SOFIA PETRÉN

CORRECTION OF UNILATERAL POSTERIOR CROSSBITE IN THE MIXED DENTITION

Studies of treatment effects, stability and cost-effectiveness
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PREFACE

This thesis is based on the following papers, which are referred to in the text by their Roman numerals:


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ABSTRACT

Unilateral posterior crossbite of dento-alveolar origin is a transverse discrepancy of the maxillo-mandibular relationship and is one of the most common malocclusions in the mixed dentition. If untreated, the crossbite and the abnormal lateral movement of the lower jaw may strain the orofacial structures, causing adverse effects on the temporomandibular joints, the masticatory system and facial growth. Thus, early orthodontic intervention is usually undertaken to correct the condition at the mixed dentition stage and the orthodontist may choose from a range of treatment methods. The method of choice for orthodontic treatment should not only be clinically effective, with long-term stability, but also cost-effective.

The overall aim of this thesis was to compare and evaluate different methods of correcting unilateral posterior crossbite, in terms of clinical effectiveness, stability and cost-effectiveness. The approach was evidence-based; randomized controlled trial (RCT) -methodology was used in order to generate a high level of evidence.

This thesis is based on four studies:

Paper I comprise a systematic review of the scientific literature and evaluation of the quality of the retrieved studies from an evidence-based perspective. The literature search spanned from January 1966 to October 2002 and was subsequently expanded in the frame story of this thesis to December 2010.
Papers II, III and IV were randomized controlled trials. Paper II compared and evaluated different strategies (Quad Helix, expansion plate, composite onlay and expectance for possible spontaneous correction) for correcting unilateral posterior crossbite in the mixed dentition. Paper III compared and evaluated the long-term stability and post-treatment changes associated with the Quad Helix and expansion plate methods, compared to normal controls. In paper IV, the cost-effectiveness of the Quad Helix and expansion plate methods was evaluated, using a cost-minimization analysis.

The following conclusions were drawn:

**Paper I**

The systematic review, including the supplementary literature search, disclosed that:

- RCT:s are needed to determine which treatment is the most effective for early correction of unilateral posterior crossbite.

- Future studies should also include assessments of long-term stability as well as analysis of costs and side-effects of the interventions.

**Papers II and III**

- Quad Helix is an appropriate and successful method and superior to expansion plate in terms of clinical effectiveness; the major disadvantage of the expansion plate method is the dependence on patient compliance.

- The composite onlay method is not effective for correction of unilateral posterior crossbite in the mixed dentition. Spontaneous correction does not occur.

- In cases of successful crossbite correction by Quad Helix or expansion plate appliances, both methods achieve similar long-term stability and the prognosis is favourable.
• Despite active transverse expansion, the width of the maxilla in the former crossbite patient group never reached the mean maxillary width of the normal group.

Paper IV

• Quad Helix offers significant economic benefits over the expansion plate appliance for correction of unilateral posterior crossbite.

• Quad Helix has lower direct and indirect costs and fewer failures needing re-treatment.

• Even with full compliance, i.e. when only successful treatments are considered, expansion plate treatment is more expensive than Quad Helix treatment.

Key conclusions and clinical implications

For correction of unilateral posterior crossbite in the mixed dentition, the Quad Helix appliance is superior to the expansion plate in terms of clinical effectiveness and cost-minimization and is thereby the preferred method of treatment. Both methods, provided that the outcome has been successful, show similar long-term stability.
POPULÄRVETENSKAPLIG SAMMANFATTNING

Enkelsidigt korsbett är en av de vanligaste bettavikelserna i växelbettet, dvs. i de åldrar då barnets tänder byts ut från mjölkätänder till permanenta tänder. Enkelsidigt korsbett innebär att överkäkens och underkäkens bredd inte passar ihop när man biter samman käkarna. Detta betyder att när patienten skall bita ihop glider underkäken åt sidan och patienten ”biter snett”. Om enkelsidigt korsbett inte behandlas finns risk för problem i form av avvikande funktion och smärttillstånd i käkar, ansiktsmuskler och käkleder samt att ansiktet kan bli asymmetriskt.

God tandvård innebär att använda effektiva behandlingsmetoder med god långsiktig stabilitet och kostnadseffektivitet. Det övergripande syftet med denna avhandling var att i växelbettet jämföra och utvärdera olika behandlingsmetoder för att korrigera enkelsidigt korsbett med avseende på effektivitet, stabilitet och kostnadseffektivitet. För att uppnå ett så högt vetenskapligt underlag som möjligt, utfördes randomiserade, kontrollerade studier (RCT), vilket innebär att patienterna som är med i studien har lottats till respektive behandlingsgrupp.
Avhandlingen är baserad på följande studier:


Konklusioner i delarbete I, inklusive den kompletterande litteratursökningen:
• RCTs behövs för att fastställa vilken behandlingsmetod som är mest effektiv för att behandla enkelsidigt korsbett i växelbettet.
• Framtida studier bör också analysera behandlingsmetodernas långsiktiga stabilitet, kostnadseffektivitet och sidoeffekter.

Konklusioner i delarbete II och III:
• Quad Helix är en effektiv behandlingsmetod och är överlägsen expansionsplåten.
• Composituppbyggnad på underkäkens kindtänder är inte effektiv för att korrigera enkelsidigt korsbett, och spontan korrektion sker ej vid avvaktan/utebliven behandling.
• Om korsbettsbehandlingen lyckas, antingen med Quad Helix eller med expansionsplåt, kan man förvänta sig likvärdig långsiktig stabilitet och prognosen är gynnsam.
• Trots aktiv expansion av överkäken på de patienter som tidigare hade korsbett uppnåddes aldrig samma vidd i överkäken som hos patienter utan tidigare korsbett (normalpatienterna).
Konklusioner i delarbete IV:
- Quad Helix är mer kostnadseffektiv än expansionsplåt.
- Quad Helix hade lägre direkta och indirekta kostnader och färre misslyckade behandlingar som behövde göras om.
- Även när enbart de lyckade behandlingarna räknades var behandling med expansionsplåt dyrare än Quad Helix.

**Klinisk betydelse:**

För att korrigera enkelsidigt korsbett i växelbettet är Quad Helix överlägsen expansionsplåten med avseende på behandlingseffektivitet och kostnader och är det primära behandlingsalternativet. Båda behandlingsalternativen, förutsatt att behandlingen lyckas med expansionsplåten, har god långsiktig stabilitet.
INTRODUCTION

Posterior crossbite

Definition
Posterior crossbite is defined as a malocclusion in the canine, premolar and molar region, in which the maxillary buccal cusps occlude lingually to the buccal cusps of the corresponding mandibular teeth.\(^1\) One or more teeth may be involved. The condition may be uni- or bilateral, but unilateral crossbites predominate. The condition may be of skeletal or dento-alveolar origin: skeletal crossbites usually result from a narrow maxilla, whereas dento-alveolar crossbites are caused by palatal tipping of the upper teeth. Unilateral posterior crossbite of dento-alveolar origin is most often associated with forced guidance of the lower arch, causing a midline deviation to the crossbite side (Figure 1, page 20).\(^2\)

Etiology
Environmental and hereditary factors are implicated, but there are also unknown causative factors. The correlation between sucking habits and posterior crossbite has been extensively investigated.\(^3\)-\(^7\) These studies suggest that during digital (thumb or finger) and pacifier sucking, the tongue is forced into a lower position in the mouth, thereby reducing the pressure of the tongue against the palatal surfaces of the maxillary canines and molars: such pressure normally counteracts the pressure of the cheeks. Thus pressure from muscular activity of the cheeks, in the absence of counter-pressure from the tongue against the palatal surfaces of the maxillary teeth, will result in a narrower upper arch. These changes
create a transverse disharmony that will increase the tendency for development of crossbite.

Similar changes of the tongue position are reported in patients with impaired nasal breathing, caused-for example- by obstruction of the oropharynx, by enlarged tonsils, or chronic respiratory obstruction in children with allergies.8-11 The role of heredity in the etiology of crossbite is unclear. The relatively high heritability of craniofacial dimensions and low heritability of dental arch variations are recognized, but the relative influence of these factors in the development of malocclusions which have both skeletal and dental components is unclear. Non-skeletal crossbites are often attributed to alterations in function.11

Prevalence
The prevalence of posterior crossbite is reported to be 8.5-17%; this implies that posterior crossbite is one of the most common malocclusions in the primary and mixed dentitions.2,12-14 The wide range of prevalence can be attributed to lack of uniformity in the different studies with respect to subject age, population, sample size and definitions.2

Figure 1. Unilateral posterior crossbite on the patient’s left side, causing deviation of the mandibular midline to the left.
Consequences of crossbite and treatment indications

In crossbite patients, the abnormal movement of the lower jaw may lead to additional strain on the orofacial structures, causing adverse effects on the temporomandibular joints (TMJs), the masticatory system and facial growth.15-23

Electromyographic (EMG) studies have disclosed asymmetrical activity of the temporal and masseter muscles in children with unilateral cross-bite,24-26 caused by differences in thickness of the muscles on the crossbite and non-crossbite sides.27 It is reported that correction of unilateral posterior crossbite normalizes the growth and development of the muscles and eliminates asymmetric activity.28,29

The lateral displacement of the mandible also results in a change in condylar position in relation to the temporal fossa and may cause TMJ clicking and pain. This may also influence the remodelling process in this area and cause undesirable changes in growth, i.e. facial asymmetry (Figure 2, page 22).28,29 Thus, early treatment is indicated to eliminate the risk that the functional crossbite will progress to become a skeletal malocclusion, a condition which may require extensive orthodontic and surgical treatment.

The maximum bite force in children with unilateral posterior crossbite is significantly smaller than in controls.25,30,31 While the bite force on the crossbite side is still impaired immediately after completion of active treatment32, in the long term symmetrical bite force and masticatory capacity are achieved.32,33 Headache is also reported more frequently in patients with unilateral posterior crossbite than in control patients.18,22,30

Most of the above-cited studies are included in a systematic review of posterior crossbite and functional changes, disclosing moderate to strong evidence of an association between posterior crossbite and temporomandibular disorder (TMD) symptomatology.23

An indistinct or weak association between unilateral posterior crossbite and TMD has also been claimed.35-38 However, the underlying scientific support is quite weak.

Finally, it has been claimed that a constricted maxilla may reduce the space required to accommodate the permanent maxillary teeth; in such cases maxillary expansion is often necessary to provide adequate dental arch space.11,34 However, these claims are based primarily on expert opinion, rather than on well-designed studies.
Figure 2. Patient with untreated unilateral posterior crossbite that has resulted in facial asymmetry and deviation of the mandible to the crossbite side.

Treatment strategies and methods
Crossbite correction can be undertaken early, at the primary or mixed dentition stage, or late, at the permanent dentition stage. Early treatment is often recommended: studies of adolescents and adults show that patients with unilateral posterior crossbite are at increased risk of developing TMD\textsuperscript{15-17,19} and it is believed that posterior crossbite in the primary dentition is transferred to the permanent dentition.\textsuperscript{11,34}

It has been claimed that spontaneous correction of unilateral posterior crossbite can occur.\textsuperscript{39,40} If a sucking habit is discontinued early, the conditions for spontaneous correction are favourable: tongue position and muscular activity can be normalised. To evaluate the eventual emergence of spontaneous correction, the presence or absence of sucking habits as a confounding factor must be clarified.

At the primary and early mixed dentition stages, cases of moderate transverse discrepancies (max./mand. arch width difference > 3.3mm in the canine region) may be treated by grinding the interfering cusps of the deciduous teeth.\textsuperscript{40-42} As with spontaneous correction, when the outcome is evaluated, the confounding effects of sucking habits must be considered.

Maxillary expansion may be achieved rapidly, in 2-3 weeks, using, for example, a rapid maxillary expansion (RME) appliance, or gradually, over 3-14 months, using, for example, a Quad Helix
appliance or an expansion plate. The difference in expansion rates reflects differences in the frequencies of activation, the magnitude of applied force, the duration of treatment and the proportion of dento-alveolar to skeletal effects. The skeletal effect implies opening of the midpalatal suture.

For RME, a fixed appliance is used, comprising stainless steel bands cemented onto the maxillary first molars and premolars and a standard stainless steel arch attached to a palatal screw (Figure 3c, page 24). The screw is activated once or twice a day (normally 0.25 mm) causing both dental and skeletal effects.\textsuperscript{43-45}

Quad Helix is a fixed appliance comprising stainless steel bands cemented onto the maxillary first molars and a standard stainless steel arch (MIA system, 3M, Unitek, US) attached to the palatal surfaces of the teeth (Figure 3a, page 24). The expansion of the steel arch (normally 10 mm before insertion) exerts a lateral force on the teeth, resulting in transverse expansion of the maxillary arch. If necessary, the appliance can be reactivated after 6 weeks. The effects are primarily dento-alveolar, with only minor skeletal effect. Once inserted, the appliance is not dependent on patient compliance.\textsuperscript{43,46-51}

An expansion plate is a removable maxillary appliance consisting of an acrylic palatal plate with a central expansion screw, retained by stainless steel clasps on the first primary and permanent molars (Figure 3b, page 24). To expand the plate, the screw is activated one or two notches per week, i.e. 0.2-0.4 mm, exerting pressure on the teeth in contact with the plate. The appliance is intended to be worn day and night, except for meals and toothbrushing. Progress is usually monitored at 4-6 weekly intervals until normal transverse relationships are achieved. The appliance has primarily dento-alveolar effects and only minor skeletal effects. The expansion plate is highly dependent on patient compliance.\textsuperscript{43,46-51}

It is claimed that occlusal onlays (Figure 3d, e, page 24) can correct unilateral posterior crossbite. The onlay, consisting of composite dental restorative material, is applied to the occlusal surfaces of the mandibular first molars: this is intended to open the bite, which in turn should inhibit the forced lateral movement and allow the maxilla to grow and develop in the transverse dimension, without locking the mandible in occlusion.\textsuperscript{52}
Expansion using a temporary anchorage device (TAD)
In recent years, use of the temporary anchorage device (TAD) (Figure 3f, page 24) has become more widespread.53-55 The extensive range of anchorage systems, such as palatal implants, miniscrews, miniplates and onplants, offers improved anchorage and various treatment effects, and can also be used as skeletal anchorage in combination with different expansion appliances.
Stability
When comparing the success rates and effectiveness of different methods, the long-term effects such as stability, should also be considered. It is only when a treatment method shows long-term stability that the real effectiveness can be evaluated. The definition of “long-term” is open to discussion, because it is highly dependent on the context. A common definition is five years after completion of active treatment, but this depends on the kind of outcome achieved or the aim of the treatment.56,57

In general, the stability of crossbite correction has not been adequately evaluated. With the exception of a few studies with follow-up periods of 2-5.5 years,41,42,51 the observation period after active treatment is rarely more than a few months.43,46,48,49 There is only one published study comparing the stability of outcomes of expansion plate and Quad Helix treatments.51

Evidence-based health care
In the health care sector, scientific assessment is undertaken in order to identify interventions which offer the greatest patient benefit while utilizing resources in the most effective way. Both established and innovative health care methods should be subject to scientific assessment.

Evidence-based health care can be defined as the precise and systematic implementation of evidence in clinical decision-making. However, such evidence cannot be applied indiscriminately to all patients. Thus, factors of importance in determining treatment outcome include not only the scientific evidence, but also the patients’ circumstances, values and preferences and the clinicians’ experience. Satisfactory dialogue with the patient requires more than adequate technical expertise and clinical experience on the part of the clinician; a further requirement is that the clinician is well informed about research and developments in the field.58

Why is evidence-based health care so important? Its primary goal is to enhance health by providing a more reliable foundation for clinical decisions. It also supports rapid adoption of effective methods and inhibits the dissemination of ineffective methods. Furthermore, it promotes economy of resources by favouring effectiveness. From
a scientific perspective, the evidence-based approach is a valuable instrument for identifying knowledge gaps, managing large volumes of information and clarifying the need for clinical trials.\textsuperscript{58}

Evidence-based health is founded on systematic reviews. These are critical compilations of all available scientific evidence about a designated question/problem, with reference to the benefits or risks of different methods of diagnosis, prevention or treatment.\textsuperscript{59} As it is almost impossible for the clinician to access and analyse all the available information, systematic reviews are excellent tools, providing comprehensive summaries of the evidence in a specified scientific field.

In an evidence-based approach to evaluation of effectiveness, the randomized controlled trial (RCT) is the acknowledged standard and is considered to generate the highest level of evidence, followed by controlled trials. Trials without controls, case series, case reports, and finally expert opinion, generate low or insignificant evidence.\textsuperscript{60} In the RCT, the randomized allocation of subjects ensures that both known and unknown determinants are evenly distributed among the different study groups. This minimizes bias in assessment of differences in effects between two or more treatment alternatives.

However, there are some misconceptions about evidence-based health, such as the concept that all evidence that has not been scientifically evaluated should be dismissed. Lack of evidence is not necessarily synonymous with lack of effect. Furthermore, while some claim that only evidence from RCTs should be considered, others maintain that the study design should be determined by the research question to be addressed. RCTs may be expensive and time-consuming and can sometimes be inappropriate for ethical reasons, especially when the control subjects remain untreated. Therefore, it is important to acknowledge that well-designed prospective and retrospective studies may also provide valuable evidence. However, because the limitations inherent in these study designs, the results must be carefully analyzed and interpreted with caution, because of the limitations inherent in the design.\textsuperscript{61}
Economic evaluation in Health Care

Economic evaluation – why should we use it?

For several decades, there has been increasing emphasis on economic evaluation of health care interventions. The main motivation is that resources in the health sector (people, time, facilities, equipment and knowledge) are limited: thus failure to apply the principles of cost-effectiveness may result in unsustainable financial overexpenditure, or withdrawal or reduction of services or resources in other areas of health care. It is, however, most important that pressure to deliver health care in a cost-effective environment is supported by studies which evaluate the economics of the services provided. When studies of different treatment methods are supported by strong evidence, it is possible to undertake comparative economic evaluations i.e. the outcome in relation to the cost, thus ensuring that limited resources are allocated to areas where they are most beneficial.

In future, economic evaluations are expected to assume increasing importance in the delivery of orthodontic services: when allocating resources, health service planners will require evidence not only of the clinical effectiveness of treatment, but also data disclosing “value for money”.

What is economic evaluation?

Economic evaluation is defined as “the comparative analysis of alternative courses of action in terms of their costs and consequences”. Two features characterize economic evaluation: it deals with the relationship between costs (input) and consequences (output) and secondly, it is concerned with selection of diagnostic or therapeutic options, implying alternative ways of allocating resources.

Four different types of economic evaluation can be used to gather evidence and compare the expected costs and consequences of different procedures in health care:

- A cost-effectiveness analysis is characterized by analysis of both costs and outcomes, where the magnitude of the outcomes of the various methods might differ.
• In a **cost-minimization analysis**, which is a type of cost-effectiveness analysis, the consequences of the treatment methods are identical (e.g. crossbite will be corrected) and the aim is to identify which method is least expensive.

• A **cost-utility analysis** focuses particular attention on the quality of the health outcome produced by the treatments and is used, for example, in health-related quality of life studies.

• A **cost-benefit analysis** is characterised by the fact that consequences are expressed in monetary units. This is used, for example, when evaluating distribution of resources to different areas of health care, etc.

Economic evaluations often include calculations of direct, indirect and societal costs.

**Direct costs** are those directly associated with the treatment, i.e. the costs of material and clinical treatment time, including costs for the premises and equipment, maintenance cleaning and staff costs.

**Indirect costs** arise as consequences of treatment, often defined as the loss of income incurred by the patient or the patient’s parents in taking time off from work to attend clinical appointments.

**Societal costs** are defined as the sum of direct and indirect costs.
SIGNIFICANCE

Early treatment of unilateral posterior crossbite has been extensively investigated. However, because of lack of uniformity of sample size and study design, the studies are difficult to interpret and compare. Therefore, from an evidence-based perspective, a systematic review of the literature on early crossbite correction would identify knowledge gaps and manage the large volume of information available in the literature, thus increasing understanding of the topic.

Because unilateral posterior crossbite is common in the mixed dentition, large numbers of children present with the condition every year and early intervention is clearly indicated. Many different treatment methods are available, however much of the treatment might be difficult to accomplish and some treatment might be unnecessary, because of inadequate treatment indications or the use of ineffective methods. The doubtful outcome also implies that some treatments are not cost-effective. Furthermore, the long-term stability of unilateral posterior crossbite correction is not sufficiently evaluated and requires further investigation.

When two treatment methods have been shown to achieve comparable clinical outcomes under optimal conditions, a cost-minimization analysis is the appropriate approach for comparing their cost-effectiveness.

The series of studies on which this thesis is based was designed to evaluate the treatment effects, stability and cost-effectiveness of unilateral posterior crossbite correction in the mixed dentition, using an evidence-based approach.
AIMS

**Paper I**
To conduct a systematic review of the literature, in order to:
- evaluate the retrieved studies according to the effectiveness of posterior crossbite correction
- determine which treatment method is the most effective
- evaluate the long-term stability of the treatment outcome
- analyze the methodological quality of the selected studies

**Paper II**
To compare and evaluate the effectiveness of different treatment strategies to correct unilateral posterior crossbite in the mixed dentition, in a randomized controlled trial.

**Paper III**
To evaluate the long-term stability of crossbite correction by Quad Helix appliances and expansion plates, with reference to a matched control group with normal occlusion, in a randomized controlled trial.

**Paper IV**
To determine and evaluate the costs of crossbite correction using Quad Helix or expansion plate appliances and relate the costs to the treatment effects by cost-minimization analysis.
HYPOTHESES

Paper I
Despite numerous studies, correction of unilateral posterior cross-bite in the mixed dentition is not sufficiently evaluated from an evidence-based perspective.

Paper II
Treatment of unilateral posterior crossbite by Quad Helix, expansion plate, and composite onlays on lower first molars is equally effective, and in untreated cases, no spontaneous correction will occur.

Paper III
Follow-up changes of patients treated with Quad Helix and expansion plates are similar, and of a magnitude comparable with those in subjects with normal occlusion.

Paper IV
Treatment with Quad Helix and expansion plate appliances is equally cost-effective.
MATERIALS AND METHODS

SUBJECTS
The study participants were consecutively recruited from two clinics of the Public Dental Health Service, Skane County Council, Sweden and from the Department of General Pediatric Dentistry, Faculty of Odontology, Malmö University, Malmö, Sweden. All patients met the following inclusion criteria: mixed dentition stage (eruption of all incisors and first molars), unilateral posterior crossbite, no sucking habits, or sucking habit discontinued at least one year before the trial started, and no previous orthodontic treatment.

Sixty-one patients were selected. One declined to participate; thus 60 patients were randomized into four groups (A-D). Group A (Quad Helix group) comprised 9 girls and 6 boys (mean age 9.1 years, SD 1.03), group B (expansion plate group) 9 girls and 6 boys (mean age 8.7 years SD 0.82), group C (composite onlay group) 8 girls and 7 boys (mean age 8.3 years SD 0.70), and group D (untreated group) 8 girls and 7 boys (mean age 8.8 years SD 0.70) (Paper II).

In Paper III the Quad Helix and expansion plate patients from Paper II were re-evaluated. Thus, in Paper III the patients comprised a majority of the patients in Paper II, supplemented with 10 extra patients, selected according to the pre-set inclusion criteria; these extra patients were randomly allocated to the two treatment groups (five to each group).
Twenty control subjects with normal occlusion were allocated to the follow-up investigation. This group was recruited from The Institute for Postgraduate Dental Education, Jönköping, Sweden. These subjects had normal sagittal occlusion, no crossbite or other malocclusion traits, and were matched for age and dental age to the treated subjects.

The composite onlay group and the untreated control group (30 patients) were excluded before the follow-up study started because the treatment outcomes had been unsuccessful. They were later treated for crossbite correction by their general dental practitioner, using Quad Helix appliances.

The study subjects in Paper IV included all patients from the Quad Helix (N=20) and expansion plate groups (N=20) from Papers II and III, i.e. both successful patients and patients needing re-treatment. Figures 4, 5 and 6, pages 34-36, present flow charts of the patients in Papers II, III and IV.

Ethical considerations
The Ethics Committee of Lund University, Lund, Sweden, which follows the guidelines of the Declaration of Helsinki, approved the informed consent form and study protocol (reg. nr. LU 399-00).

Consent and randomization
Before studies II and III, the participating general dental practitioners provided the patients and parents with oral and written information about the study. After written consent was obtained, the patients were randomized in blocks of five, into the different treatment groups. The subjects were randomized as follows: 4 opaque envelopes were prepared with 20 sealed notes in each (5 notes for each group). Thus, for every new patient in the study, a note was extracted from the first envelope. When the envelope was empty, the second envelope was opened, and the 20 new notes were extracted as patients were recruited to the study. This procedure was then repeated twice. The envelope was in the care of one investigator (S.P.), who randomly extracted a note and informed the dentist as to which treatment method was to be used.
Figure 4. Flow chart of the patients in Paper II.
Randomized crossbite patients
N = 40

Allocated to Quad Helix (A)
N = 20

Allocated to expansion plate (B)
N = 20

Did not complete treatment due to failure to comply
N = 5

Normal controls
N = 20

Analyzed and completed treatment
N = 20

Analyzed and completed treatment
N = 15

Analyzed and completed long-term follow-up
N = 20

Analyzed and completed long-term follow-up
N = 15

Analyzed and completed long-term follow-up
N = 20

Figure 5. Flow chart of the patients in Paper III.
Randomized patients
N = 40

Allocated to
Quad Helix
N = 20

Allocated to
expansion plate
N = 20

Did not complete
treatment due to
failure to comply
N = 5

Analyzed and com-
pleted treatment
and follow-up
N = 20

Analyzed and com-
pleted treatment
and follow-up
N = 15

Relapse at
follow-up
N = 1

Re-treatment with
Quad Helix
N = 1

Successful at
follow-up
N = 19

Successful at
follow-up
N = 15

Re-treatment with
Quad Helix
N = 5

Figure 6. Flow chart of the subjects in Paper IV.
METHODS

Paper I – Systematic review

Search strategy
The strategy for undertaking the systematic review was influenced primarily by the National Health Service, NHS, Center for Reviews and Dissemination.59 To identify all studies of early orthodontic treatment of unilateral posterior crossbite, a literature survey was done by applying the Medline database (Entrez PubMed, http://www.ncbi.nlm.nih.gov/pubmed). The survey covered the period from January 1966 to October 2002 and used the MeSH (Medical Subject Headings) terms: “palatal expansion” or “palatal expansion technique,” which were cross-referenced with various combinations of the MeSH terms “dentition, primary” and “dentition, mixed.” The Cochrane Controlled Clinical Trials Register was also searched.

Selection criteria
Early treatment of unilateral posterior crossbite was defined as treatment at the primary or early mixed dentition stage, i.e. before the age of 10 years. The studies selected for inclusion were those which reported data on the treatment effects and which had the following study designs: randomized controlled trials (RCT), prospective and retrospective studies with concurrent untreated as well as normal controls, and clinical trials comparing at least two treatment strategies without any untreated or normal control group. Abstracts, case reports, case series, reviews, and opinion articles were not considered. No restrictions were set for sample size. Articles written in English, German, French, and the Scandinavian languages were included. The reference lists of the articles retrieved were also hand-searched for additional studies.

Data collection and analysis
The following data were extracted: year of publication, study design, materials, dropouts, measurements, duration of treatment, success rate, expansion attained and expansion retained, side effects, costs, and author’s conclusion. Additionally, to document the methodological soundness of each article, a quality evaluation, modified
from the methods described by Antczak et al\textsuperscript{67} and Jadad et al\textsuperscript{68}, was undertaken with respect to the following pre-determined characteristics: study design, sample size and prior estimate of sample size, selection description, withdrawals (dropouts), valid methods, confounding factors considered, (for example, sucking habits), method error analysis, blinding for measurements, and adequate statistics. The quality was categorized as low, medium, or high. Two reviewers (authors S.P. and L.B.) scrutinised the articles independently. The data were extracted from each article without blinding to the authors, and inter-examiner disagreements were resolved by discussion of each article to reach a consensus. One author (B.S.) undertook quality evaluation of the statistical methods used in the articles.

\textit{New literature search}

Several articles on this topic have been published since October 2002. Therefore, Paper I was supplemented with a new survey spanning from October 2002 to December 2010 in the PubMed database, CINAHL databases and the Cochrane Controlled Clinical Trials Register. The MeSH terms in Paper I were complemented with the terms “maxillary expansion” and “crossbite correction”. The reference lists of the retrieved articles were also hand-searched. The same selection criteria, data collection and analysis as described in Paper I were used.

Based on the evaluated studies, the grading and the final level of evidence was judged according to the protocol of the Swedish Council on Technology Assessment in Health Care (SBU).\textsuperscript{57,69} (Tables I and II, page 39-40)
### Table I. Criteria for grading of assessed studies.

**Grade A – High value of evidence**

All criteria should be met:

- Randomized clinical study or a prospective study with a well-defined control group
- Defined diagnosis and endpoints
- Diagnostic reliability tests and reproducibility tests described
- Blinded outcome assessment

**Grade B – Moderate value of evidence**

All criteria should be met:

- Prospective or retrospective study with defined controlled or reference group
- Defined diagnosis and endpoints
- Diagnostic reliability tests and reproducibility tests described

**Grade C – Low value of evidence**

One or more of the conditions below:

- Large attrition
- Unclear diagnosis and endpoints
- Poorly defined patient material
Table II. Definitions of the evidence level.

<table>
<thead>
<tr>
<th>Level</th>
<th>Evidence</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Strong</td>
<td>At least two studies assessed as grade ”A”</td>
</tr>
<tr>
<td>2</td>
<td>Moderate</td>
<td>One grade ”A” study and at least two grade ”B” studies.</td>
</tr>
<tr>
<td>3</td>
<td>Limited</td>
<td>At least two grade ”B” studies</td>
</tr>
<tr>
<td>4</td>
<td>Insufficient</td>
<td>Fewer than two grade ”B” studies</td>
</tr>
</tbody>
</table>

Papers II and III
After randomization, all patients were treated according to a preset standard concept developed for each treatment strategy. Impressions for study casts were taken on all crossbite subjects at the start (T0), after one year (T1) (Paper II) and at three years post-treatment (T2) (Paper III). Impressions of the control subjects with normal occlusion (Paper III) were taken at T0 and T2.

Quad Helix
The Quad Helix appliance comprised a standard stainless steel arch (MIA system, 3M Unitek, US) with stainless steel bands attached with glassionomer cement to the maxillary first molars (Figure 3a, page 24). The Quad Helix was expanded 10 mm before insertion and then reactivated every 6 weeks until normal transverse relationship was achieved, i.e. no overcorrection was attempted. In order to prevent or compensate for buccal tipping, the appliance was adjusted for buccal root torque. The treatment result was retained for 6 months, with the same appliance serving as a passive retainer.

Expansion plate
The expansion plate was made of acrylic, with a central expansion screw and stainless steel clasps on the first primary and permanent molars (Figure 3b, page 24). The plate was activated 0.2 mm once a week by the patient until normal transverse relationship was achieved, i.e. no overcorrection was attempted. The dentist gave the patient strict instructions that the appliance was to be worn day and night, except for meals and toothbrushing. Treatment progress
was monitored monthly and the treatment result was retained for 6 months, with the same appliance serving as a passive retainer.

*Composite onlay*

The composite onlay technique was based on the theory that opening the bite will inhibit the forced lateral movement and thereby allow the upper jaw to grow and develop in the transverse dimension without the lower jaw being locked in occlusion. The bite-opening was achieved by bonding composite restorative material (Point Four, 3M, Unitek, US) onto the occlusal surfaces of the mandibular first molars (Figures 3d,e, page 24). The composite onlay was checked every 6 weeks, and was removed after one year. None of the cases required adjustment i.e. there was no need for supplementary composite material.

*Untreated control group*

For the crossbite patients who were randomized to the untreated control group, no orthodontic treatment was undertaken during the one-year observation period.

*Outcome measures*

- success rate for crossbite correction (Papers II-III)
- duration of treatment (Paper II)
- maxillary and mandibular intercanine and intermolar transverse distances, (Papers II and III)
- overbite, overjet and midline discrepancy (Paper III)
- maxillary and mandibular arch lengths (Paper III)
- sagittal occlusal relationship (supplementary analysis presented in the frame story of the thesis)

Successful treatment was defined as the attainment of normal transverse relationship within one year, i.e. the buccal cusps of all upper teeth should be in buccal relationship to the buccal cusps of the lower teeth. The success rate was judged by examination of study casts taken before (T0) and after one year (T1) (Paper II) and three years post-treatment (Paper III).

The duration of treatment was registered from the patient files as time taken (in months) to correct the crossbite (Paper II). If normal
transverse occlusion was not achieved, the treatment time was recorded as one year, i.e. the total observation period.

The maxillary and mandibular intercanine and intermolar distances were measured as shown in Figure 7a, page 42 (Papers II and III). The measurements were made with a digital sliding caliper (Mauser, Digital 6, 8M007906, Switzerland) and all measurements were made to the nearest 0.1 mm.

In Paper III, supplementary measurements of overbite, overjet, midline deviation and arch length were taken (Figure 7b, page 42). Overbite and overjet were measured to the nearest 0.5mm with a stainless steel ruler. Overjet was measured on the most protruding maxillary incisor. Midline deviation was defined as the discrepancy in millimetres between the maxillary and mandibular midlines.

Figure 7a

Figure 7b

Figure 7a. The transverse linear measurements made on the study casts in Paper II. Figure 7b. The linear measurements made on the study casts in Paper III.
One orthodontist undertook all the measurements in Paper II (L.B) and another in Paper III (S.P). All measurements and assessments of crossbite correction were conducted blindly, i.e. the examiner was not aware which treatment the patients had received, or if the study casts were from before or after treatment or at follow-up. Changes during treatment were calculated as the difference in the after-minus-before position.

*Intention-to-treat (ITT)*

Data on all patients who were randomly assigned to the different groups were analyzed on an ITT basis. This implies that if the crossbite was not corrected within the trial period of one year or if a corrected crossbite relapsed during the three-year follow-up period, the outcome was defined as unsuccessful and the eventual expansion effect that had occurred was noted. This means that all cases, successful or not, were included in the final analysis. In addition, any drop-outs were considered as unsuccessful, with no expansion.

*Supplementary study model analysis*

To investigate whether any changes had occurred in sagittal occlusal relationships during the observation period, a supplementary study model analysis was undertaken. The relationships at T0 and T1 were registered on the study models from Paper II (20 Quad Helix and 20 expansion plates) and at T0, T1 and T2 on the models from Paper III (20 Quad Helix and 15 expansion plates). The occlusal relationship was determined by the relationship between the first molars:

- Angle Class I: normal, up to or equal to \( \frac{1}{2} \) cusp postnormal or prenormal relationship.
- Angle Class II: More than \( \frac{1}{2} \) cusp postnormal relationship on at least one side.
- Angle Class III: more than \( \frac{1}{2} \) cusp prenormal relationship on at least one side.

When a Class II or Class III molar relationship was observed, the maxillary and mandibular canine relationship was checked to verify the result. The relationship of the distal surfaces of the maxillary and mandibular second deciduous molars was also recorded. If they
were in the same vertical plane (flush terminal plane) a Class I relationship was registered.

**Paper IV**

*The outcome measures were:*

- total costs, referred to as societal costs, representing both direct and indirect costs
- success rate after treatment and at 3 years post-treatment
- clinical treatment time
- number of appointments
- maxillary and mandibular intermolar and intercanine transverse distances

**Direct costs**

The direct costs comprised material costs and clinical treatment costs.

*Material costs* such as impression material, orthodontic bands, orthodontic cement, consumables, laboratory materials and fees etc, were compiled and calculated according to average commercial prices.

*Treatment costs* included costs for the premises and equipment, maintenance and cleaning, calculated according to average commercial prices in Sweden. In like manner, staff costs for dental assistants, general dentists and supervising orthodontists were calculated, including payroll tax. Clinical treatment time costs (minutes) for both scheduled and emergency appointments, the number of appointments, broken and cancelled appointments were registered for each patient, on a form included in the patient records.

The cost of clinical chairside time was calculated and estimated at 900 SEK (€98.50) per hour. All costs were based on 2010 prices and were expressed in Euros (€) (100 Swedish crowns = 10.94 Euros on December 14th, 2010, www.xe.com).

**Indirect costs**

The indirect costs were defined as the patients’ parents’ loss of income due to time taken off work to accompany their child to the appointment. The costs were calculated as wages plus social secu-
rity costs. The indirect costs per hour of an average Swedish worker were 235 Swedish Crowns (SEK), i.e. ~26 Euros (www.scb.se). The period of absence from work was assumed to be 90 minutes per visit.

Cost-minimization analysis
The cost-analysis was performed according to the intention to treat principle (ITT), i.e. all cost data of patients needing re-treatment due to non-compliance were also included in the analysis.

Three different outcome measures were performed:

- To compare and evaluate the mean societal costs in each group, of successful cases only, after active treatment (Quad Helix group: N=20 and expansion plate group: N=15), by dividing the societal costs of the successful cases by the number of successful cases.
- To compare and evaluate the actual mean societal costs in each group, of successful cases after active treatment, by dividing the costs for all patients (the Quad Helix group: N=20 and expansion plate group N=20) by the number of successful cases (Quad Helix group; N=20 and expansion group; N=15).
- To compare and evaluate the mean societal costs for the two groups to correct all patients. Thus, one re-treatment in the Quad Helix group and five re-treatments in the expansion plate group were added to the societal costs of each group; these costs were then divided by the number of all patients (Quad Helix group; N=20 and the expansion group; N=20).

Break-even point
A supplementary sensitivity analysis was made, using TreeAge software (TreeAge Software, Inc., 1075 Main Street Williamstown, MA 01267, USA, www.treeage.com) to investigate how much the cost for the Quad Helix treatment could increase before break-even point was reached, i.e. when the two treatments are identical in terms of cost-effectiveness.
Statistical analysis

Sample size calculation
In Papers II and III, the sample size for each group was calculated and based on a significance level of $\alpha=0.05$ and a power $(1-\beta)$ of 90% to detect a mean inter-group difference in expansion of 2 mm ($\pm1.5$ mm) between the different treatment strategies. The sample size calculation showed that 12 patients in each group were needed, but to increase the power even further and to compensate for possible drop-outs during the trial it was decided to select 15 patients for each group. Furthermore, when planning the follow-up study, it was decided to add ten more subjects (five in each group) to increase the power even more and compensate for possible drop-outs.

Descriptive statistics
The data were statistically analyzed using SPSS software (version 16.0, SPSS, SPSS Inc., Chicago, Ill., USA). For numerical variables, the arithmetic mean and standard deviation (SD) were calculated (Papers I-IV). The 95% confidence interval for the mean was calculated for all study model measurements in Paper III and costs in Paper IV.

Differences between groups
Fishers’ exact test was used to calculate the success rate of crossbite correction and midline deviation (Papers II and III).

Analysis of variance (ANOVA) with Tukey’s post-hoc test was used to compare treatment effects and active treatment time within and between groups. Differences with probabilities of less than 5% ($P < 0.05$) were considered statistically significant (Papers II and III).

In Paper IV, differences in costs between the two groups were analyzed by Students’ t-test. A $p$-value < 0.05 was considered as statistically significant.

Method error analysis
In Papers II and III, twenty randomly selected study casts were measured on two separate occasions. Paired $t$-tests disclosed no significant mean differences between the two series of records. The method error according to Dahlbergs’ formula did not exceed 0.2 mm for any of the measured variables.
RESULTS

Paper I - Systematic review
The search strategy yielded 1001 articles. After selection according to the inclusion/exclusion criteria, 12 articles qualified for inclusion in the final review. The main reasons for exclusion were:

- technical and clinical presentation of appliances
- case series
- case reports
- studies involving permanent dentition/adult patient
- surgically assisted treatment
- treatment combined with extractions
- full-fixed appliances
- discussion or debate articles.

Nine of the reported studies were from Nordic countries, two from Turkey and one from USA.

Treatment effects and duration of active treatment
The retrieved studies showed a success rate of 100% or close to 100% for treatment using Quad Helix and Rapid Maxillary Expansion (RME). For expansion plates, the success rate was between 51% and 100% and for grinding, between 27% and 70%. Spontaneous correction was found to occur in 16% to 50% of the untreated control groups. The treatment modalities Quad Helix and expansion plates were compared in five studies, and one study compared treatment with Quad Helix, expansion plate and RME. Four studies evaluated the effects of grinding versus no treat-
ment, whereas one study\textsuperscript{33} compared Quad Helix and grinding. One study\textsuperscript{46} analyzed and compared Quad Helix treatment in the primary dentition with treatment in the early mixed dentition stage.

The mean expansion obtained immediately after treatment by Quad Helix varied between 3.3 and 5.7 mm in the molar region and between 1.2 and 5.2 mm in the canine region. For expansion plate treatment, the corresponding figures were respectively 2.6 to 4.7 mm and 0.7 to 4.1 mm. The study on RME showed expansion of 5.5 mm in the molar region and 3.2 mm in the canine region. Grinding achieved minor expansion in the molar region and up to three mm in the canine region.

The duration of active treatment with the Quad Helix appliance varied between one and 7.7 months and for the expansion plate between four and 14 months. The reported duration of active treatment in the RME study was 19 days.

**Stability of crossbite correction**

In most of the articles the expansion effect was followed longitudinally, but there was a wide range of follow-up times. Four studies reported follow-up times of 0-1 year,\textsuperscript{43,46,48,49} 2 had a follow-up time of 1-2.5 years\textsuperscript{42,47} and three studies reported 3 years or more.\textsuperscript{33,41,51} Thus, the remaining expansion, i.e. expansion after retention or follow-up, varied between 3.3 and 5.1 mm in the molar region and between 2.2 and 3.3 mm in the canine region for Quad Helix treatment. For expansion plates, the corresponding values were between 3.1 and 3.7 mm and 2.5 and 3.7 mm respectively. The remaining expansion in the molar and canine region for RME was 5.4 and 3.3 mm, respectively.

**Comparison of treatment methods**

With respect to the most effective treatment, the results of the studies were contradictory, one study reporting equivalent effects for Quad Helix, RME and expansion plates\textsuperscript{43} whereas other studies reported that Quad Helix was superior to expansion plate treatment.\textsuperscript{49,50} Discrepant results were also reported with respect to the effects of grinding in the primary dentition and molar tipping between Quad Helix and expansion plate treatment. Boysen \textit{et al}\textsuperscript{49} found more tipping in the expansion plate group than in the Quad Helix group,
whereas in the study by Erdinc et al\textsuperscript{50} the Quad Helix group showed the most tipping. Four studies\textsuperscript{39-42} compared the treatment effect of grinding with spontaneous correction: two\textsuperscript{39,42} reporting that the effect of spontaneous correction was almost equal to that of grinding, whereas the other two\textsuperscript{40,41} supported grinding as an effective treatment in the primary dentition.

**Treatment complications and costs**

Reported complications were loose bands in Quad Helix cases and poor fit and broken appliances in expansion plate cases\textsuperscript{40,46-48}.

Four studies included mandibular arch measurements with inconclusive results, i.e. small but statistically significant increases, decreases as well as no effects\textsuperscript{43,47,49,51}.

Two studies\textsuperscript{47,48} involved calculation of costs. Both studies evaluated successful cases only and no indirect costs were considered. In these studies, the costs of Quad Helix and expansion plates were compared, and both studies reported lower costs for Quad Helix treatment. Further data of the systematic review are summarized in Table III, Paper I.

**Quality analysis**

The quality of the studies is summarized in Table IV, Paper I. The analysis revealed that the research quality or methodological soundness was low in eight studies and of medium quality in four studies. The most obvious shortcomings were small sample sizes, implying low power, problems of bias and confounding variables, lack of method error analysis, blinding in measurements, and deficient or lack of statistical methods. Furthermore, no study declared any power analysis or discussed the possible occurrence of type-II error.

**New literature search**

The supplementary literature search yielded a further 60 articles but only six studies met the inclusion criteria. The reasons for exclusion and the number of excluded articles are listed in Table III, page 50. In all, 162 independent decisions were made (S.P. and L.B.) and 97\% were in agreement. The remaining 3\% were resolved by discussion of each article to reach a consensus.
**Table III. Number of articles excluded in the new literature search.**

<table>
<thead>
<tr>
<th>Exclusion criteria</th>
<th>Number of articles excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case reports and case series</td>
<td>7</td>
</tr>
<tr>
<td>Permanent dentition, adults</td>
<td>9</td>
</tr>
<tr>
<td>Syndromes</td>
<td>5</td>
</tr>
<tr>
<td>Surgically assisted RME</td>
<td>10</td>
</tr>
<tr>
<td>Do not follow the objective of this review</td>
<td>23</td>
</tr>
<tr>
<td>Total number</td>
<td>54</td>
</tr>
</tbody>
</table>

**Treatment effects and duration of active treatment**

Overall, the reported expansion effects and duration of treatment in the new studies showed values similar to those of the earlier studies reported in Paper I. Data on treatment effects and stability, extracted from the new literature search, are summarized in Table IV, page 52.

**Quality analysis**

The new search revealed that the research quality or methodological soundness was medium in four studies and high in two studies, which partly involved the same sample. The shortcomings revealed were similar to those noted in the original search, i.e. absence of sample size calculation and blinding in measurements and the fact that confounding factors, e.g. sucking habits, were not considered. All studies provided adequate selection description, negligible if any withdrawals, valid methods, method error analysis and adequate statistics. Three of the six studies had 30 subjects in each group, and the two studies by Petrén and co-workers had undergone a sample size calculation prior to the start of the studies. The quality evaluation of the new literature search is summarized in Table V, page 53.
**Overall evidence**

According to the definitions of evidence level by the Swedish Council on Technology Assessment in Health Care (SBU)\(^69\) the following results can be stated:

There is moderate evidence for the effectiveness of Quad Helix and RME in the mixed dentition.\(^{44,51,71-75}\) There is also moderate evidence that Quad Helix is as good as or better than expansion plate in the mixed dentition.\(^{51,73,75}\)

It can also be stated that compared to Quad Helix, RME achieves greater transverse expansion in the canine region\(^{44,71,73-75}\) and that the two methods achieve similar changes in the molar region (moderate evidence).\(^{44,71,73-75}\)

Moderate evidence has also been found of small or clinically negligible transverse dimensional changes in the mandible.\(^{44,71-75}\)

There is insufficient evidence to support claims for space gain following maxillary expansion with Quad Helix, expansion plate and RME in the mixed dentition.

Finally, there is insufficient evidence to determine the cost-effectiveness of posterior crossbite correction.

**Stability of crossbite correction**

There is limited evidence for stability of crossbite correction at least 3 years post-treatment. Only two studies, one with strong evidence\(^73\) and one with moderate evidence\(^51\) reported good stability following both Quad Helix and expansion plate treatment.
**Table IV. Summary of data from studies retrieved by supplementary search.**

<table>
<thead>
<tr>
<th>Article, Material and age</th>
<th>Study design</th>
<th>Material &amp; Methods measurements</th>
<th>Treatment time/retention time</th>
<th>Success rate</th>
<th>Expansion achieved (mm)</th>
<th>Residual expansion (mm)</th>
<th>Side effects</th>
<th>Authors’ conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barzela and Jonas, 2007</td>
<td>R, CT</td>
<td>50 RME</td>
<td>treatment time unknown</td>
<td>unknown</td>
<td>unknown</td>
<td>unknown</td>
<td>unknown</td>
<td>79% of all cases</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 EP</td>
<td>unknown</td>
<td></td>
<td>2 years post-tx</td>
<td></td>
<td></td>
<td>long-term stable.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>–7.2 years (early)</td>
<td>unknown</td>
<td></td>
<td>3 years</td>
<td></td>
<td></td>
<td>No sign diff</td>
</tr>
<tr>
<td></td>
<td></td>
<td>–9.9 years (late)</td>
<td>unknown</td>
<td></td>
<td>2 years</td>
<td></td>
<td></td>
<td>between groups</td>
</tr>
<tr>
<td></td>
<td></td>
<td>study casts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cozzani et al, 2007</td>
<td>P; CCT</td>
<td>31 RME</td>
<td>treatment time unknown</td>
<td>all treated</td>
<td>4.1 / 5.9</td>
<td>3.7 / 4.0</td>
<td>unknown</td>
<td>RME anchored on</td>
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<tr>
<td></td>
<td></td>
<td>30 + 30 UC</td>
<td>unknown</td>
<td>succeeded</td>
<td></td>
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<td>–7.3 years</td>
<td>unknown</td>
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<td>1 year tx</td>
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<td></td>
<td>provide stable</td>
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<tr>
<td></td>
<td></td>
<td>–6.0 years</td>
<td>unknown</td>
<td></td>
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<td></td>
<td>expansion effects</td>
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<td></td>
<td></td>
<td>–8.4 years</td>
<td>unknown</td>
<td></td>
<td>1 year tx</td>
<td></td>
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<td>on permanent</td>
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<td></td>
<td></td>
<td>Study casts</td>
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<td></td>
<td></td>
<td></td>
<td>molars</td>
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<tr>
<td></td>
<td></td>
<td>1 yr post-tx</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Huynh et al, 2009</td>
<td>R, CT</td>
<td>74 S-RME (Haas)</td>
<td>–1 year at least 2 years</td>
<td>86% at follow</td>
<td>5.0</td>
<td>3.7 mm</td>
<td>molar tipping</td>
<td>Stability rate of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>41 S-RME (Hyrax)</td>
<td>follow-up, mean of 4 years</td>
<td>follow-up</td>
<td></td>
<td></td>
<td></td>
<td>expansion is 94%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>45 QH</td>
<td></td>
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<td>Hyrax, Haas and QH</td>
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<td></td>
<td>1 year post tx</td>
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<td>are equally</td>
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<td>effective in</td>
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<td>1 year observation</td>
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<td>expansion and</td>
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<td></td>
<td>6 months retention</td>
<td></td>
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<td>stability</td>
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<tr>
<td>Petrén and Bondermark, 2008</td>
<td>RCT</td>
<td>15 QH</td>
<td>4.8 months</td>
<td>15 / 15</td>
<td>4.4 / 1.4</td>
<td>not reported</td>
<td>not reported</td>
<td>Quad Helix is an</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15 EP</td>
<td>9.6 months</td>
<td>10 / 15</td>
<td>3.0 / 2.4</td>
<td></td>
<td></td>
<td>appropriate and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15 composite onlay</td>
<td>6 months retention</td>
<td>2 / 15</td>
<td>0.3 / 0.5</td>
<td></td>
<td></td>
<td>the most</td>
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<tr>
<td></td>
<td></td>
<td>15 UC</td>
<td>1 year observation</td>
<td>0 / 15</td>
<td>0.3 / 0.2</td>
<td></td>
<td></td>
<td>successful method</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>6 months retention</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Petrén et al, 2011</td>
<td>RCT</td>
<td>20 QH</td>
<td>1 year observation</td>
<td>19 / 20</td>
<td>3.7 / 1.5</td>
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<td>Overall good and</td>
</tr>
<tr>
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<td></td>
<td>20 EP</td>
<td>6 months retention</td>
<td>15 / 20</td>
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<td>2.6 / 0.6</td>
<td>broken EP</td>
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</tr>
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<td>2.0 / 0.2</td>
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<td>successful cases.</td>
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<td>6 months retention</td>
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<td>3 years follow-up</td>
<td></td>
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<tr>
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<td>RCT</td>
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<td>5.7 / 5.1</td>
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<td>structures</td>
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<td>Prior estimate of sample size</td>
<td>Selection withdrawal</td>
<td>Confounding factors considered</td>
<td>Method error in analysis</td>
<td>Blinding in measurements</td>
<td>Adequate statistics provided</td>
<td>Assessed standard of quality</td>
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<td>50+50</td>
<td>unknown</td>
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<tr>
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<tr>
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<td>yes</td>
<td>unknown</td>
<td>unknown</td>
<td>yes</td>
<td>medium</td>
</tr>
</tbody>
</table>

**Table V. Quality evaluation of the six new studies.**
Paper II - Treatment effects
In all, 61 patients were invited to participate, one of whom declined. Thus, 60 patients were randomized into the 4 groups, and all patients completed the trial (Figure 4, page 34). There were no significant differences between the groups with respect to age or crossbite side, and all 60 patients had a midline deviation favouring the crossbite side. No significant difference was found between boys and girls with respect to any of the study variables; hence the data for the genders were pooled for analysis. The transverse measurement variables of the jaws at baseline showed no significant differences between the groups.

A statistical analysis was undertaken to ensure that the five unsuccessful cases in the expansion plate group had no baseline characteristics which might have predisposed to treatment failure. No significant differences were found in the baseline characteristics of the successful and unsuccessful cases.

Success rate
The crossbites in all patients in the Quad Helix group were corrected. In the expansion plate group, two thirds (10 of 15) were corrected (p<0.05). In the composite onlay group, a few crossbites (2 of 15) were corrected and in the untreated control group, no spontaneous correction occurred. Thus, composite onlay was deemed an unsatisfactory method for crossbite correction and showed no significant differences compared with the untreated group.

Expansion effects in the maxilla
Maxillary intermolar and intercanine distances increased significantly in the Quad Helix and expansion plate groups. The Quad Helix had a more beneficial expansion impact on the molars, whereas gingival margin measurements showed a greater intercanine effect in the expansion plate group. Maxillary expansion in the composite onlay group was small, albeit significant. Minor changes were also noted in the untreated group.
Effects on the mandible and midline
In the mandible, small but significant intermolar expansion occurred in the expansion plate and untreated control groups. The mandibular intercanine distance changes were clinically negligible. The mandibular midlines were corrected in almost all patients in the Quad Helix and expansion plate groups. In the untreated control and composite groups, a few subjects showed correction of the mandibular midline, although the crossbite was not corrected.

Duration of treatment
The average duration of treatment was 4.8 months (SD 3.52) in the Quad Helix group and 9.6 months (SD 3.04) in the expansion plate group. Thus, the duration of treatment was significantly shorter in the Quad Helix group ($P = 0.0004$).

Untoward effects of treatment
Untoward effects necessitating emergency treatment occurred in both groups. In the Quad Helix group, these comprised loss of ligatures, loosened molar bands, and displacement of the palatal arch. In the expansion plate group, some appliances required repair or replacement due to fracture or unsatisfactory fit. An average of one emergency appointment per patient were registered in each group.

Paper III - Long-term effects and stability
Baseline
There were no significant differences between the treated groups with respect to age or crossbite side. As no significant gender differences were found for any of the study variables, the data for the genders were pooled for analysis. The crossbite subjects had significantly smaller values for all the maxillary variables. With respect to the mandibular variables, overbite, overjet and arch length, no intergroup differences were disclosed, except that the arch lengths of quadrants 2 and 4 in the control group were greater than in the crossbite groups. The prevalence of midline deviation was 19 out of 20 in the Quad Helix group, 14 out of 15 in the expansion plate group, and 10 out of 20 in the normal group.
Success rate and transverse maxillary changes

The maxillary intermolar and intercanine distances increased significantly in both treatment groups during treatment.

Three years post-treatment, all 15 patients in the expansion plate group and 19 of the 20 patients in the Quad Helix group had normal transverse relationships, i.e. the treatment outcome was longitudinally stable with no statistical difference between the groups. However, during the post-treatment period, a significant decrease in maxillary transverse dimensions occurred in both treatment groups (Quad Helix: -0.8 mm in the molar region, -1.2 mm in the canine region and expansion plate: -0.6 mm in the molar region and -1.4 mm in the canine region).

The changes during the overall observation period showed a significant increase in maxillary transverse distances in all groups (p<0.01), except for the intercanine distance at the gingival margin in all groups. There was no significant inter-group difference in expansion, except for the maxillary intermolar cusp tip distance, which was greater in the treatment groups (QH: 3.4 mm, expansion plate: 3.5 mm) than in the normal control group (1.9 mm).

At the end of the follow-up period, the transverse distances for all maxillary variables remained significantly smaller in the treatment groups than in the normal control group, i.e. despite active transverse expansion, the mean maxillary width in the former crossbite patient group never reached the mean maxillary width of the normal control group. The changes in maxillary measurements in the two treatment groups are illustrated in Figure 8.

**Figure 8:** Diagram showing the maxillary intermolar expansion at T0, T1 (after treatment) and T2 (3 years after treatment) for the two treatment groups.
Transverse mandibular changes
During treatment, mandibular intermolar expansion was significantly greater in the expansion plate group (gingival margin: +0.4 mm, mesiobuccal cusp tips: +1.2 mm) than in the Quad Helix group (gingival margin: – 0.4 mm, mesiobuccal cusp tips: -0.1 mm). However, during the post-treatment period this difference was erased.

During the observation period there were small, albeit significant, differences in the mandible within the groups, but no inter-group differences except for the intermolar distance at the gingival margin, which was greater in the control group (+0.5 mm) than in the treated groups (-0.6 mm). However, at the final registration there were no differences between the groups. The changes in mandibular measurements in the three groups are illustrated in Table V, paper III.

Overbite, overjet and midline
Throughout the entire observation period, there were no differences within or between groups with respect to overbite or overjet.

After treatment, a correct midline was achieved in more than half the crossbite patients but there was no significant inter-group difference. However, in some cases the corrected midlines in the treatment groups relapsed post-treatment; a few spontaneous corrections also occurred and new deviations arose. In the same manner, both spontaneous midline corrections and new deviations occurred in the normal control group. No significant differences were found between the groups.

Changes in arch length
The arch length in quadrant 3 became greater in the expansion plate group (+0.4 mm) than in the Quad Helix group (-0.7 mm) after treatment.

At T2, the arch length in both jaws on the right side was significantly larger in the control group (Q1: 38.8 mm; Q4: 34.4 mm) than in both the Quad Helix group (Q1: 36.8 mm, Q4: 32.9 mm) and the expansion plate group (Q1: 36.8 mm, Q4: 33.6 mm). However, during the overall observation period there were no differences within or between groups. Thus, crossbite correction, regardless of
treatment method, achieved no clinically relevant increase of space in the dental arches to accommodate the permanent teeth.

Changes in sagittal molar relationship - supplementary analysis
The supplementary model analysis revealed no changes in molar relationship during the observation period. Thus, correction of a crossbite did not result in any benefit to or deterioration of the sagittal molar relationship.

Paper IV - Cost-minimization
Societal costs
Costs for successful patients only
The mean societal costs for the patients with successful treatment outcomes were significantly lower (p<0.05) for the Quad Helix than for the expansion plate patients (Table VI, page 60).

Costs for successful and unsuccessful patients
To achieve 15 successful treatment outcomes with the expansion plate method, 20 patients had to undergo treatment. Thus, the mean societal costs, including both successful and unsuccessful outcomes, increased even more (p<0.01) in the expansion plate group (Table VI, page 60.)

Costs for successful treatment of all patients, including re-treatment costs
As five of the expansion plate treatments failed during active treatment and one of the Quad Helix patients relapsed during the 3-year follow-up period, these patients had to undergo further treatment (with Quad Helix) to achieve crossbite correction. This implied that the final mean societal costs for successful treatment outcome for all 20 patients in each group were €1031 (SD 244) for the Quad Helix group and €1395 (SD 539) for the expansion plate group, i.e. expansion plate treatment was 35% more expensive than Quad Helix (p<0.01) (Table VI, page 60).
Direct costs
The mean material costs and treatment time costs for the successful cases, all cases and all cases including re-treatments are summarized in Table VI, page 60.

Indirect costs
The indirect costs were €39 per appointment. Multiplied by the number of appointments, the mean indirect costs for the successful patients, all patients and all patients including re-treatment are summarized in Table VI, page 60. When re-treatment appointments are included, the indirect costs for the expansion plate group were 43.8% higher. Furthermore, the results disclosed that the indirect costs comprise approximately 40% of the societal costs.

Break-even Point
Supplementary sensitivity analysis showed that the costs for Quad Helix could increase by €438 before reaching the point of break-even, i.e. when the two treatments would be identical in terms of cost-effectiveness.

Untoward effects and number of appointments
The mean number of appointments for patients with successful treatment outcomes was 10.2 for the Quad Helix patients and 12.4 for the expansion plate patients. The mean number of appointments for both successful and unsuccessful outcomes (20 QH and 20 EP) was 10.2 for the Quad Helix and 17.1 for the expansion plate. Finally, all patients, including the re-treatments, required approximately 10.7 and 15.4 appointments, respectively.

During the course of treatment, an average of one emergency/unscheduled appointment per patient was recorded in each group. In the Quad Helix group, patients presented for loss of ligatures, loose molar bands, or displacement of the palatal arch. Emergencies in the expansion plate group comprised repair or remake of the appliance due to fracture or unsatisfactory fit.
Table VI. Mean costs in Euros for the Quad Helix group and the expansion plate group for successful patients only, successful and unsuccessful patients and after re-treatment of one patient in the Quad Helix group and five in the expansion plate group.

<table>
<thead>
<tr>
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<th>Successful only</th>
<th>Successful and unsuccessful</th>
<th>Including re-treatment</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Societal costs</td>
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<td>981</td>
<td>1031</td>
</tr>
<tr>
<td>Direct costs -material</td>
<td>230</td>
<td>230</td>
<td>241</td>
</tr>
<tr>
<td>Direct costs -time</td>
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<td>359</td>
<td>377</td>
</tr>
<tr>
<td>Indirect costs</td>
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<td>392</td>
<td>413</td>
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<td><strong>Expansion plate</strong></td>
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<tr>
<td>Societal costs</td>
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<td>1395</td>
</tr>
<tr>
<td>Direct costs -material</td>
<td>285</td>
<td>380</td>
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</tr>
<tr>
<td>Direct costs -time</td>
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<td>458</td>
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<tr>
<td>Indirect costs</td>
<td>479</td>
<td>662</td>
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DISCUSSION

This thesis presents a systematic, comprehensive evaluation of the effectiveness of unilateral posterior crossbite correction in the mixed dentition. The strength of the evidence was of high priority; thus the initial step was to undertake a systematic review of the literature, in order to survey and grade the currently available evidence. Then followed a series of studies, using RCT-methodology, to determine the effectiveness, stability and cost-minimization of unilateral posterior crossbite correction.

The main findings of the initial systematic review were that the available scientific evidence was insufficient to determine which treatment modality for correcting unilateral posterior crossbite in the mixed dentition: grinding, Quad Helix, expansion plates or RME, was the most appropriate, in terms of clinical effect, long-term stability and cost-effectiveness.

The main findings of the clinical studies were that the Quad Helix method was the most effective treatment, followed by the expansion plate method. In cases with successful outcomes, the two methods achieved similar results in terms of stability at the three year follow-up. However, the cost-minimization analysis clearly revealed that the Quad Helix method was less expensive, primarily because there were fewer failures needing re-treatment. Thus the Quad Helix method should be the orthodontist’s preferred method of treatment.
Methodological aspects

Paper I
In evidence-based health care, decisions are based on the best available scientific evidence from rigorous trials, complemented by knowledge from other sources and input from patients and caregivers. For summarizing the best possible scientific evidence in the literature, a helpful tool is a systematic review, based on a literature search and evaluation of the evidence, applying strict rules for reliability and validity.

The strategy for undertaking the systematic review was adopted from the National Health Service, NHS, Center for Reviews and Dissemination which is an acknowledged methodology for systematically reviewing the literature. To minimize the risk of overlooking important information, highly regarded, comprehensive databases were searched and the reference lists of retrieved articles were hand-searched.

The quality of the articles was denoted as low, medium or high. This may imply some subjectivity, but two independent observers scrutinized the articles and any conflicting assessments were solved by discussion, to reach a consensus. Furthermore, at the final evaluation the definitions of evidence levels developed by the Swedish Council on Technology Assessment in Health Care (SBU) were applied to define and grade the retrieved studies.

One methodological challenge encountered in the review process was the classification of the studies; in some cases, the study design was unclear. To facilitate this, it is recommended that the authors should clearly state which study design has been used.

The review covers a wide range of study designs, i.e. prospective and retrospective observational studies with concurrent controls, as well as observational studies comparing different treatment modalities. The main reason for this strategy was that in assessing the scientific literature it has been claimed that randomized trials are to be preferred, but observational prospective or retrospective studies should not be disregarded.

The supplementary search up to December 2010 showed that during the last eight years, a series of new studies has been undertaken, mainly on rapid maxillary expansion (RME), but the
studies constituting Papers II and III in the present thesis have also contributed to current knowledge. The new search revealed six studies, four with medium evidence levels\(^4,4_{4,71,72,74}\) and two with high evidence levels.\(^73,75\) These studies contribute significantly to the overall conclusions of the systematic review, that there is moderate evidence that the Quad Helix method is as good as or even more effective than the expansion plate for correcting unilateral posterior crossbite in the mixed dentition. Despite the results from Papers III and IV in this thesis, the scientific evidence of long-term stability following Quad Helix and expansion plate treatment is limited and there is insufficient scientific evidence of cost-effectiveness of unilateral posterior crossbite correction. To reach higher level of evidence would require at least one more study supporting the results from Papers III and IV.

**Papers II-IV**

To achieve the highest level of evidence, the clinical design was based on the standard criterion – RCT methodology. By using RCT methodology, problems of different bias and confounding variables are avoided by ensuring that both known and unknown determinants of outcome are evenly distributed between the groups. The prospective design also implies that baseline characteristics, treatment progression, treatment times, and side effects can be controlled and observed accurately. Additionally, it is also important that the clinicians participating in a clinical study should preferably be equally competent in the different methods, as was the case in the present studies. The allocation procedures guaranteed external validity and the results could therefore be generalized to other orthodontic patients.

Method error analysis was performed. Twenty randomly selected study casts were measured on 2 separate occasions. No systemic errors were found and the measurement error was low. In addition, the measurements were blinded, i.e. the examiner was unaware of the patient’s group affiliation, thus minimising the risk of measurements being affected by the researcher. The results have therefore provided high levels of evidence for the conclusions presented in this thesis.

The sample size of the studies might seem rather small. However, prior to the onset of the studies, a sample size calculation was made to determine adequate sample size (\textit{http://biostat.mc.vanderbilt.edu/})
The power analysis in Paper II showed that 12 patients per group were sufficient (power 90%); to increase the power further and to compensate for possible dropouts, it was decided to select 15 patients for each group. For the follow-up study (Paper III) it was decided to add further 10 subjects.

Crossbite correction is undertaken in the growing child; hence, post-treatment changes must be evaluated in the context of changes associated with growth in children who have had no orthodontic treatment. Therefore, it seemed appropriate to use an untreated control group in Paper II. Furthermore, correct evaluation of the long-term changes achieved in the successful cases would require an untreated control group. For ethical reasons this was not possible, but comparison was made with changes in normal controls.

The presence of an ongoing sucking habit may be a confounding variable in a clinical study like the present. False conclusions may be drawn, as an ongoing sucking habit inhibits spontaneous correction. On the other hand, if a sucking habit is discontinued early during the trial, this will facilitate normal transverse development and crossbite correction. One of the inclusion criteria for the present study was that the patients should have no ongoing sucking habit or should have discontinued the sucking habit at least one year before entering the trial. This reduced the risk of drawing false conclusions on possible spontaneous correction due to termination of sucking habits during the trial.

Data on all patients who were randomly assigned to the different groups were analyzed on an ITT basis. Thus, if the crossbite was not corrected within the trial period of one year, or if a corrected crossbite relapsed during the three-year follow-up period, the outcome was recorded as unsuccessful and the eventual expansion effect that had occurred was noted. This means that all cases, successful or not, were included in the final analysis. In addition, if any subjects withdrew from the trial, these cases were recorded as unsuccessful, with no expansion, and were included in the intention to treat analysis. An example of how the outcome can be impacted by using ITT is illustrated in Table VII. The data show outcomes with and without the application of ITT: without ITT, the data on unsuccessful cases are not included. Thus the expansion plate method appears to have more favourable outcome.
Table VII. Differences in treatment outcome for expansion plate with and without the Intention-to-treat approach.

<table>
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<th>Variable</th>
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<th>Without ITT</th>
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<tbody>
<tr>
<td>Mean molar expansion at gingival margin (mm)</td>
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<td>3.5</td>
</tr>
<tr>
<td>Mean cuspid expansion at gingival margin (mm)</td>
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<td>2.8</td>
</tr>
<tr>
<td>Mean treatment time (months)</td>
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<td>8.4</td>
</tr>
<tr>
<td>Success rate (%)</td>
<td>67</td>
<td>100</td>
</tr>
</tbody>
</table>

In retrospect, it is clear that some additional recordings would have yielded valuable data; unfortunately these were not included in the initial study protocol. Since compliance emerged as the critical determinant of the success rate of the expansion plate method, a compliance protocol would serve not only to remind/encourage the patients to wear their removable appliances as instructed, but also to disclose the reasons for poor compliance. Furthermore, a protocol recording discomfort, pain and other difficulties associated with both appliances would have been offered valuable insight into the impact of the orthodontic treatment on quality of life.

Untreated posterior crossbites can have untoward effects on the temporomandibular joints, the masticatory system and facial growth: thus a clinical examination by a specialist in stomatognathic physiology before and after treatment would have been valuable, as would extraoral photographs of all patients, to record possible enhancement of facial symmetry.
Treatment effects of crossbite correction

The results of Paper II rejected the hypothesis that treatment with Quad Helix, expansion plate, and composite onlay on the mandibular first molars was equally effective in correcting unilateral posterior crossbite and confirmed the hypothesis that spontaneous correction in the mixed dentition did not occur. Thus, the results clearly showed that for correction of crossbite at the mixed dentition stage, Quad Helix is an appropriate and successful treatment. This is probably due to the fact that the Quad Helix is not dependent on patient compliance, i.e. the application of force is continuous.

Patient compliance is an important determinant of the effectiveness of treatment with a removable appliance. In Paper II, poor patient compliance was probably the cause of failure in one-third of cases treated with expansion plates. The small significant transverse changes which occurred in the composite onlay and untreated groups were not clinically relevant, and attributable mainly to physiological change. Thus, it was concluded that approximately 0.5 mm of the expansion was due to growth changes.

Although there are many studies of unilateral posterior crossbite correction, to date, this is the only comparative study using RCT methodology which also includes an untreated control group. Therefore, direct comparison with previous studies was not feasible. In contrast to the present study, results from retrospective and prospective clinical trials have shown that expansion plate and Quad Helix treatments appear to be equally effective in correcting crossbites, i.e. these studies reported a somewhat higher proportion of successful expansion plate cases than the present study. One explanation might be that the present study used the ITT approach.

Long-term stability of crossbite correction

The results of Paper III confirm the hypothesis that the follow-up changes in the Quad Helix and expansion plate groups are similar and of a magnitude comparable with those in subjects with normal occlusion. The study clearly confirmed that if unilateral posterior crossbite of dento-alveolar origin is successfully corrected by the Quad Helix appliance or the expansion plate, similar long-term stability is achieved and the prognosis is favourable. These results contradict in part those of the retrospective study by Bjerklin, reporting that treatment with expansion plate was somewhat more stable.
At the end of the follow-up period, the maxillary transverse distances were still significantly smaller in both treatment groups compared with the normal control group and these data confirmed the earlier findings by Bjerklin.\textsuperscript{51} Thus, it can be stated that despite active transverse expansion, the width of the maxilla in the former crossbite patient group never reached the mean maxillary width of the normal group. This may be because the malocclusion in former crossbite patients is of such long standing that facial growth is impaired, implying that despite active treatment, facial growth does not catch up. Moreover, the crossbite may have caused a skeletal impact on the maxilla, which cannot be fully corrected by maxillary slow expansion. However, in the present material, the difference in width does not seem to have any clinical importance. These findings are not in agreement with the retrospective study by Huynh et al\textsuperscript{44} comparing the outcomes of treatment with Hyrax, Haas or Quad Helix with non-crossbite norms, reporting that former posterior crossbite patients show equivalent or even greater intermolar width after expansion and also at two years post-treatment. This might partly be explained by the more powerful forces of the Haas and Hyrax appliances, implying possible skeletal effects.

The baseline measurements showed no difference in mandibular width between the crossbite group and the normal group. This implies that the crossbites were due to a transverse discrepancy of the maxilla and not to a broad mandible.

The present study also investigated the potential for space gain following maxillary expansion with Quad Helix and expansion plate in the mixed dentition, but no clinically significant changes were found, i.e. the evidence for space gain is still insufficient.

Moreover, since to date the evidence of stability of unilateral posterior crossbite correction in the mixed dentition remains limited to only two published studies,\textsuperscript{51,73} no clear evidence-based conclusions can be drawn from these data. Therefore, further studies on both stability and space changes are needed.

A correct midline was achieved in more than half the crossbite patients during treatment. However, in some cases the corrected midlines relapsed post-treatment, a few spontaneous corrections occurred and new deviations arose. In the same manner, both spontaneous midline corrections and new deviations occurred in the normal control group. The explanation for these unpredictable changes may
be that the patients were observed during a period of facial growth and occlusal development, i.e. tooth migrations within the jaws because of permanent teeth on the right and left sides may erupt or deciduous teeth be lost at different occasions. Hence, the possible treatment impact on the midline in the mixed dentition should not be overestimated.

**Cost-minimization analysis**

The data from Paper IV reject the initial hypothesis that treatment with Quad Helix and expansion plate is equally cost-effective in correction of unilateral posterior crossbite of dento-alveolar origin. It was clearly shown that Quad Helix offers significant economic benefits over expansion plate treatment. The Quad Helix had lower direct and indirect costs and fewer failures needing re-treatment. Even when successful treatments were considered exclusively, expansion plate treatment was more expensive than the Quad Helix treatment. The supplementary sensitivity analysis showed that the costs for Quad Helix could increase by €438 before reaching the break-even point, i.e. when the two treatments would be identical in terms of cost-effectiveness. This analysis further highlights the difference in costs between the two methods.

There are few published studies of economic evaluations of orthodontic treatment. This was the first study to evaluate cost-minimization of crossbite correction. The main findings are partly in accordance with those of some previous studies. In a retrospective study it was reported that treatment with expansion plates was 40% more expensive than treatment with Quad Helix. The calculations were based on material and chair-time costs of successful cases only, i.e. indirect costs were not included. In another retrospective study, the average laboratory costs for the expansion plate group were three times greater and the number of appointments was 3.5 times greater than in the Quad Helix group. Despite variations in study design and the lack of separate cost-minimization analyses of direct and indirect costs in these earlier studies, the findings of the present study are in general agreement that treatment with Quad Helix offers greater economic benefits than treatment with an expansion plate.

Numerous factors may contribute to the differences in costs between the two treatment groups. By far the major direct cost was
for clinical treatment time, particularly staff salaries; the salaries of the dentists and dental assistants accounted for about 85% of total clinical treatment costs. The mean total treatment time and the number of appointments were significantly greater for the expansion plate group, possibly because of poor patient compliance. The greater number of appointments was also reflected in higher indirect costs in the expansion plate group. These data support the principle of preferentially selecting treatment methods which are less dependent on patient compliance, in order to ensure that treatment time and number of appointments are as low and effective as possible.

With respect to complications requiring unscheduled appointments, the Quad Helix appliances were adjusted by the dentist at the actual appointment, whereas adjustments to the expansion plates usually also required the services of a dental technician. This may have contributed to additional costs in the expansion plate group.

An inherent difficulty in economic evaluation is ascertaining the true values for all the key aspects of an intervention: when values need to be estimated, some uncertainty arises about the true cost-effectiveness. In the present study, it was necessary to estimate the mean parental time per visit, because this aspect was not factored in at the onset of the studies. When planning the study, a protocol for the parents would have provided accurate, individual data about indirect costs.

Finally, because the study presented in Paper IV is to date the only one reporting on this topic, there is insufficient evidence on cost-effectiveness of unilateral posterior crossbite correction. Accordingly, more such studies are needed.

While the mean differences in costs in the present study are clearly significant, extrapolation of the data to a national level further highlights the differences between the economics of the two treatment modalities. In 2009, there were 96,706 8 year-old children in Sweden. The prevalence of unilateral posterior crossbite is estimated at 10%. Assuming that all or half of all cases of unilateral posterior crossbite would be treated, the differences in societal costs between the two treatment methods would amount to 3.5 or 1.7 million Euros, respectively.
Treatment indications for expansion plate
On the basis of the results of this thesis, it is correct to state that expansion plate should *not* be used routinely. However, due to the design of the appliance, the expansion plate offers supplementary treatment potential of unilateral posterior crossbite correction in *some specific cases*, if the clinician is certain that the patient will co-operate. For example, spring coils or labial arches can easily be added to an expansion plate when a secondary treatment goal is to correct the position of the incisors.

Future research
The overall results of the studies provide moderate evidence that the Quad Helix appliance is more effective than the expansion plate for correction of unilateral posterior crossbite in the mixed dentition.\(^73,75\) However, several aspects require further research. New projects, based on a larger patient base, are being planned, such as a multi-centre RCT to evaluate RME versus Quad Helix in the mixed dentition. Among outcomes of interest are success rate, maxillary expansion, possible space gain, cost-effectiveness, long-term stability, facial asymmetry and possible effects on the orofacial structures.

Quality of life is also an important issue and may be impacted by e.g. discomfort and pain. Patient compliance is an important determinant of the outcome of most orthodontic procedures and this could be enhanced by improved understanding of the patient’s background, such as the family’s socio-economic status, cultural identity and possible language barriers. Another question of interest is whether there are differences in treatment outcomes (clinical effectiveness and cost-effectiveness) between cases treated by specialist orthodontists and those treated by general dentists working under the supervision of a specialist.

In everyday practice, the treatment method to be used is determined primarily by specialists in orthodontics; thus it would be of interest to document, by means of a questionnaire to all consultant orthodontists in Sweden, their indications for crossbite correction, choice of treatment method and timing of treatment.
CONCLUSIONS

The systematic review, including the supplementary literature search, led to the following conclusions:

- RCT:s are needed to determine which treatment is the most effective for early correction of unilateral posterior crossbite.
- Future studies should also include assessments of long-term stability as well as analysis of costs and side-effects of the interventions.

In the RCT comparing and evaluating different treatment strategies to correct unilateral posterior crossbite in the mixed dentition it was concluded that:

- Quad Helix is an appropriate and successful method.
- The success rate of expansion plate is limited.
- Composite onlays are not effective.
- Spontaneous correction does not occur.
- Small or clinically negligible transverse dimensional changes in the mandible may occur during maxillary expansion.

In the RCT comparing and evaluating the three-year stability of unilateral posterior crossbite correction using Quad Helix or expansion plate appliances, it was concluded that:

- If crossbite is successfully corrected by either method, similar long-term stability is achieved and the prognosis is very favourable.
- Despite active transverse expansion, the width of the maxilla in the former crossbite patient group never reached that of the normal group.
• The treatment strategies did not result in any clinically relevant space gain of the dental arches.

In the RCT on cost-minimization it was concluded that:

• Quad Helix offers significant economic benefits over expansion plate treatment.
• The Quad Helix method has lower direct and indirect costs and fewer failures needing re-treatment.
• Even with full co-operation, i.e. when successful treatments were considered exclusively, expansion plate treatment was more expensive than the Quad Helix treatment.

<table>
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<th>Key conclusions and clinical implications:</th>
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<td>For correction of unilateral posterior crossbite in the mixed dentition the Quad Helix appliance is superior to the expansion plate in terms of effectiveness and cost-minimization and is therefore the preferred method of treatment. In cases with successful outcomes, both methods show similar long-term stability.</td>
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SOFIA PETRÉN
CORRECTION OF UNILATERAL POSTERIOR CROSSBITE IN THE MIXED DENTITION
Studies of treatment effects, stability and cost-effectiveness