57) months in the CB group and 24.35 (SD 7.10) months in the PSLB group (total sample 22.94, SD 7.44). This difference was not statistically significant (MD –2.61 months, 95% CI –5.23 to 0.02, *P* = 0.051).

One PSLB outlier (57.63 months total treatment time) was excluded from these analyses after consultation with a statistician and consensus within the research group; an analysis including this patient is reported in Paper I.

Post hoc subgroup analysis on treatment time by severity of crowding

Participants were divided according to the severity of crowding at baseline (LII ≤ 5 mm or >5 mm).

Among patients with mild crowding (LII ≤5 mm), no differences in treatment time were observed between the groups (Table 6).

Among patients with more pronounced crowding (LII >5 mm), total treatment time was significantly shorter in the CB group than in the PSLB group, in both the maxilla and the mandible. Time to alignment was also significantly shorter in the CB group, but only in the mandible (Table 6).

This analysis was performed for the thesis summary and was inspired by previous research[14]. However, the analysis was not prespecified, and the trial was not powered for treatment time. Furthermore, only three patients per group had maxillary baseline LII ≤5 mm. The findings should therefore be interpreted with caution and be regarded mainly as hypothesis-generating.

Table 6. Exploratory subgroup analysis of time to alignment and total treatment time in months, mean (SD), by baseline Little's Irregularity Index (LII; ≤5 or >5)

Time to alignment Months (SD)	Maxillary LII (≤5/>5 mm)	n	LII ≤ 5	n	LII > 5
	PSLB	3	10.75 (6.36)	52	13.80 (5.57)
	CB	3	7.68 (1.64)	60	12.04 (4.63)
	Intergroup Δ	–3.08, *P* = 0.462		–1.76, *P* = 0.071	
	Mandibular LII (≤5/>5 mm)	n	LII ≤ 5	n	LII > 5
	PSLB	22	12.18 (4.26)	32	14.50 (6.27)
	CB	14	13.98 (6.98)	51	11.61 (4.22)
	Intergroup Δ	1.80, *P* = 0.341		**–2.88, *P* = 0.026**	
Total treatment time Months (SD)	Maxillary LII (≤5/>5 mm)	n	LII ≤ 5	n	LII > 5
	PSLB	3	21.44 (5.16)	53	24.36 (7.17)
	CB	3	22.77 (14.33)	62	21.51 (7.22)
	Intergroup Δ	1.33, *P* = 0.888		**–2.85, *P* = 0.037**	
	Mandibular LII (≤5/>5 mm)	n	LII ≤ 5	n	LII > 5
	PSLB	22	23.31 (6.68)	34	24.94 (7.47)
	CB	14	25.45 (9.33)	53	20.77 (6.80)
	Intergroup Δ	2.14, *P* = 0.427		**–4.18, *P* = 0.009**	

Note: Intergroup difference was calculated as CB minus PSLB. Independent-samples t-test, per protocol analysis, excluding one PSLB outlier with a treatment time of 57.63 months. *P*-values in bold are statistically significant (***P* <0.05**). Only three participants per group had maxillary baseline LII ≤ 5 mm, and that comparison is not interpretable (shown in grey). These analyses were not prespecified.
Abbreviations: LII, Little's Irregularity Index; CB, conventional bracket system; PSLB, passive self-ligating bracket system; SD, standard deviation; Δ, intergroup difference.

Dental patient-reported outcomes

In total, 132 participants were included (Figure 14). The number of analysed CPQ11–14 and Feldmann's questionnaires is presented in Table 7. Total missing item-rates for the CPQ11–14 questionnaires across time points ranged between 1.10% and 11.4%, and from 0.7 to 2.9% for Feldmann's questionnaires.

Among the collected questionnaires, the proportion of missing items was 0.7% (T0), 1.5% (T1), and 0.8% (T2) for CPQ11–14, and 0.7% (T0 and T1) and 2.9% (T2) for Feldmann's questionnaires. The 'not applicable' option was selected for 1.1%–1.7% of items across time points, most often for item 6 (bad breath; 8.4%–13.6%), item 9 (mouth breathing; 3.3%–7.6%), and item 34 (difficulty playing an instrument; 13.3%–24.4%).

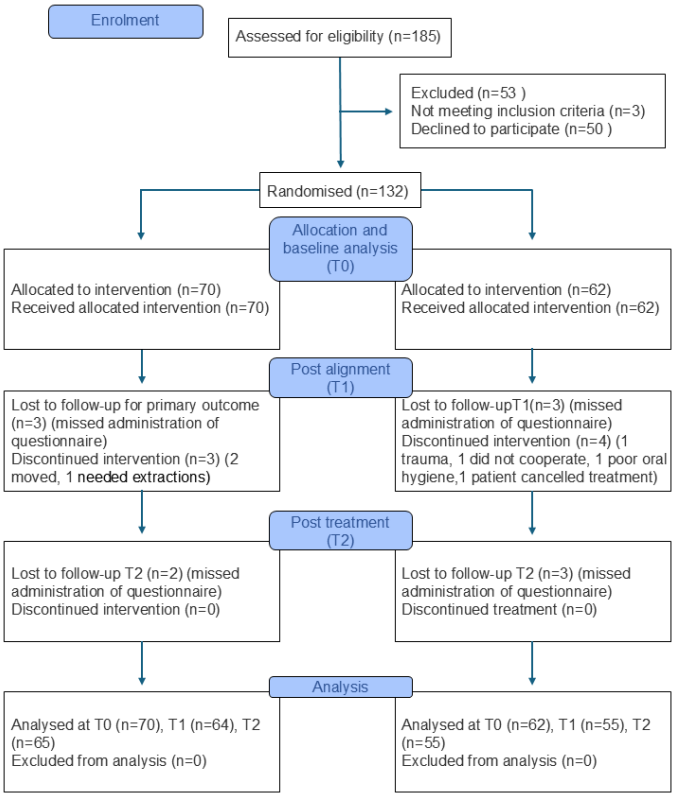

Figure 14. CONSORT 2025 flow diagram showing the progress of participants through the phases of the trial (Paper II). Abbreviations: CB, conventional bracket system; PSLB, passive self-ligating bracket system; n, number of patients. Adapted from Hopewell et al.[125] licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

Table 7. Reasons for missing questionnaires

Collected questionnaires	Missing (CB/PSLB)	Not administered	Discontinued treatment (n)	Patient moved
CPQ11–14				
132 at T0	0	0	0	0
119 at T1	13 (6/7)	6	5	2
120 at T2	12 (5/7)	5	5	2
Feldmann's questionnaires				
131 at T0	1 (1/0)	1		
118 at T1	14 (7/7)	7	5	2
118 at T2	14 (8/6)	7	5	2

Reasons for discontinued treatment: trauma (1), poor oral hygiene (1), patient discontinued treatment/did not cooperate (2), needed extractions (1)

Oral health-related quality of life

In the total sample, CPQ scores increased during alignment, indicating poorer OHRQoL at T1, and then decreased to below baseline levels at T2 (median change between T0 and T2: 4.5, r = 0.37, P <0.001; Figure 15). Total CPQ scores did not differ significantly between the treatment groups at any time point.

Scores in the OS and FL domains also increased during alignment and then improved beyond baseline after treatment, whereas EW improved throughout treatment and SW had improved by T2 (Figure 15).

The CB group had statistically significantly higher SW scores at baseline, indicating poorer social well-being in the CB group than in the PSLB group (median 2 vs 1, r = 0.21, P = 0.016). The OS scores improved more in the CB group than in the PSLB group from T0 to T2 (median 1; r = 0.25, P = 0.005). All other differences between treatment groups were NS.

Girls reported poorer baseline OHRQoL than boys (total CPQ median 18 vs 12; r = 0.18, P = 0.035), reflected primarily in higher baseline EW score (median 4 vs 1; r = 0.30; P < 0.001). Girls also showed greater EW improvement over the treatment period (median 3 vs 0; r = 0.23, P = 0.010), and at T2, no sex differences remained in total CPQ or any domain.

Sensitivity analyses using the CPQ11–14 16-item short-form regression version (RSF16) and complete questionnaires indicated that the omission of two items and the imputation of missing responses had minimal impact on effect sizes and statistical significance.

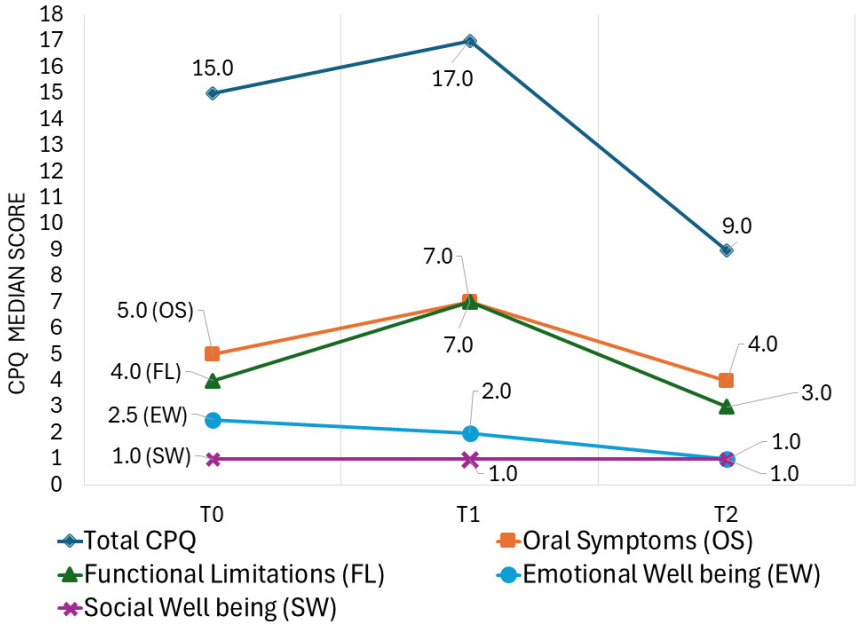

Figure 15. Child Perceptions Questionnaire 11–14 (CPQ11–14) total and domain median scores at baseline (T0), post-alignment (T1), and post-treatment (T2) for the total sample. Note: all changes in total and domain scores were statistically significant (Wilcoxon signed-rank test; $P \leq 0.027$) except for the change in SW between T0 and T1. Adapted from Bokander Matilainen et al., 2026 [126] licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

Motivation, expectations, and satisfaction

Scores for motivation and expectations were favourable or high, and post-treatment satisfaction was high regardless of appliance system. The CB group reported higher scores on three items (item 2 at T1, items 3 and 4 at T2), with mean intergroup differences below 0.5 points.

Before treatment, no intergroup differences were statistically significant. Patients reported high motivation (item 4, mean 8.32) and a strong belief that treatment would benefit their teeth (item 5, mean 8.86). They also wished to change the appearance of their teeth (item 2, mean 8.19), but reported comparatively little concern about their appearance while wearing braces (item 10, mean 3.36). Expectations were favourable, with low to midscale scores for expecting that wearing braces would be difficult and for worrying about having orthodontic treatment (items 8–9, means 4.66 and 2.89, respectively).

After alignment, regret about having started treatment was low (item 13, mean 1.56) and treatment fatigue was low to mid-scale (item 14, mean 3.08). Patients reported feeling properly informed and cared for at both scheduled revisits and acute appointments (items 5–6, means ~9.5), and teasing was minimal (item 12, mean 1.25).

The CB group reported higher scores than the PSLB group for 'braces working as expected' (item 2, mean 9.22 vs 9.09, r = 0.21, *P* = 0.02; Figure 16).

Following treatment, satisfaction with the changes achieved (item 3, mean 9.64) and with dental appearance (item 4, mean 9.42) was high, and regret about having started treatment was low (item 5, mean 1.63). In contrast, willingness to make the same decision again scored lower (item 6, mean 6.66), although the median score was 9, indicating a skewed distribution. Perceived quality of care and attention was high (items 7–10, means 8.78–9.75), though information on expected treatment duration was rated somewhat lower (item 11, mean 8.12). Pain was recalled at mid-scale, higher at bonding (item 12, mean 5.5) than at debonding (item 14, mean 3.03) and teasing related to wearing braces was minimal (item 17, mean 1.27). Two intergroup differences with small effect sizes favoured the CB group: satisfaction with the changes achieved (item 3, r = 0.25, *P* = 0.006) and with dental appearance (item 4, r = 0.20, *P* = 0.029; Figure 16).

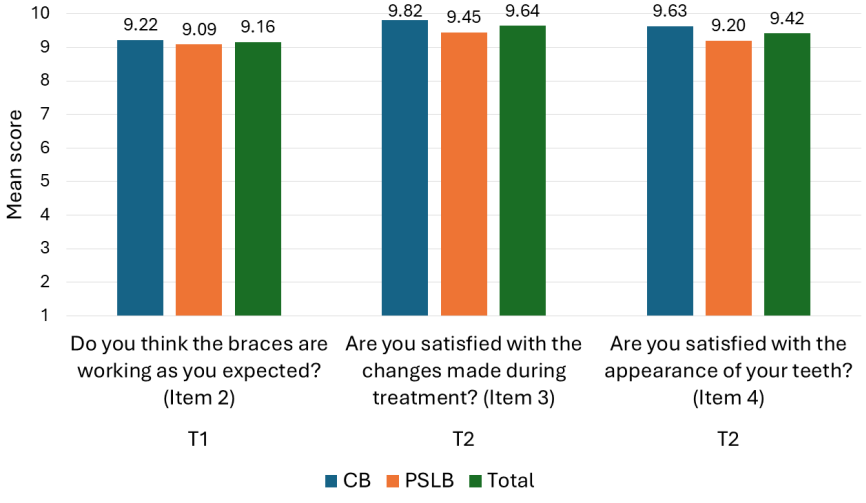

Figure 16. Items from Feldmann's questionnaires that showed statistically significant intergroup differences, registered at T1 (item 2) and T2 (items 3 and 4). The bars show the mean score per item by group: CB (blue), PSLB (orange), and total sample (green). Abbreviations: T1, post-alignment; T2, post-treatment; CB, conventional bracket group; PSLB, passive self-ligating bracket group.

Factors associated with treatment satisfaction

After Bonferroni correction for multiple comparisons, five correlations with satisfaction with the treatment outcome remained statistically significant (Figure 17).

Before treatment: patients who expected wearing braces to be difficult were less satisfied with their dental appearance afterwards ($\rho = -0.298$, $P = 0.001$).

At T1: treatment fatigue was positively correlated with willingness to make the same decision (to undergo treatment) again ($\rho = 0.332$, $P < 0.001$).

At T2: patients who believed that treatment had been good for their teeth were more satisfied both with the changes achieved ($\rho = 0.525$, $P < 0.001$) and with the appearance ($\rho = 0.342$, $P < 0.001$). Patients who felt that the treatment had worked as expected were also more satisfied with the changes made ($\rho = 0.330$, $P < 0.001$).

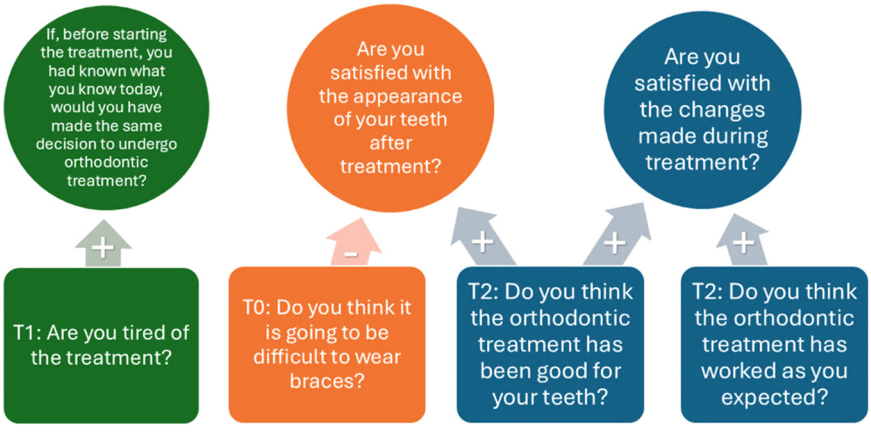

Figure 17. Items (boxes) significantly correlated with satisfaction with treatment outcome (circles) after Bonferroni correction, assessed with Spearman's rank correlation. Green circle: 'If, before starting the treatment, you had known what you know today, would you have made the same decision to undergo orthodontic treatment?' Orange circle: 'Are you satisfied with the appearance of your teeth after treatment?' Blue circle: 'Are you satisfied with the changes made during treatment?' Abbreviations: T0, baseline; T1, post-alignment; T2, post-treatment.

Reliability and agreement of the alveolar bone measurement protocol

A random sample of 48 adolescents (mean age 14.4 years) was included. Each contributed with two CBCT scans from T0 and T2 (n = 96). The CBCT scans were acquired at three clinics using five CBCT units representing four manufacturers. After random selection, one T0 scan was excluded owing to motion artefacts, and two second premolars owing to incomplete eruption, leaving 1136 measurement sites (4544 linear measurements and 3408 fenestration assessments).

Linear bone-level measurements

Intrarater reliability

Surface-specific ICC estimates ranged from moderate to excellent: from 0.639 to 0.894 at T0 and from 0.571 to 0.950 at T2; with 95% CIs ranging from 0.346 to 0.972. ICCs for pooled sites ranged from good to excellent at both time points: the buccal ICC was 0.840 (95% CI 0.802–0.871) at T0 and 0.910 (95% CI 0.888–0.928) at T2; the palatal/lingual ICC was 0.813 (95% CI 0.769–0.849) at T0 and 0.856 (95% CI 0.822–0.884) at T2.

Interrater reliability

The ICC for pooled sites was moderate at both time points: buccal ICC was 0.600 (95% CI 0.537–0.658) at T0 and 0.729 (95% CI 0.616–0.805) at T2; the palatal/lingual ICC was 0.660 (95% CI 0.604–0.711) at T0 and 0.680 (95% CI 0.495–0.789) at T2. Buccal and palatal/lingual surface-specific ICC estimates ranged from poor to good: from 0.327 to 0.679 at T0 and from 0.324 to 0.753 at T2.

Intrarater Bland–Altman analysis

Bland–Altman analysis showed minimal systematic bias overall, with mean differences clustering close to zero. Two sites reached statistical significance on paired-samples t-tests: 15p and 11p, both at T2 (mean differences of –0.11 mm, $P = 0.037$, and –0.16 mm, $P = 0.016$, respectively). Limits of agreement differed across sites and time points, being narrowest for maxillary measurements at baseline, and were influenced by outliers. A sensitivity analysis excluding observations exceeding 3 SD narrowed the LoA to -0.89 to 0.86 mm at T0 and -

1.01 to 0.90 mm at T2, performed solely to evaluate outlier influence rather than as a substitute for the primary analysis.

Intrarater and interrater agreement using Dahlberg's formula

Intrarater random error ranged from 0.19 to 0.71 mm at T0, and from 0.19 to 0.72 mm at T2, except at site 13b, where it reached 1.07 mm at T2. Interrater random error spanned a wider range, from 0.27 to 1.27 mm at T0 and from 0.23 to 1.87 mm at T2, except at site 13b, where it reached 2.54 mm at T2. Random errors for pooled measurements were 0.45 mm (T0) and 0.61 mm (T2) buccally, and 0.33 mm (T0) and 0.44 mm (T2) lingually.

Table 8. Standard error of measurement (SEM) in mm at T0 and T2 by site (one rater, LBM)

	15b	15p	13b	13p	11b	11p	35b	35l	33b	33l	31b	31l
SEM T0	0.32	0.26	0.35	0.37	0.23	0.19	0.31	0.23	0.70	0.47	0.60	0.37
SEM T2	0.41	0.26	1.08	0.50	0.19	0.32	0.46	0.29	0.48	0.33	0.65	0.73

Standard error of measurement and minimal detectable change

The SEM values ranged from 0.19 to 1.08 mm, and MDC_{95} ranged from 0.53 to 1.94 mm (Table 8; Figure 18).

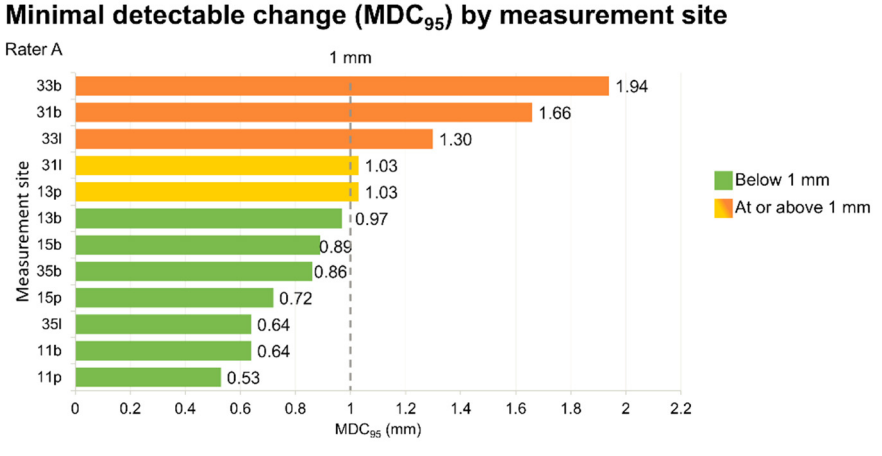

Figure 18. Minimal detectable change at 95% confidence (MDC_{95}, mm) by measurement site, based on repeated intrarater measurements. Sites are ordered by increasing MDC_{95}.

Fenestrations

Intrarater percentage agreement exceeded 81% and interrater agreement exceeded 74% (Figure 19).

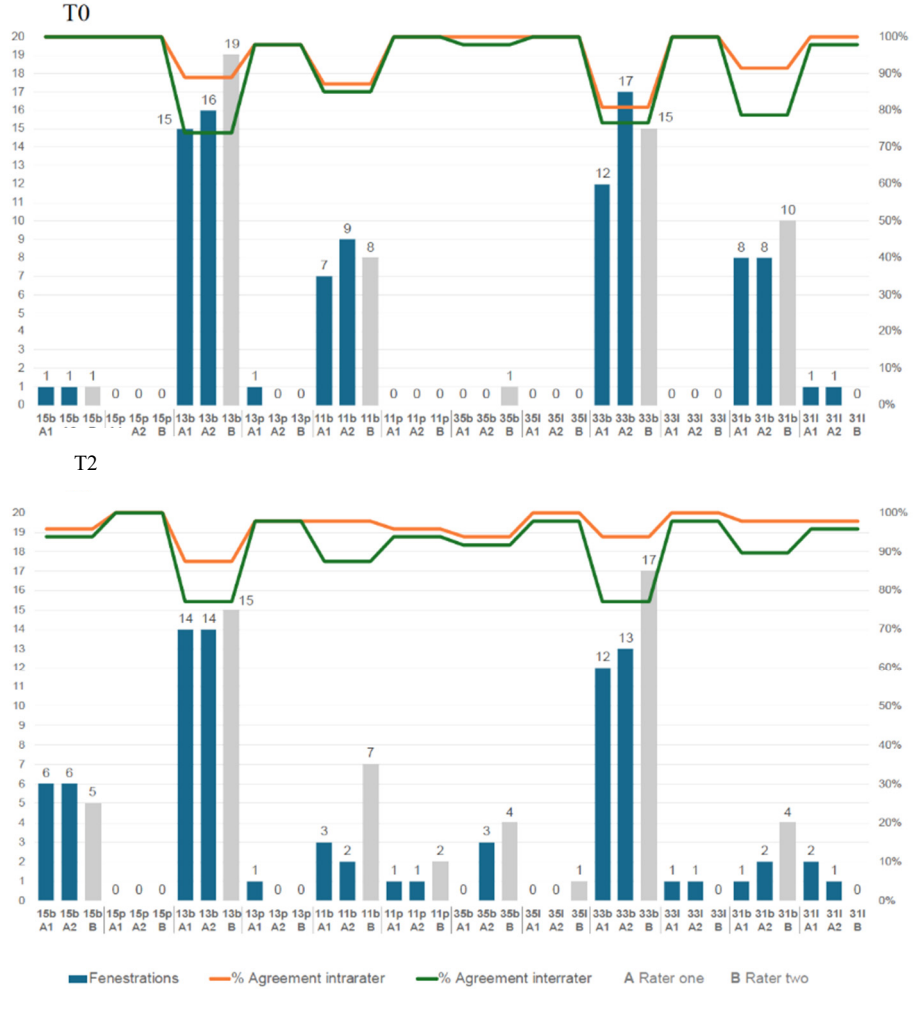

Figure 19. Number of fenestrations (bars, left y-axis) identified by rater A at the initial (A1) and repeated (A2) assessments and by rater B, at baseline (T0) and post-treatment (T2). The lines show the corresponding intrarater (A1 vs A2, orange) and interrater (A1 vs B, green) percentage agreement (right y-axis). Adapted from Bokander Matilainen et al., 2026[114] licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

Alveolar bone outcomes

Of the 75 participants randomised at the three clinics, 61 (33 CB, 28 PSLB) were analysed, and attrition was similar in both arms (seven per group; Figure 20). In total, 2434 teeth and 4866 surfaces were analysed, and 14 surfaces (0.3%) were excluded, either because canines were positioned high and labially in the arch, overshadowing the buccal surfaces of adjacent laterals, or due to incomplete eruption.

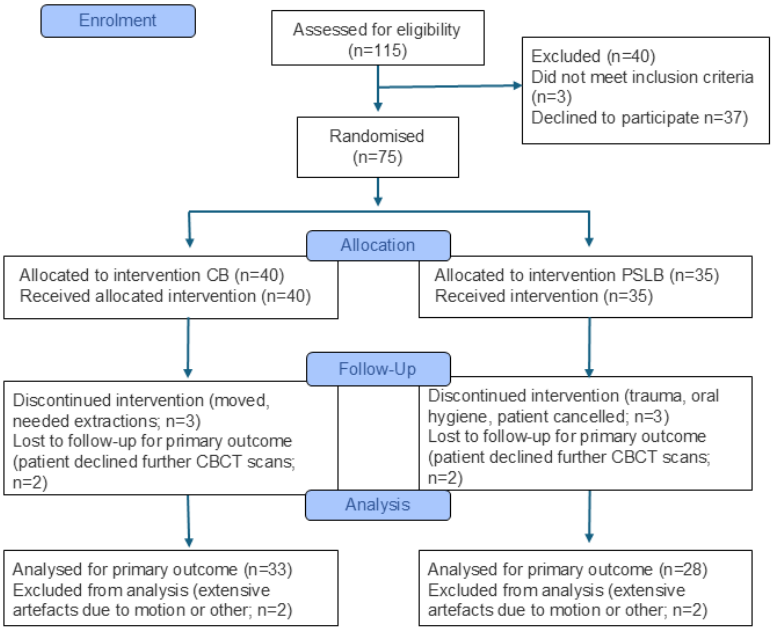

Figure 20. CONSORT 2025 flow diagram showing the progress of participants through the phases of the trial (Paper IV). Abbreviations: CB, conventional bracket system; PSLB, passive self-ligating bracket system; n, number of patients. Adapted from Hopewell et al.[125] licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

Alveolar bone level assessment

The intergroup differences in ABL-CEJ change from T0 to T2 were not significant, which was supported by the ANCOVA sensitivity analysis.

In the total sample, all patients had at least one surface with an ABL-CEJ increase of at least 1 mm; 84% had at least one surface with ≥ 2 mm, 69% with ≥ 4 mm, 36% with ≥ 6 mm, and 20% with ≥ 8 mm. Bone level reductions and effect sizes

were largest at the buccal surfaces of the mandibular incisors (r = –0.53 to –0.57). Bone loss was generally more extensive in the mandible, where it was greater buccally than lingually. Most changes remained statistically significant after Bonferroni correction (Table 9).

Table 9. ABL-CEJ (mm) change from T0 to T2 in the total sample by tooth surface

Tooth	Mean change	SD	r	*P*-value	Tooth	Mean change	SD	r	*P*-value
15b	–0.07	0.55	–0.07	0.463	25b	0.09	0.59	–0.08	0.399
15p	–0.23	0.41	–0.32	**<0.001**	25p	–0.10	0.41	–0.16	0.085
14b	–0.20	0.57	–0.22	0.012	24b	–0.21	0.46	–0.29	**<0.001**
14p	–0.34	0.62	–0.33	**<0.001**	24p	–0.24	0.71	–0.24	0.007
13b	–1.11†	2.07	–0.38	**<0.001**	23b	–0.61	1.29	–0.29	0.001
13p	–0.74	1.06	–0.46	**<0.001**	23p	–0.47	0.88	–0.34	**<0.001**
12b	–0.89†	1.21	–0.52	**<0.001**	22b	–0.69†	1.25	–0.42	**<0.001**
12p	–0.56†	0.76	–0.45	**<0.001**	22p	–0.25	1.27	–0.34	**<0.001**
11b	–0.29	0.53	–0.34	**<0.001**	21b	–0.16	0.59	–0.22	0.014
11p	–0.67†	1.00	–0.47	**<0.001**	21p	–0.71†	1.21	–0.48	**<0.001**
45b	–0.30	1.08	–0.21	0.018	35b	–0.33	0.81	–0.29	**0.001**
45l	–0.34	0.56	–0.37	**<0.001**	35l	–0.28	0.60	–0.32	**<0.001**
44b	–0.75	1.87	–0.37	**<0.001**	34b	–0.83	1.60	–0.38	**<0.001**
44l	–0.34	0.76	–0.28	0.001	34l	–0.47	0.94	–0.32	**<0.001**
43b	–1.09	2.53	–0.31	**<0.001**	33b	–0.95	1.80	–0.35	**<0.001**
43l	–0.60	0.84	–0.47	**<0.001**	33l	–0.54	1.13	–0.34	**<0.001**
42b	–2.58†	3.15	–0.53	**<0.001**	32b	–2.33†	2.75	–0.54	**<0.001**
42l	–0.86	1.98	–0.40	**<0.001**	32l	–0.79	1.50	–0.50	**<0.001**
41b	–2.25†	2.30	–0.57	**<0.001**	31b	–2.29†	2.25	–0.57	**<0.001**
41l	–1.21†	1.86	–0.46	**<0.001**	31l	–0.75	1.64	–0.29	**0.001**

Abbreviation: ABL–CEJ, distance from the alveolar bone level to the cementoenamel junction; mm, millimetre; T0, baseline; T2, post-treatment; b, buccal; p, palatal; l, lingual; SD, standard deviation. Note: The Wilcoxon signed-rank test was used to assess statistical significance, r, effect size; and unadjusted *P* -values are presented. Changes remaining significant after Bonferroni correction for multiple comparisons ($P < 0.00125$) are marked in bold. Surfaces not meeting the Bonferroni-adjusted significance threshold were 15b, 14b, 21b, 23b, 24p, 25bp, 44l, and 45b. † Mean change exceeding the MDC95 [Paper III]

Fenestrations

The occurrence of fenestrations after treatment did not differ significantly between the groups.

In the total sample, the proportion of patients with at least one fenestration decreased from 85% at T0 to 75% at T2. At the surface level (buccal and palatal/lingual), fenestrations were observed on 8% of surfaces at T0 and 5% at T2. The highest proportion at baseline was observed at the buccal surfaces of the mandibular lateral incisors (35%), and at T2 at the buccal surfaces of the

maxillary first premolars (19%). The occurrence was significantly lower at T2 than at T0 at the buccal surfaces of the mandibular incisors ($P \leq 0.027$), except at 31b ($P = 0.065$) (Figure 21).

Transition analysis of the buccal surfaces of the mandibular incisors showed that surfaces with fenestrations at T0 had shifted to a category without fenestration but with greater ABL-CEJ at T2. Some remained in the same category at both time points, whereas in others the fenestrations were no longer observed, without an increase in ABL-CEJ category. Overall, fewer surfaces transitioned into a fenestration category than out of one (Figure 22).

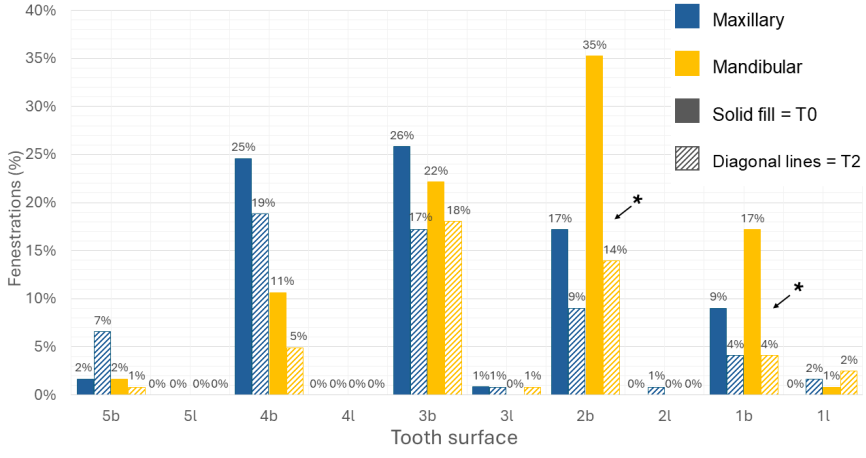

Figure 21. Proportion of surfaces with fenestrations (%) by tooth surface and jaw at baseline (T0) and post-treatment (T2). The proportion generally decreased or remained unchanged, with minor increases at a few surfaces, and was statistically significantly lower at T2 at the buccal surfaces of the mandibular lateral and central incisors ($P \leq 0.027$, except at 31b, $P = 0.065$). Abbreviations: b, buccal; l, lingual.

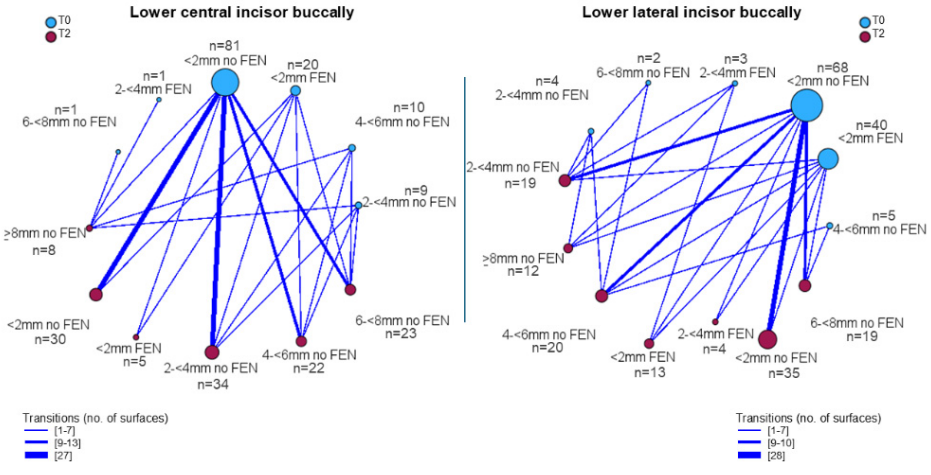

Figure 22. Transitions between combined alveolar bone level and fenestration categories from baseline (T0) to post-treatment (T2) at the buccal surfaces of the mandibular central and lateral incisors in the total sample (n = 244 surfaces). Categories combine ABL-CEJ ranges (e.g. <2 mm, 2 to <4 mm) with fenestration status (FEN or no FEN). Node area reflects the number of surfaces in each category at each time point, and line thickness reflects the number of surfaces transitioning between categories. Abbreviations: ABL-CEJ, distance from the alveolar bone level to the cementoenamel junction; FEN, fenestration.

Harms

Recorded harms across Papers I–IV included plaque accumulation, gingivitis, mucosal chafing, transient pain, and minor root shortening, all of which are commonly expected during fixed appliance treatment. The observed alveolar bone level reduction was itself considered a potential harm, and one that likely goes largely undetected in routine practice, since CBCT is not a standard post-treatment examination. The most pronounced cases were noted for continued clinical follow-up. No other treatment-related adverse events were reported.

DISCUSSION

Main findings

A comprehensive evaluation of health outcomes requires both objective and subjective perspectives.[29] This thesis investigated occlusal, patient-reported, and alveolar bone outcomes of non-extraction orthodontic treatment in adolescents with dental crowding and tooth displacement, comparing passive self-ligating and conventional fixed appliances. Both treatment groups achieved successful and comparable improvement in occlusion and correction of crowding, as measured by the Peer Assessment Rating index and Little's Irregularity Index, respectively. Both were also associated with a temporary decline in oral health-related quality of life during alignment, followed by improvement beyond baseline levels after treatment. Patients were highly satisfied with the treatment outcome, and few regretted undergoing treatment, and the differences between the bracket systems were small and of questionable clinical relevance. Treatment with both bracket systems resulted in a comparable reduction in alveolar bone support at most surfaces. This suggests that the observed alveolar bone changes may be attributable to the non-extraction expansion approach rather than to the choice of bracket system, although the absence of an untreated control group limits causal interpretation. The occurrence of fenestrations decreased buccally at the mandibular incisors, possibly because fenestrations merged with the receding marginal bone or resolved as the roots became more favourably positioned within the alveolar bone. Considerable inter-individual variation was observed.

The findings of this thesis, together with other results from the CROWDIT project so far, indicate that neither system offers a clinically meaningful advantage over the other. The choice between them may therefore be guided

primarily by patient and clinician preference. The planned long-term follow-up and health-economic analyses within CROWDIT may provide further guidance.

Treatment outcomes and treatment time

Occlusal outcomes

As hypothesised, both treatment groups showed comparable occlusal improvement, with no significant differences in wPAR and LII after treatment. On average, both groups exceeded the 30% reduction required for an individual case to be judged as 'improved' and reached the 22-point reduction required for a 'greatly improved' outcome.[107] The 95% CI for the between-group difference in mean wPAR reduction (–5.99 to 2.07 points) was relatively narrow relative to the mean reductions of 22–24 points. Although a difference of up to approximately 6 points in favour of CB cannot be ruled out, the interval as a whole suggests that any difference in occlusal outcome between the two systems is small.

Crowding and tooth displacement were resolved through a combination of transverse expansion and incisor proclination in both groups, but to different extents during alignment. The CB group showed greater incisor proclination, whereas the PSLB group showed greater transverse expansion. In accordance with the manufacturers' recommendations, the broad Damon arch form was used in the PSLB group and the ovoid arch form in the CB group during this phase, which may partly explain the greater expansion in the PSLB group.

Previous findings also suggest that arch form, rather than bracket type, may explain differences in expansion. Several trials using identical archwires in both groups found no intergroup difference in expansion at completed alignment,[15,127,128] seven months after treatment initiation,[129] or at the end of treatment,[130] whereas a trial using different archwires (Sentalloy medium and Damon), with a broader arch form in the PSLB group, reported a 1.3 mm (95% CI 0.3–2.3 mm) greater mandibular intermolar expansion in the PSLB group at the end of non-extraction treatment in adolescents.[13] Most notably, an RCT that compared the same two arch forms as in the present study, using conventional brackets (Victory) in both groups, likewise found that the Damon form produced greater expansion after alignment, whereas the ovoid form produced greater mandibular incisor proclination.[131] Expansion was numerically greater at all measured sites with the Damon form in the previous trial and in the PSLB group

in the present study, but the differences varied in size and in where they were significant. Both observed significant differences at the mandibular first and second premolars; the previous trial also found them at the maxillary second premolars and mandibular first molars, and the present study at the maxillary canines and first premolars. In the present study, mandibular intermolar width did not change significantly in either group, despite the broader Damon form in this region (Figure 5). Moreover, the greater mandibular incisor proclination in the CB group was not accompanied by significantly greater incisor advancement, unlike with the group with ovoid form in the previous trial.[131] These differences were temporary. Both groups were finished with identical ovoid stainless steel archwires, and by the end of treatment, no significant differences in expansion, incisor proclination, or incisor advancement remained.

In the PSLB group, the reduction in transverse width from T1 to T2 may reflect root torque correction, more fully expressed with the rectangular stainless steel wire following tipping during alignment,[87] in combination with the possible contraction produced by the narrower ovoid archwire form. However, whether the expansion occurred through tipping or bodily movement was not assessed, and the finishing arch form was standardised. The trial therefore cannot show whether the intergroup differences in expansion and incisor proclination would have persisted if the groups had maintained their different arch forms until debonding. An RCT reporting 0.91 mm of greater mandibular intermolar expansion during alignment with PSLB despite identical archwires[132], suggests that factors other than arch form also contribute to final results.

Treatment time

Time to alignment and total treatment time were numerically shorter in the CB group, but the intergroup differences were not significant; in agreement with a previous systematic review.[133] One PSLB patient with a total treatment time of 57.63 months was excluded from the treatment time analysis, as the extended duration was unrelated to the orthodontic treatment. This decision was made after consultation with a statistician and by consensus within the research group, and a sensitivity analysis including this patient is reported in the supplementary material of Paper I. As the sample size was not calculated for treatment time, the results of this outcome should be interpreted with caution.

In cases with pronounced irregularity and rotations, the deflection of the archwire may prevent full closure of the PSLB sliding lid. This can delay full wire engagement, whereas in CB, the archwire can be engaged with elastic ligatures.

A deflected and pinched wire may also restrict sliding, reducing the claimed low friction advantage[67] and potentially the rate of tooth movement. Consistent with this, Pandis et al.[14] found that mandibular crowding was aligned 2.7 times faster with self-ligating brackets when LII was < 5, whereas the difference was not significant when LII was > 5. To explore this further, an additional subgroup analysis by baseline LII (cut-off: 5), not included in Paper I, was conducted for this thesis (Table 6).

In patients with mandibular LII ≤ 5, neither time to alignment nor total treatment time differed significantly between the groups, whereas the maxillary comparison could not be meaningfully interpreted, as only three patients per group had maxillary LII ≤ 5.

In patients with LII > 5, total treatment time was significantly shorter in the CB group in both subgroups, on average by 2.9 months when grouped by maxillary LII ($P = 0.037$) and by 4.2 months ($P = 0.009$) when grouped by mandibular LII. Time to alignment was also shorter in the CB group in the mandibular subgroup (by 2.9 months, $P = 0.026$), whereas no significant difference was observed in the maxillary subgroup (1.8 months, $P = 0.071$). These findings are consistent with the hypothesis that severe irregularity reduces the efficiency of PSLB systems. However, the subgroup analyses were not prespecified but were conducted to inform the discussion. They involved unadjusted comparisons of subgroups of unequal size, some of them small, and did not account for patients having different LII categories in the two arches. The results should therefore be interpreted with caution and be regarded as hypothesis-generating only.

The recall intervals differed between the groups in accordance with the manufacturers' recommendations (≥ 6 weeks for CB and 8–10 weeks for PSLB), and this difference may have influenced treatment time. Longer recall intervals could prolong treatment time while reducing the total number of appointments. Treatment duration is therefore only one aspect of treatment efficiency. The number of appointments and direct and indirect costs will be evaluated in a planned health-economic analysis within the CROWDIT project.

Dental patient-reported outcomes

Oral health-related quality of life

Changes through treatment

OHRQoL declined during active treatment, possibly reflecting the burdens of fixed-appliance therapy,[134,135] and subsequently improved beyond pretreatment levels. This pattern has previously been reported in adolescents, with the decline typically occurring earlier in treatment than at completed alignment as in the current study.[134,135] The participants in the current study had pronounced irregularity in the aesthetic zone (Paper I). Anterior crowding has been associated with poorer OHRQoL in Swedish adolescents,[5] and to mainly affect the emotional and social well-being domains.[4,19] In the present study, the oral symptoms and functional limitations domains deteriorated during treatment, while emotional and social well-being improved throughout. Similar patterns have been reported elsewhere. A recent meta-analysis found a decline in the functional limitations domain during the first three months of treatment, although with low certainty of evidence owing to the many non-randomised studies without control groups.[136] Likewise, a study of Austrian adolescents with great or very great treatment need (IOTN-DHC 4–5), reported worsening in oral symptoms and functional limitations, but improvement in emotional and social well-being during the first six months of treatment.[137] In the current study, the deterioration in these domains was observed at completed alignment, after a mean of 12.8 months of treatment. As OHRQoL was not assessed earlier, it cannot be determined when the decline or improvement in OHRQoL began.

The improvements in the emotional and social well-being domains are in agreement with previous research,[137] and may partly reflect growing social acceptance and normalisation of fixed appliances,[138] as well as adolescents' gradual adaptation to the appliance.[139] In contrast, oral symptoms and functional limitations, such as food impaction and difficulty chewing, are likely to persist for as long as the appliance is in place, which may explain why these domains deteriorated during treatment.

Differences between treatment groups

Differences in OHRQoL between treatment groups were few and small with questionable clinical relevance. The only significant difference over the course of treatment was a greater improvement in oral symptoms within the CB group

(CB mean 1.55, PSLB mean 0.27, r = 0.25, *P* = 0.005). Pain can negatively affect OHRQoL,[34,135] and intergroup differences in pain levels have been observed.[75] However, the questionnaires were completed before scheduled treatments, and therefore not during the days after bonding or insertion of the stainless steel archwire, when pain levels peaked.[75] These short-term, pain-related potential effects on OHRQoL were thus not assessed. This was intentional, as the aim was to capture the overall treatment experience rather than transient post-appointment discomfort. The timing of questionnaire administration is important to avoid conflating the effects of the intervention with those of the appointment itself.[35]

The absence of other differences between treatment groups agrees with previous cohort studies[140,141] and RCTs[142,143]. These studies differed in population, age range, timing of assessment, and choice of instrument, which limits direct comparison. Nevertheless, the consistency of the non-significant findings across designs and samples strengthens the indication that any differences in OHRQoL between PSLB and CB are small.

Differences between the sexes

At baseline, girls reported poorer OHRQoL than boys, mainly in the emotional well-being domain (mean 6.18 vs 3.02; median 4 vs 1; r = 0.30, *P* <0.001). This occurred despite a slightly higher objective treatment need among boys (IOTN-DHC, mean 3.86 vs 3.68; *P* = 0.023). This suggests that clinically assessed and patient-perceived treatment need may not correspond.[29] However, girls improved more in emotional well-being, so that no significant difference remained after treatment.

Reports on sex differences are inconsistent. Girls have been reported to have a higher subjective treatment need than boys,[144] and a greater impact of an aesthetically impairing malocclusion on OHRQoL, moderated by their self-esteem.[145] In contrast, the effect of crowding on OHRQoL has been reported to be largely independent of sex.[4,5]

Patient perceptions of orthodontic treatment

Treatment motivation

Adolescents were generally motivated to undergo orthodontic treatment and wished to change the appearance of their teeth. This is consistent with appearance being an important reason for adolescents to seek treatment.[134,146] Perceptions of dental appearance and treatment need may be shaped by peers, social media,[139]

parents and health professionals,[146] and social media may influence both the decision to seek care and how the result is judged.[139] This highlights the importance of realistic expectations before treatment.[147] Participants regarded the decision to undergo treatment as largely their own. However, a Swedish interview study from 2002 found that social norms and beauty culture contributed to decisions that adolescents perceived as independent,[148] suggesting that self-reported independence does not necessarily exclude external influence.

Treatment expectations

Expectations before treatment were positive, with low to moderate anticipated difficulty in wearing the appliance and little worry about undergoing treatment (items 8, median 5, IQR 3–6; and item 9, median 2, IQR 1–4). The participants' low concern before treatment about how they would look wearing an appliance (item 10, median 2, IQR 1–5) agrees with a UK qualitative study in which the appearance of the fixed appliances was not a concern before treatment, and choosing the colour of the elastomeric ligatures was something to look forward to.[139] In that study, the appliance was sometimes perceived as a marker of progression through adolescence, and its pain and physical feel were gradually tolerated and normalised. In contrast, an earlier Swedish study reported that concerns about appearance when wearing an appliance were an argument against treatment,[148] which suggests, as the UK study also indicated,[139] that attitudes may change over time.

Expectations appear to have been met, as patients reported that treatment had worked as they expected, and the CB group rated this marginally higher after alignment with a small effect size.

Satisfaction with treatment outcome

Following Feldmann et al.,[44] satisfaction with treatment outcome was assessed with three items (items 3, 4 and 6), which also served as outcome variables in the correlation analyses. Satisfaction with the changes achieved (item 3, median 10, IQR 9–10) and with dental appearance (item 4, median 10, IQR 9–10) was high, and regret about having started treatment was low (item 5, median 1, IQR 1–2). In contrast, willingness to make the same decision again showed a divided response (item 6, median 9, IQR 1–10). This may indicate that the wording of the item was difficult to grasp, or that it conflated the burden of study participation with the treatment experience.

The CB group rated items 3 and 4 slightly higher than the PSLB group ($P = 0.006$, r = 0.25, and $P = 0.029$, r = 0.20) despite similar wPAR and LII outcomes (Paper I). However, both groups had a median of 10 on both items, and the effect sizes were small, so the clinical relevance of the differences is uncertain.

Factors associated with satisfaction with treatment outcome

The strongest association was between believing that treatment had been good for the teeth and satisfaction with the changes achieved ($\rho = 0.525$, $P < 0.001$). This belief was also associated with satisfaction with dental appearance ($\rho = 0.342$, $P < 0.001$). Perceiving at the end of treatment that treatment had worked as the patient had expected was associated with satisfaction with the changes achieved ($\rho = 0.330$, $P < 0.001$), whereas anticipating difficulty in wearing the appliance at baseline was inversely associated with satisfaction with dental appearance after treatment ($\rho = -0.298$, $P = 0.001$). This suggests that how patients perceive treatment beforehand may relate to how they later evaluate the outcome. Clarifying expectations may increase satisfaction, although the evidence is weak and warrants further research,[149] and the clinician-patient relationship has been suggested to matter more for patient satisfaction with treatment than the technical treatment success alone.[150] This highlights the importance of communication and realistic expectations before treatment.[147]

Unexpectedly, being tired of treatment after alignment was positively associated with willingness to make the same decision again ($\rho = 0.332$, $P < 0.001$). This may reflect effort justification and cognitive dissonance, whereby a treatment perceived as demanding is subsequently valued more highly.[151] Effort justification would be expected mainly when the effort is not excessive and is rewarded,[151] which appeared to apply in the present sample, as tiredness after alignment was generally low (median 2), and treatment outcomes were good and satisfaction at the end of treatment was high.

Reliability and agreement of the alveolar bone assessment protocol for follow-up

Several studies have evaluated the reliability and validity of linear measurements of alveolar bone on CBCT.[72,101,103,152] Many have used conditions that may facilitate measurement, such as human specimens, which eliminate motion artefacts,[101,152] markers such as metal ligatures[152] or gutta-percha,[153] to guide orientation and measurement sites, preselected images, which omit slice selection

and plane orientation[103] or have used the incisal edge for orientation[72] or as a landmark for linear measurements[101]. Although suited to their purposes, such protocols may not be directly applicable to follow-up studies or clinical evaluation. In those settings, tooth movement, abrasion and attrition, bone remodelling, and growth between examinations may alter the anatomy of interest, making repeatable orientation and reliable measurement more challenging. Because orientation within the volume itself is a source of variation, repeated measurements in the present work included the full procedure, from orientation of the volume and slice selection to landmark identification and the final measurement. This is a strength of the study, as it captures sources of variation that would otherwise go unmeasured, although it may yield lower reliability estimates than those obtained under more controlled conditions.

Using multiplanar reconstruction for assessment

Before assessments, using MPR, the sagittal and coronal reference planes are typically aligned parallel to the long axis of the tooth.[72,97] In some protocols, their orientation is then adjusted in the axial plane at a defined level, such as the CEJ, according to an anatomical criterion, for example, the shortest intersection of the coronal plane through the tooth or the orientation of the incisal edge.[72,97] Linear measurements are then made between predefined landmarks. In follow-up studies, the volume must be reoriented and the landmarks re-identified at each time point. Identifying the CEJ and orienting the reference lines at this level can be difficult, particularly in teeth with nearly circular cross-sections, where criteria such as the shortest or widest intersection provide little guidance.[97] Small rotations in the axial plane alter the depicted anatomy, and because the CEJ and the alveolar crest vary in height around the tooth, this can change both the measurement site and the recorded bone level (Figure 23).[97]

Protocols in which the reference lines are oriented according to the arch form[101] may risk shifting the measurement site once the tooth has been moved. High-contrast landmarks such as incisal edges and cusp tips are easier to identify than the CEJ,[101] but are subject to change over time, for example, through abrasion and attrition. The present study therefore based orientation solely on the anatomy of the tooth of interest, with the final orientation based on crown landmarks at the DEJ. For incisors, the reference lines in the axial plane were oriented according to the incisal edge at the DEJ.[97] For canines and premolars, the sagittal reference line in the axial plane was positioned to intersect the mid-buccal and mid-lingual aspects of the root, and its orientation was adjusted at several levels along the root

from the apex in a coronal direction, with final orientation approximately 2 mm apical to the CEJ (Figure 10). A limitation of this approach is that palatal/lingual measurements in rotated teeth may capture interproximal bone.

Experienced clinicians, such as maxillofacial radiologists, may achieve reliable measurements through training. For general dentists, other specialists using CBCT for treatment planning or outcome evaluation, and researchers, however, a standardised protocol supporting reproducible orientation may be beneficial. This is particularly true in follow-up, where the planes must be oriented as identically as possible at both time points.

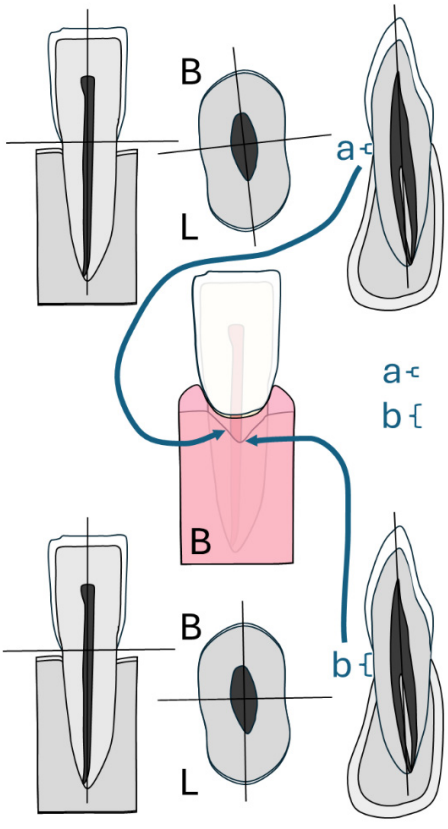

Figure 23. Effect of reference line orientation in the axial plane on measurement of buccal distance from the cementoenamel junction to the marginal alveolar bone. In a and b (blue, lower-case letters) the buccolingual (sagittal) reference line has been rotated differently; all other conditions are identical, yet the resulting measurements differ. Identical plane orientation at baseline and follow-up is therefore a prerequisite for valid comparison of change. B, buccal; L, lingual (black capital letters).

Measurement error

Measurement errors can be systematic or random. Systematic error is consistent and unidirectional. It may arise, for example, from an uncalibrated instrument or from rater expectations at follow-up, the latter underlining the importance of blinding. Random error is unpredictable, equally likely to over- or underestimate a measurement,[100] and ultimately limits accuracy.[154] Its sources include difficulty in identifying landmarks,[155] environmental variation, and rater fatigue and inexperience.[100] Averaging several measurements allows positive and negative errors to cancel out, thereby reducing random error and improving reliability.[100,155,156]

Agreement using Bland-Altman Plots

The Bland-Altman plots and paired t-tests revealed minor systematic bias at two sites (15p and 11p) at T2. As these differences were small and did not remain significant after adjustment for multiple comparisons, they may reflect chance. The widths of the limits of agreement were driven by outliers, particularly at 13b. These outliers may reflect difficulty in detecting thin alveolar bone, especially after expansion treatment.

Dahlberg's random error

Dahlberg's random error assumes the absence of systematic error[155], an assumption that was reasonable here, as systematic error was minor for intrarater measurements. Pooled random errors (0.33–0.61 mm) were larger than in a previous study of 13 adolescents treated for crowding with premolar extractions (0.21–0.31 mm).[157] As acquisition parameters influence image noise and spatial resolution,[93,158] the presumably higher image quality in the previous study may have facilitated landmark detection, although this was not assessed.

Reliability

Intraclass correlation coefficient

The ICC is a unitless measure of relative reliability, reflecting a test's ability to differentiate between individuals.[100,159]

Intrarater ICC point estimates were moderate to excellent, with confidence intervals ranging from poor to excellent depending on measurement site, whereas interrater ICCs and confidence intervals ranged from poor to good. Intrarater estimates were higher than, and interrater estimates comparable to, those of a

previous study of 10 adolescents with crowding that used preselected images.[103] The use of a standardised protocol may have contributed to these results.

At most sites, ICC estimates and random errors were higher at T2 than at T0. The higher ICCs may in part reflect greater between-subject variability in bone level after treatment, as ICC estimates increase with sample heterogeneity.[156,159] The larger random errors may reflect difficulties in identifying thin, diffusely defined bone after treatment.

The ICC estimates were generally lower than those obtained under controlled conditions, such as on phantoms with preselected images[160] or on human specimens[161,162], where motion artefacts are eliminated and, in some cases, slice selection and orientation are not part of the raters' task. The present estimates therefore better reflect the conditions under which the current protocol is intended to be used.

Intrarater reliability was assessed by the least experienced rater to provide a conservative rather than best-case estimate, assuming that more experienced raters would achieve equal or higher reliability. As this cannot be taken for granted, reliability should be established locally when the protocol is implemented. Finally, reliability and agreement are prerequisites for validity evaluation but provide no evidence of validity, which would require comparison with a reference standard such as a direct measurement.

Standard error of measurement

The SEM is an estimate of absolute reliability[100] and agreement[104] and expresses the precision of individual measurements in the unit of the measurement.[100,159] In the current study, the SEM was calculated from the mean square error of the intrarater repeated measurements at each time point, reflecting random error.[100,159] The values were similar to Dahlberg's random error, given the minimal systematic bias.

All SEM values were below the baseline CEJ–alveolar bone crest distances previously reported in adolescents with crowding (mean age 15.3 years), with means ranging from 2.0 to 3.3 mm buccally and from 1.4 to 2.9 mm palatally/lingually.[82] They were also below the baseline means in Paper III[114] and the corresponding site means at both time points in Paper IV (mean age 14.24 years). This indicates acceptable measurement precision relative to the magnitudes recorded magnitudes.

Minimal detectable change

The MDC_{95} formula, based on the SEM at T0, assumes equal SEM at both time points. However, the SEM at T2 was markedly larger at 13b and 31l, probably owing to the large T2 outliers at these sites (Paper III, Bland–Altman plots). With some caution at these sites, changes exceeding the site-specific MDC_{95} can be regarded as exceeding measurement error.

In a previous study of adolescents treated for crowding with premolar extractions, all affected patients had at least one surface with bone loss exceeding 1 mm,[82] so the ability to detect a change of 1 mm was considered clinically relevant. The MDC_{95} exceeded 1 mm at 31b, 31l, 33b, 33l and 13p. However, larger alveolar bone level changes were reported at these sites in the same study (a mean of 5.7 mm at 31l and 1.4 mm at 33l, more than 2 mm in over a fifth of buccal surfaces at 31 and 33, and more than 2 mm in 16.3% of palatal surfaces at 13).[82] The protocol therefore remains informative for changes of these magnitudes.

Because measurement error at T0 and T2 can differ, approaches to calculating MDC_{95} that incorporate the SEM values from both time points have been described.[163,164] These approaches assume independent errors, an assumption often not fully met in clinical settings.[164] The standard MDC formula used in the present study was chosen in consultation with a statistician based on this assumption. However, accounting for both time points would yield a larger MDC_{95} estimate at 13b, for which the SEM was clearly larger at T2 than at T0.

Percentage agreement for fenestrations

Agreement for fenestration detection was high, exceeding 81% for intrarater and 74% for interrater assessments. Most disagreements occurred at the canines and incisors, where the buccal bone is thinnest. Percentage agreement was used instead of kappa, as fenestrations were rated as absent at several sites, leaving insufficient variability. Where fenestrations were present, the imbalance between sites with and without observed fenestrations would render kappa paradoxically low despite high observed agreement.[156]

As the presented estimates are rater-, sample- and equipment-specific, they may not apply directly to other settings.

Alveolar bone outcomes

Treatment group comparison

No significant differences in alveolar bone outcomes were observed between the bracket systems, neither in ABL-CEJ change nor in fenestration occurrence. The ABL-CEJ results persisted after adjustment for baseline ABL-CEJ distance, arch width, incisor inclination and position, and voxel size. This finding was consistent with the first hypothesis, which was based on the similar occlusal outcomes reported in Paper I.[165] However, as the sample size was calculated for ABL-CEJ, the fenestration analyses may have been underpowered. The changes occurred mainly on the buccal surfaces, particularly in the mandible, in line with the second hypothesis, which was based on both systems addressing crowding through arch expansion. Because both groups were finished with identical stainless steel archwires, any effects of the differences in expansion and proclination on the alveolar bone may have been attenuated between completed alignment and the end of treatment, although this cannot be determined without an intermediate assessment.

The Damon system is marketed as a low-friction, low-force system,[63,67,166] and lower forces may cause fewer side effects.[69] Nevertheless, significant alveolar bone loss has been reported in adolescents treated without extractions with Damon.[87,120] The present study likewise observed increased ABL-CEJ and found no advantage over CB, although forces were not measured. This agrees with previous CBCT studies of non-extraction treatment reporting no differences in buccal bone thickness or height between self-ligating and conventional brackets in patients (mean ages 14–21 years),[129,167] or between passive and active self-ligating systems.[168] However, alveolar bone loss is not specific to non-extraction expansion treatment.[98] In a comparable adolescent sample treated with premolar extractions, bone loss was even greater, primarily at the lingual surfaces of the mandibular incisors.[82]

Alveolar bone support in the total sample

Baseline ABL-CEJ values were generally similar to those previously reported in young adults with crowding (LII 4–6 mm),[121] and individual variation was pronounced.

The greatest loss of alveolar bone support occurred buccally at the mandibular incisors, which together with the maxillary canines have been identified as being

at high risk of vertical alveolar bone loss after non-extraction treatment.[91] ABL-CEJ increased significantly at nearly all surfaces, except at seven premolar sites and at 21b and 23b (after Bonferroni correction). The changes exceeded the MDC_{95} established in Paper III[114] at the buccal surfaces of the mandibular incisors, at 41l, and at several maxillary incisor surfaces, and are therefore unlikely to reflect measurement error alone at these surfaces.[114] However, the changes at 12p and 22b only marginally exceeded the MDC_{95}, and at 13b, the MDC_{95} may be underestimated, as it was derived from the SEM at T0, whereas the SEM at T2 was higher.[114]

Fenestrations occur in untreated individuals across skeletal Classes I–III,[169] suggesting that they are a physiological trait.[80] Baseline proportion of fenestrations in Paper IV was generally lower than that reported in a sample of 12–26-year-olds.[170] This may partly reflect methodological differences, as that study reported fenestrations irrespective of size in both extraction and non-extraction patients. After treatment, it reported an increase in lingual and a decrease in buccal fenestration occurrence.[170] Likewise, a reduced occurrence in fenestrations was observed at T2 in the current sample. However, this does not necessarily indicate improved bone support, as the reduction may reflect fenestrations merging with the receding marginal bone and thus being recorded as part of it.

The merging of fenestrations with the marginal bone is consistent with the transition analysis, as many surfaces with fenestration at T0 were classified at T2 as having a greater ABL-CEJ distance without fenestration. Moreover, many baseline fenestrations were separated from the crest only by a thin layer of bone, and thin pretreatment buccal bone has been associated with greater marginal bone loss during orthodontic treatment.[81,87] However, some fenestrations were no longer observed at T2 without a change in ABL-CEJ category, which may reflect new bone coverage owing to a more favourable root position within the alveolar bone after treatment.[71]

Longer follow-up is needed to confirm the clinical relevance of these findings, particularly given the large individual variation in alveolar bone response to orthodontic treatment.

Methodological considerations and limitations

Study design and planning

A randomised controlled design was chosen to achieve a high level of evidence, and a multicentre setting to strengthen external validity. Adolescents with crowding were studied because crowding is commonly treated at this age,[1] and all treatments were made by experienced specialists familiar with both appliance systems. However, the multicentre design and the long trial duration made protocol adherence challenging. It also exposed the project to practical disruptions, such as the replacement of a CBCT unit after water leakage at a radiology clinic, and required material stored at different clinics to be coordinated and collected.

An untreated control group was not included, as withholding treatment from adolescents with established treatment need was not ethically justifiable. Therefore, the changes assessed in the total sample (Papers II and IV) should be interpreted as changes occurring during treatment rather than as treatment effects. For OHRQoL, a Danish study reported a median CPQ11–14 score of 9 in 154 healthy sixth-grade schoolchildren,[171] corresponding to the post-treatment score in the present sample. This suggests that the participants in the current study reached a level similar to that of healthy children, although potential confounders are unknown, and two questionnaire items were omitted in the present study, which limits the comparison.

Treatment

The two appliance systems were used according to the manufacturers' recommendations at the start of CROWDIT, each with its own archwire sequence: Damon broad archwires with PSLB and ovoid archwires with CB. The CB manufacturer recommended the ovoid form for the standardised protocol, as it was the arch form most commonly used in Europe (personal communication between the manufacturer and the principal investigator during study planning). Both groups were finished with an identical ovoid 0.019×0.025-inch stainless steel archwire. One deviation from the manufacturers' recommendations was that this archwire was not adapted to the dental arch form achieved during alignment in either group, which may have influenced the final dental arch dimensions. Individual adaptation would, however, have introduced an additional operator-dependent step.

Treatment success also depends on clinician skill, patient compliance, biological response, anatomical variation, and appliance limitations, and clinician decisions such as the need for interproximal enamel reduction or bite disarticulation. Randomisation was intended to balance known and unknown confounders, such as cooperation and motivation, across groups. The involvement of four experienced orthodontic specialists reduced the influence of any single clinician.

Intention to treat, per protocol and imputation

As intention to treat (ITT) and per protocol analyses are defined inconsistently in the literature, a detailed description of the analysis is essential.[172] In Paper I, an ITT approach was used for wPAR to reflect the effectiveness of being assigned to treatment and to reduce the risk of overestimation associated with excluding participants who discontinued or were lost to follow-up.[172,173] All patients were analysed as randomised, and missing post-treatment wPAR values were replaced with baseline values (last observation carried forward, LOCF), which assumes that participants who discontinued did not improve. The remaining secondary outcomes were analysed per protocol to estimate the efficacy of receiving treatment.[173,174] Both approaches may give biased estimates. ITT depends on the assumptions underlying imputation, whereas per protocol analysis may introduce selection bias and disturb the balance of confounders achieved by randomisation.[173,175] However, both are considered valid, with different scopes and interpretations.[173]

In Paper II, missing questionnaire items were imputed with the item median to allow total and domain scores to be calculated. This was inspired by previous research using the same modified CPQ11–14,[176] and was decided in consultation with a statistician. A sensitivity analysis of complete questionnaires showed that the imputations had only a minor impact.

Dental patient-reported outcome measures

CPQ 11-14

The modified CPQ11–14, which has been used in previous research,[177] includes a ‘not applicable’ option, absent from the original instrument.[40] This allows respondents to indicate that an item does not apply to them, such as difficulty playing an instrument for those who do not play one. Non-response may also arise when items are difficult to understand or recall, or from irritation at a lengthy

questionnaire, whereas respondents may be motivated by the satisfaction of helping, having a voice, and the opportunity to reflect and give feedback.[178]

Two items were omitted owing to a printing error, although a sensitivity analysis indicated minimal impact on effect sizes and statistical significance. Changes in scores are nonetheless likely to be more informative than comparisons of absolute scores with other studies, particularly as translated and culturally adapted versions differ, including in the number of items.[171,179]

Questionnaire burden

Participants completed several questionnaires on OHRQoL, patient experience, satisfaction with treatment outcome, and pain, on multiple occasions. The CPQ11—14 and Feldmann's questionnaires were completed on paper at the clinic, with staff providing clarification if needed. Short-form versions of the CPQ would have reduced patient burden but cover less of the construct;[123] instead, participants were given time at the clinic and encouraged to consider their answers, which probably improved response quality.

Clinically important change

Minimal detectable change (MDC) indicates whether a real change has occurred, whereas the minimal clinically important difference (MCID) indicates whether the change is meaningful.[100] Neither is a fixed property of an instrument, and both are constrained by floor and ceiling effects, which limit the instrument's capacity to register change.[100] In the current study, baseline emotional and social well-being scores were close to the floor, while responses to Feldmann's questionnaires mainly clustered towards the ends of the scale.

The MCID can be established through anchor-based approaches, which compare change measured on the instrument with an external criterion, such as patients' ratings of their own change ('worse', 'about the same', 'better').[100,180] However, such retrospective ratings correlate more closely with present than baseline status, reflecting current perception rather than accurate recall of the earlier condition.[156] Distribution-based approaches instead derive the threshold from score statistics, without reference to patients' own perceptions of the change,[100] for example defining the MCID as half of the baseline SD,[181] a method that has been criticised for lacking conceptual justification.[182] For the CPQ11–14, a distribution-based calculation in Brazilian adolescents aged 11–12 years, assessed before and 12 months after fixed appliance treatment onset, yielded an MCID of 3.35 for the total score, and 0.87–1.28 for the domains,[183] although based on the 16-item short

form and on the variability of that sample.[183] Sociocultural differences in perceptions of malocclusion and dental aesthetics may further limit comparison.[184] An anchor-based approach of the full CPQ11–14 suggested an MCID[185] of four points in a New Zealand population sample, not selected on treatment need, assessed at 13 and 16 years of age[185]. In the present study, the intergroup difference in change in oral symptoms (1.28 points) was smaller than half the baseline SD of that domain in the total sample (approximately 1.5 points), which is consistent with the difference being of questionable clinical importance.

CBCT

Image quality and multiple units

Image quality determines what can be discerned in a CBCT volume and may thereby influence landmark identification and the resulting measurements.[103]

As described in the introduction, the absence of visible bone on CBCT does not necessarily mean clinical absence.[93] The alveolar bone support was therefore primarily assessed as change over time rather than in absolute terms. No intermediate CBCT assessment was made at T1, as ongoing bone remodelling with reduced bone mineral density would likely have complicated the assessment.[186]

The use of different CBCT units may increase clinical relevance and external validity, as no single machine represents clinical practice and patients may be examined at different clinics. Acquisition protocols were established before the trial through calibration and phantom-based dose optimisation at each radiology clinic, with specific exposure parameters set by an oral and maxillofacial radiologist based on objective image quality relative to radiation dose in accordance with ALARA.[187] Viewing conditions were standardised, with assessments performed under dimmed lighting on a high-resolution monochrome monitor, and contrast and brightness calibrated against a reference image prepared by a radiologist. However, variation in image quality between units cannot be separated from rater variation in the present design, which limits the interpretation of the reliability estimates.

Subjective image quality assessment, alongside objective phantom testing, would have allowed the reliability and agreement estimates to be related to the quality of individual volumes, and equal numbers of examinations per unit, ideally with random allocation, would have permitted comparison between units. However, as patients could not be expected to travel to distant clinics for the duration of

CROWDIT, random allocation to clinic or unit was not feasible. Equal group sizes could not be achieved, as recruitment was halted early owing to the COVID-19 pandemic combined with changes to regulations governing free orthodontic care.

Choice of measurement sites

The alveolar bone assessment did not include the molars. In Paper I, there was no significant expansion between the mandibular first molars and only approximately 0.81 mm between the maxillary first molars, with no intergroup differences; the intergroup differences in expansion instead occurred at the canines and premolars during alignment. As CROWDIT primarily compares two appliance systems, and the lack of a control group limits the assessment of fixed appliance treatment as such, the assessment focused on the incisors, canines, and premolars. Molars may be included in future follow-up, which would require the protocol to be extended for these teeth.

Reliability and agreement

Assessing intrarater reliability and agreement for all three raters, rather than one, would have strengthened the conclusions of Paper III and may be considered in future studies. Evaluating reliability and agreement for averaged measurements, which reduce random error,[156] might also have shown whether assessments could be distributed across several raters, rather than relying on a single rater, as the present findings suggest. This could facilitate multicentre studies and reduce vulnerability to the loss of individual raters over the course of a long study.

Clinical implications

- **Choice of appliance system.** During alignment, treatment with the PSLB system, including the broad Damon archwire form, produced more transverse expansion, whereas treatment with the CB system, including the ovoid archwire form, produced more incisor proclination. These differences did not persist after finishing with identical archwires, suggesting that the finishing archwire may influence the final arch dimensions. As both systems achieved similar occlusal outcomes, the choice of system may be guided by clinical preference, whereas the form of the finishing archwire may deserve attention during treatment planning.

- **Patient information.** Patients can be informed that oral health-related quality of life may worsen temporarily during treatment, mainly through oral symptoms and functional limitations, and may subsequently be better after treatment than before. Such information may help establish realistic expectations, which is relevant, as perceiving that treatment had worked as expected was moderately associated with satisfaction with the treatment outcome.
- **CBCT assessment of alveolar bone.** The protocol for assessing alveolar bone on CBCT over time showed moderate to excellent intrarater reliability. It may be used in settings and samples similar to those of the present study, and by raters with comparable experience, preferably with all assessments performed by the same rater. Before it is applied in other settings or samples, or by other raters, its reliability should be re-evaluated. When several raters are involved, additional calibration and averaging of repeated measurements may improve reliability, although the effect of these measures was not tested in this thesis.
- **Alveolar bone support**. Alveolar bone support may decrease during non-extraction treatment of crowding, particularly buccally at the mandibular incisors, with large individual variation with both appliance systems. Without an untreated control group, the extent to which the observed changes reflect treatment effects cannot be determined, and their long-term clinical consequences remain unknown.

Ethical considerations

Participants were 12–17 years of age at enrolment. Under the Ethical Review Act, participants aged 15–17 years who understand what the research entails may consent themselves.[188] For younger children, guardians decide after the child has been informed as far as possible, and a child who understands and declines cannot be included.[188] All participants received verbal and written information, and were included after assent with signed consent from participants and guardians, and all were informed of their right to withdraw consent at any time.

Children are considered vulnerable research participants, with limited ability to protect their interests or give fully informed consent. They therefore require additional protection, and research should not be conducted on them if it could be carried out on other groups.[189] However, excluding them poses an ethical

dilemma, as it may withhold knowledge that could benefit them, so the harms of inclusion must be weighed against those of exclusion.[189] Children and adolescents were studied because crowding is commonly treated at these ages in Sweden, and alveolar bone remodelling and treatment-related bone changes may differ between adolescents and adults.[86]

As both systems are established treatments with which successful outcomes could be expected, and it was unknown whether they differed in the outcomes assessed, randomisation was ethically justifiable.

CBCT was required to assess alveolar bone and other research outcomes in CROWDIT. Orthodontic treatment was previously thought to have little impact on marginal bone,[83] but CBCT studies have adjusted this view.[82]

However, exposure to ionising radiation carries a risk of DNA damage, most of which is repaired immediately.[190] In accordance with the ALADA (As Low As Diagnostically Acceptable) principle[187] (later developed into ALADAIP[191]; As Low As Diagnostically Acceptable being Indication-oriented and Patient-specific), exposure was kept as low as diagnostically acceptable through phantom-based dose optimisation at each radiology clinic.[160] The additional X-ray examinations within CROWDIT were estimated to amount to approximately 0.42 mSv, comparable to approximately two months of natural background radiation.[160,192,193]

Generalisability

The multicentre design involving a university clinic, a private practice, and two public dental service specialist clinics supports generalisation of the findings of Papers I and IV to adolescents treated for crowding without extractions in similar settings. It should be borne in mind that the ovoid stainless steel archwire was not adapted to the individual arch form, and that newer generations of the appliances may yield different results.

The results of Paper II are likely to be generalisable primarily to northern European populations with similar characteristics, as the perception and reporting of dPROs may be influenced by cultural factors,[3] and possibly by access to publicly funded treatment, as socioeconomic status may shape perceived treatment need.[144] As the sample size was not sufficient to conclude that non-significant differences are truly absent, the findings may also inform sample size calculations in future studies.

Paper III may guide the choice of method in future studies and encourage further reliability analyses. Its results may be transferable to similar settings, samples, and raters of comparable experience. However, reliability is not an inherent property of an instrument and should be assessed when the protocol is applied in new settings or by other raters.[156]

CONCLUSIONS

In adolescents with dental crowding and displaced teeth treated without extractions using either a passive self-ligating or a conventional fixed appliance system, it was concluded that:

Occlusal outcomes and treatment time

- Both appliance systems produced successful occlusal outcomes, as measured by the weighted Peer Assessment Rating index and Little's Irregularity Index, with no statistically significant intergroup differences after treatment.
- Crowding was resolved through transverse expansion and incisor proclination in both groups, but the pattern differed during alignment: greater transverse expansion was observed in the PSLB group and greater mandibular incisor proclination in the CB group. These differences did not remain after treatment.
- Treatment time did not differ significantly between the appliance systems, although it was numerically approximately 2.6 months shorter in the CB group. The study was not powered for this outcome.

Oral health-related quality of life, experience, and satisfaction

- Oral health-related quality of life declined during active treatment, mainly in the oral symptoms and functional limitations domains, and improved beyond pretreatment levels after treatment.
- Motivation and satisfaction with treatment outcome were high in both groups, and regret about having started treatment was low. Differences

between the appliance systems were few and of questionable clinical relevance.

- Before treatment, girls reported poorer emotional well-being than boys, despite marginally lower objective treatment need. No difference remained after treatment.

Reliability of the alveolar bone assessment protocol

- Intrarater reliability for the measurement protocol was moderate to excellent, and interrater reliability was poor to good.
- Intrarater agreement for both alveolar bone level and fenestration outcomes was sufficient for follow-up assessment by a single rater.
- Site-specific MDC_{95} values ranged from 0.53 to 1.94 mm, indicating the minimum change in the alveolar bone level to cementoenamel junction distance distinguishable from measurement error.

Alveolar bone support as assessed by CBCT

- No significant differences were observed between the appliance systems in alveolar bone level change or in the occurrence of fenestrations.
- The distance between the alveolar bone level and cementoenamel junction increased at most surfaces, most markedly on the buccal surfaces of the mandibular incisors, where the changes exceeded measurement error. Individual variation was large, with some patients showing an increased alveolar bone level distance to cementoenamel junction exceeding 8 mm.
- Fenestrations decreased after treatment, most markedly at the buccal surfaces of the mandibular incisors. This may reflect merging with receding marginal bone defects or resolution of fenestrations, potentially associated with more favourable root positioning.

The findings of this thesis, together with the other results from the CROWDIT project, suggest that the choice of appliance system may be guided by patient and clinician preference. However, treatment planning should consider potential adverse effects, and patients comparable to this sample should be informed about a possible temporary decline in OHRQoL during treatment. Results from the planned long-term follow-up and health-economic analysis may refine this conclusion.

FUTURE RESEARCH

The between-group differences in arch expansion observed at the completion of alignment had disappeared by the end of treatment, after an identical archwire form had been used in both groups. Future research should consider individualising the final stainless steel archwire to the arch form achieved during alignment to determine whether the differences at alignment would persist.

Patient-reported outcomes were assessed with questionnaires; qualitative interviews could deepen understanding of the experiences, motivation, and satisfaction with treatment outcome reported by adolescents in Paper II and generate hypotheses for future research.

The clinical significance of the reduced alveolar bone support observed in Paper IV, and whether it recovers, will be addressed in the planned seven-year follow-up of the present sample. Assessing which types of tooth movement are associated with alveolar bone alterations could also provide information of clinical relevance.

In future radiographic studies, assessing the area of exposed root surface may be more informative than linear measurements at predetermined sites. Combining subjective assessment of image quality with objective phantom testing would allow reliability estimates to be related to the quality of individual volumes. Non-ionising modalities, such as ultrasound, merit further exploration, as they may eventually allow alveolar bone to be examined more frequently, including during treatment.

The planned health-economic analysis of treatment duration, number of appointments, and direct and indirect costs will further inform the choice between the two systems.

THE USE OF GENERATIVE ARTIFICIAL INTELLIGENCE

Generative artificial intelligence (AI) tools (Table 10) were used during the preparation of the manuscripts and the thesis summary. Specifically, they were used for language editing, including correcting spelling and grammar, improving readability, and providing feedback on structure and coherence.

During the finalisation of Papers I–II, AI tools were used to correct spelling and grammar. For Papers III–IV and the thesis summary, they were used for all the purposes described above.

The intellectual content, scientific reasoning, statistical analyses, interpretations, and conclusions of Papers I-IV are those of the authors, who take full responsibility for the final content.

Table 10. AI tools used during the preparation of Paper I-IV and the thesis summary

	Paper I	Paper II	Paper III	Paper IV	Thesis summary
Microsoft Copilot	✓	✓	✓	✓	✓
OpenAI Chat GPT			✓	✓	✓
Anthropic Claude				✓	✓

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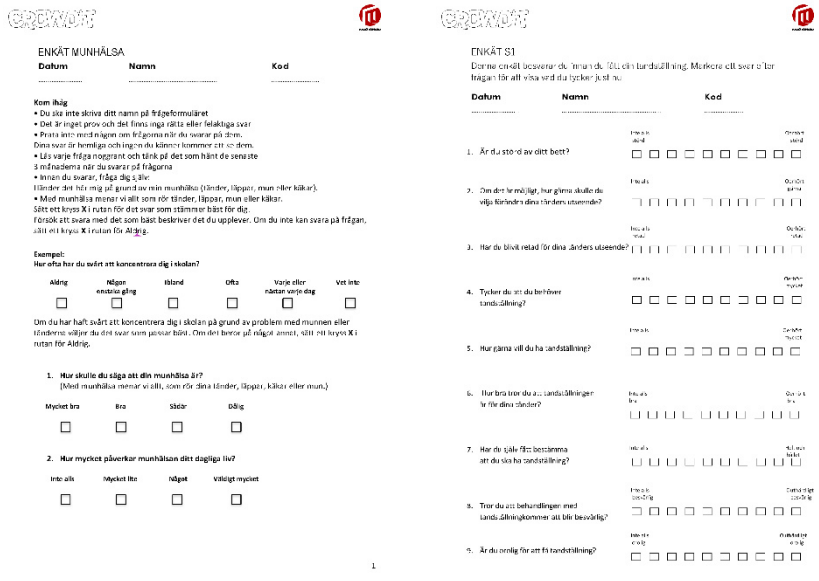
APPENDIX



ENKÄT MUNHÄLSA

Datum ..... **Namn** ..... **Kod** .....

Kom ihåg
- Du ska inte skriva ditt namn på frågeformuläret
- Det är inget prov och det finns inga rätta eller felaktiga svar
- Prata inte med någon om frågorna när du svarar på dem. Dina svar är hemliga och ingen du känner kommer att se dem.
- Läs varje fråga noggrant och tänk på det som hänt de senaste 3 månaderna när du svarar på frågorna
- Innan du svarar, fråga dig själv:
Tänder det här mig på grund av min munhälsa (tänder, läppar, mun eller käkar).
- Med munhälsa menar vi allt som rör tänder, läppar, mun eller käkar.

Sätt ett kryss **X** i rutan för det svar som stämmer bäst för dig.
Försök att svara med det som bäst beskriver det du upplever. Om du inte kan svara på frågan, sätt ett kryss **X** i rutan för Aldrig.

Exempel:
Hur ofta har du svårt att koncentrera dig i skolan?

Aldrig	Någon enstaka gång	Ibland	Ofta	Varje eller nästan varje dag	Vet inte
☐	☐	☐	☐	☐	☐

Om du har haft svårt att koncentrera dig i skolan på grund av problem med munnen eller tänderna väljer du det svar som passar bäst. Om det beror på något annat, sätt ett kryss **X** i rutan för Aldrig.

1. **Hur skulle du säga att din munhälsa är?**
(Med munhälsa menar vi allt, som rör dina tänder, läppar, käkar eller mun.)

Mycket bra	Bra	Sådär	Dålig
☐	☐	☐	☐

2. **Hur mycket påverkar munhälsan ditt dagliga liv?**

Inte alls	Mycket lite	Något	Väldigt mycket
☐	☐	☐	☐

1

ENKÄT S1

Denne enkät besvarer du innan du får din tandställning. Markera ett svar på varje frågan för att vissa vad du tycker just nu.

Datum ..... **Namn** ..... **Kod** .....

1. Är du stolt av ditt bett?
2. Om det är möjligt, hur gärna skulle du välja förändra dina tänders utseende?
3. Har du blivit retad för dina tänders utseende?
4. Tycker du att du behöver tandställning?
5. Hur gärna vill du ha tandställning?
6. Hur bra tror du att tandställningen är för dina tänder?
7. Har du själv fått bestämma att du ska ha tandställning?
8. Tror du att behandlingen med tandställningen kommer att bli besvärlig?
9. Är du orolig för att få tandställning?

Layout of the Child Perceptions Questionnaire 11-14 (left) and Feldmann's questionnaires on expectations, motivation, and satisfaction with treatment outcome (right).

CHILD PERCEPTIONS QUESTIONNAIRE 11-14
Hur skulle du säga att din munhälsa är?
Hur mycket påverkar munhälsan ditt dagliga liv?
Oral symtoms
Ont i dina tänder, läppar, käkar eller mun?
Blödande tandkött?
Sår i munnen?
Dålig andedräkt?
Mat som fastnat i eller mellan dina tänder?

Mat som fastnat i gommen?
Functional limitations
Andats genom munnen?
Behövt längre tid än andra för att äta en måltid?
Haft svårt för att sova?
Haft svårt för att bita av eller tugga mat som äpple, morot eller kött?
Haft svårt för att gapa stort?
Svårt att uttala något ord?
Svårt att äta mat som du skulle vilja äta?
Svårt att dricka med sugrör?
Svårt att dricka eller äta varm eller kall dryck eller mat?
Emotional wellbeing
Känt dig irriterad eller frustrerad?
Känt dig osäker på dig själv?
Känt dig blyg eller generad?
Oroat dig för vad andra tycker om dina tänder, läppar, mun eller käkar?
Oroat dig för att du inte ser lika bra ut som andra?
Varit upprörd?
Känt dig nervös eller rädd?
Oroat dig för att inte vara lika frisk som andra?
Oroat dig för att du är olik andra barn och ungdomar?
Social wellbeing
Varit borta från skolan på grund av munnen, tänderna eller tandbehandling?
Haft svårt att koncentrera dig i skolan?
Haft svårt att göra dina läxor?
Inte velat tala eller läsa högt inför klassen?
Undvikit att delta i fritidsaktiviteter efter skolan?
Inte velat tala med andra barn eller ungdomar?
Undvikit att le eller skratta när du varit med andra barn och ungdomar?
Haft svårt att spela musikinstrument som blockflöjt, flöjt, klarinett eller trumpet?
Inte velat vara med andra barn eller ungdomar?
Varit osams med andra barn eller din familj?
Andra barn och ungdomar retat dig eller kallat dig för dumma saker?

Feldmann’s questionnaire at baseline
Är du störd av ditt bett?
Om det är möjligt, hur gärna skulle du vilja förändra dina tänders utseende?
Har du blivit retad för dina tänders utseende?
Tycker du att du behöver tandställning?
Hur gärna vill du ha tandställning?
Hur bra tror du att tandställningen är för dina tänder?
Har du själv fått bestämma att du ska ha tandställning?
Tror du att behandlingen med tandställningkommer att blir besvärlig?
Är du orolig för att få tandställning?

Är du orolig för hur du kommer att se ut med tandställning?
Har du fått information om behandlingen?
Feldmann's questionnaire post alignment
Hur bra tror du tandställningen är för dina tänder?
Tycker du att tandställningen fungerar som du förväntat dig?
Är du nöjd med förändringarna i bettet hittills?
Känner du dig informerad om hur behandlingen går?
Har du blivit bra omhändertagen i samband med återbesöken?
Har du blivit bra omhändertagen i samband med akuta besöken?
Är du störd över tandställningen?
Skaver det från tandställningen?
Upplever du att tandställningen påverkar ditt humör?
Är det svårt att hålla tänderna rena nu när du har tandställning?
Upplever du att tandställningen förändrat ditt utseende?
Har du blivit retad för att du har har tandställning?
Har du någon gång ångrat att du började tandregleringsbehandlingen?
Är du trött på behandlingen?
Feldmann's questionnaire post treatment
Tycker du att tandställningen har varit bra för dina tänder?
Tycker du att tandställningen fungerat som du förväntat dig?
Är du nöjd med förändringarna i bettet?
Är du nöjd med utseendet på dina tänder?
Har du någon gång ångrat att du började tandregleringsbehandlingen
Om du innan behandlingsstart hade vetat det du vet idag, hade du då tagit om beslutet att genomgå en tandreglerings-behandling?
Hade du fått information om behandlingen innan du började?
Hade du fått information om hur lång tid behandlingen skulle ta?
Har du känt dig informerad under pågående behandling?
Har du blivit bra omhändertagen i samband med återbesöken?
Har du blivit bra omhändertagen i samband med akuta besöken?
Upplevde du smärta och/eller obehag när tandställningen sattes in?
Upplevde du att tandställningen skavde?
Upplevde du att tandställningen påverkade ditt humör?
Upplevde du att det var svårt att hålla tänderna rena när du hade tandställning?
Blev du retad för att du hade tandställning?
Upplevde du smärta och/eller obehag när tandställningen plockades bort?
Upplevde du smärta och/eller obehag av tråden eller skenan som nu stabiliserar dina tänder?

Dental crowding is one of the most common reasons for orthodontic treatment in adolescents. This thesis compares two types of fixed braces for treating crowding without tooth extractions. Based on a multicentre randomised controlled trial, it examines treatment outcomes, treatment time, quality of life, and patient experiences. It also evaluates a method for assessing the bone supporting the teeth using cone-beam computed tomography (CBCT), an X-ray technique that depicts the teeth and jaws in three dimensions, and describes how this bone changes during treatment.

Photo by Olivia Bokander Matilainen

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