Systematic review

Effect of chin-cup treatment on the temporomandibular joint: a systematic review

Monika A. Zurfluh*, Dimitrios Kloukos**, Raphael Patcas* and Theodore Eliades*

*Clinic of Orthodontics and Paediatric Dentistry, University of Zurich, Switzerland, **Department of Orthodontics and Dentofacial Orthopedics, Faculty of Medicine, University of Bern, Bern, Switzerland

Correspondence to: Theodore Eliades, Clinic of Orthodontics and Paediatric Dentistry, Center of Dental Medicine, University of Zurich, Plattenstrasse 11, CH-8032 Zurich, Switzerland. E-mail: theodore.eliades@zzm.uzh.ch

Summary

Aim: To systematically search the literature and assess the available evidence for the influence of chin-cup therapy on the temporomandibular joint regarding morphological adaptations and appearance of temporomandibular disorders (TMD).

Materials and methods: Electronic database searches of published and unpublished literature were performed. The following electronic databases with no language and publication date restrictions were searched: MEDLINE (via Ovid and PubMed), EMBASE (via Ovid), the Cochrane Oral Health Group's Trials Register, and CENTRAL. Unpublished literature was searched on ClinicalTrials.gov, the National Research Register, and Pro-Quest Dissertation Abstracts and Thesis database. The reference lists of all eligible studies were checked for additional studies. Two review authors performed data extraction independently and in duplicate using data collection forms. Disagreements were resolved by discussion or the involvement of an arbiter.

Results: From the 209 articles identified, 55 papers were considered eligible for inclusion in the review. Following the full text reading stage, 12 studies qualified for the final review analysis. No randomized clinical trial was identified. Eight of the included studies were of prospective and four of retrospective design. All studies were assessed for their quality and graded eventually from low to medium level of evidence. Based on the reported evidence, chin-cup therapy affects the condylar growth pattern, even though two studies reported no significance changes in disc position and arthrosis configuration. Concerning the incidence of TMD, it can be concluded from the available evidence that chin-cup therapy constitutes no risk factor for TMD.

Conclusion: Based on the available evidence, chin-cup therapy for Class III orthodontic anomaly seems to induce craniofacial adaptations. Nevertheless, there are insufficient or low-quality data in the orthodontic literature to allow the formulation of clear statements regarding the influence of chin-cup treatment on the temporomandibular joint.

Introduction

The prevalence of Class III malocclusion has been reported to vary substantially among ethnic groups reaching 23% in Asian populations (1–5), whereas it does not exceed 5% in Caucasians (6–9). A deficient maxilla accounts for only 18% of the cases of Class III malocclusion, and an excessive mandible for more than 52%, implying the critical role of the mandible as the main cause of Class III (10–15).

Owing to its high rate of relapse, treatment of Class III malocclusion remains challenging for orthodontists, particularly in young growing patients. A wide array of treatment modalities has been described, including chin-cup, face mask, maxillary protraction combined with chin-cup, and the Fränkel functional regulator III appliance (5, 9, 16–20). Among the plethora of appliances described, the chin-cup appliance, which has been in use as since the 19th century, remains of special interest (21). The popularity of this therapeutic

route may be attributed to the direction of the applied force, which incorporates both sagittal and vertical vectors (22–25).

Several cephalometric studies have confirmed that chin-cup therapy improves Class III malocclusion through posterior repositioning of the mandible, redirection of mandibular growth backwards and/or downwards, closing of the gonial angle, remodelling of the mandible and temporomandibular joint (TMJ), retardation of mandibular growth, and retroclination of mandibular incisors (26–31). Despite the large quantity of evidence available, studies have provided contradicting results with respect to the outcomes and outcome measures of chin-cup therapy. A recently published systematic review stated that the Sella-Nasion-B' Point (SNB) angle decreased, the A' Point-Nasion-B' Point (ANB) angle increased and two out of four studies showed an increase in Gonion angle but no significant change in the mandibular length. Due to insufficient data in the included studies, the authors indicated that no clear recommendations regarding the efficacy of chin-cup appliance in the retardation of mandibular growth could be made (32), whereas other authors reported that the chin-cup appliance not only influences the growth of the mandible, but also cranial base and other maxillofacial structures (9, 33–36).

The histologic changes of condylar growth accompanying chin-cup therapy have been the topic of a substantial number of investigations (37–39). To this end, Ritucci and Nanda further reported the inhibited posterior growth at the posterior cranial base (40). This positional change of the TMJ and its surrounding structures may directly influence the mandibular position (41). Therefore, the orthopaedic results of chin-cup therapy may not only influence mandibular growth but may also induce posterior displacement of craniofacial structures. It has been, moreover, claimed that the backward force of chin-cup is applied directly to the mandibular condyle, and this may, in turn, lead to internal derangement of the TMJ (42, 43). Based on the evidence of histological and morphological reorganization within the TMJ during chin-cup therapy, an association between chin-cup therapy and temporomandibular joint disorders (TMD) has been widely discussed but remains a highly controversial issue (43–47).

The aim of this systematic review was, therefore, to systematically search the literature and assess the available evidence for the influence of chin-cup therapy on the TMJ regarding morphological adaptation and appearance of TMD.

Materials and methods

Selection criteria

1. Study design: prospective and retrospective studies were considered in this review, including randomized clinical trials, controlled clinical trials, and other observational studies in the absence of the first.
2. Types of participants: patients referred for chin-cup therapy for the correction of Class III malocclusion. Any age of patients was accepted.
3. Types of intervention: chin-cup therapy with or without auxiliaries, such as lingual arches or other intraoral mechanotherapies.
4. Outcome: morphological adaptations of the TMJ, changes of the condylar configuration, dysfunctions caused by the chin-cup therapy, and incidence and types of TMD.
5. Exclusion criteria: studies not reporting outcomes relevant to the condylar morphology or symptoms. Studies not employing exclusively chin-cup for the correction of Class III malocclusion. Animal studies were not considered eligible for inclusion in this review. Case reports were also excluded, as the sample size was considered inadequate.

Search strategy for identification of studies

For the identification of studies included or considered for this review, detailed search strategies were developed for each database searched. They were based on the search strategy developed for MEDLINE but revised appropriately for each database to take account of differences in controlled vocabulary and syntax rules. The following electronic databases were searched: MEDLINE (via Ovid and PubMed, Supplementary table 1) (1946 to 7 November 2013), EMBASE (via ovid), the Cochrane Oral Health Group's Trials Register, and CENTRAL.

Unpublished literature was searched on ClinicalTrials.gov, the National Research Register, and Pro-Quest Dissertation Abstracts and Thesis database.

The search attempted to identify all relevant studies irrespective of language. There were no restrictions on date of publication. The reference lists of all eligible studies were hand-searched for additional studies.

Selection of studies

Assessment of research for including studies in the review and extraction of data were performed independently and in duplicate by MAZ and DK who were not blinded to identity of the authors, their institution, or the results of the research. The full report of publications considered by either author to meet the inclusion criteria was obtained and assessed independently. Disagreements were resolved by discussion and consultation with TE. A record of all decisions on study identification was kept.

Data extraction and management

MAZ and DK performed data extraction independently and in duplicate. Disagreements were resolved by discussion or the involvement of a collaborator (TE). Data collection forms were used to record the desired information. The following data were collected on a customized data collection form: author/title/year of study, design of the study, setting of the study, number/age/gender of patients recruited, inclusion criteria (malocclusion of patients), intervention performed, control or comparison group, magnitude of force applied, diagnostic means, type of outcome assessed, outcome, and observation period.

Measures of treatment effect

For continuous outcomes, mean differences and standard deviation were used to summarize the data for each study.

Unit of analysis issues

In all cases, the unit of analysis was primarily the patient.

Data synthesis

A meta-analysis was planned to be conducted only if there were studies of similar comparisons, reporting the same outcome measures at the same time points.

Quality assessment

The quality of methodology, performance, and statistics of each study were assessed. For prospective studies, two review authors assessed the risk of bias in the included studies, independently and in duplicate, using The Cochrane Collaboration's tool for assessing risk of bias as outlined in the Cochrane Handbook for Systematic Reviews of Interventions (48). Risk of bias was assessed and judged for six separate domains.

1. Inclusion criteria: were they adequately described?
2. Adjusting for confounders: was it implemented?

3. Description of potential biases
4. Blinding of outcome assessors: was knowledge of the allocated intervention adequately prevented during the study?
5. Reporting of the drop-outs
6. Reporting of follow-up

Each study received a judgement of low risk, high risk, or unclear risk of bias (indicating either lack of sufficient information to make a judgement or uncertainty over the risk of bias) for each of the six domains. Studies were finally grouped into the following categories:

1. Low risk of bias (plausible bias unlikely to seriously alter the results) if all key domains of the study were at low risk of bias
2. Unclear risk of bias (plausible bias that raises some doubt about the results) if one or more key domains of the study were unclear
3. High risk of bias (plausible bias that seriously weakens confidence in the results) if one or more key domains were at high risk of bias.

Retrospective studies were graded with a score of A, B, or C (Grade A: high value of evidence, Grade C: low value of evidence) according to predetermined criteria using the system of Bondemark (49). This, validated also in other studies, system describes the criteria for grading the studies as follows:

1. Grade A: high value of evidence (all criteria should be met):

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

2. Grade B: moderate value of evidence (all criteria should be met):

   (a) Cohort study or retrospective cases series with defined control or reference group.
   (b) Defined diagnosis and endpoints.
   (c) Diagnostic reliability tests and reproducibility tests described.

3. Grade C: low value of evidence (one or more of the following conditions):

   (a) Large attrition.
   (b) Unclear diagnosis and endpoints.
   (c) Poorly defined patient material.

Results

Description of studies

Applying the inclusion criteria, 209 studies were retrieved from the electronic search and deemed as relevant. An interesting finding was that case reports and several *in vitro* studies, which were not relevant for this review, were predominant. After removal of duplicates, abstract, and full text reading stage, 12 studies were finally regarded as eligible for inclusion (Figure 1) (50). Three studies were in Japanese and therefore had to be translated in English (51–53). All 12 studies were included in the qualitative analysis but a quantitative synthesis was not appropriate. Of the 12 studies, 4 had a retrospective data collection (54–57) and 8 were of prospective design (31, 51–53, 58–61). No randomized controlled trial was identified. The studies were dived into subgroups because the quality assessment to be

performed is inherently different in prospective than in retrospective studies (Table 1).

Quality assessment

The quality of methodology, performance, and statistics of each study were assessed. In order to perform an adequate quality assessment, the studies were divided into two subgroups, retrospective and prospective studies, respectively (Table 1).

Prospective studies (*n* = 8)

Only one study partially reported inclusion criteria as well as drop-outs and follow-ups and, thus, could be classified as low risk of bias (59). Binding of the assessor and description of potential biases was not reported in any of the included studies. Furthermore, adjusting for confounders was not possible in any of the studies due to the nature of research. Based on the quality assessment, the rest seven prospective studies could only be classified as high risk of bias (31, 51–53, 58, 60, 61).

Retrospective studies (*n* = 4)

The quality assessment of each study was valued according to the predetermined criteria of Bondemark *et al.* (2007) and graded with a score of A, B, or C (49). Two retrospective studies were graded as moderate (Grade B) value of evidence since outcome assessment was not blinded, and randomization could not be implemented due to the nature of the study (54, 55). The remaining two studies were scored C for their low value of evidence due to the following shortcomings: failing to report diagnostic reliability and reproducibility tests, no blinded outcome assessment and no defined control group, diagnosis, and end points (56, 57).

Studies' settings and clinical findings

Table 2 gives an overview of the experimental setup of the included studies. The qualitative synthesis is presented in two different subgroups. One contains the influence on craniofacial structures and condylar shape (Table 3), while the second assesses the influence of chin-cup therapy on the TMJ in regard to development of TMD (Table 4). It is noteworthy to realize that most of the studies of higher quality dealing with morphological adaption were retrospective, whereas most of the studies investigating a possible association to TMD were of lower quality, except one which was of higher quality and of prospective design (59).

Qualitative synthesis and chin-cup influence on craniofacial structures and condylar shape

Five studies assessed this particular issue (31, 54, 55, 58, 61). Gökalp and Kurt (2005) found out that although retraction forces were applied by the chin-cup, the increase in mandibular corpus and ramus length continued and condylar head angle was decreased non-significantly (31). A positive correlation existed between bending of the condylar head and the maxillomandibular positioning relative to the cranium. These findings supported the hypothesis that chin-cup therapy created a new growth pattern in the condyle (Table 3).

The results of the second study indicated that the treatment and control subjects had different condylar head angle at the beginning and end of the study (value decreased significantly) (58). However, the differences between the groups in terms of other measurements were not statistically significant. No significant changes were also found in the disc position in either group or condyle shape. These results showed that the relationship between the disc and the condyle
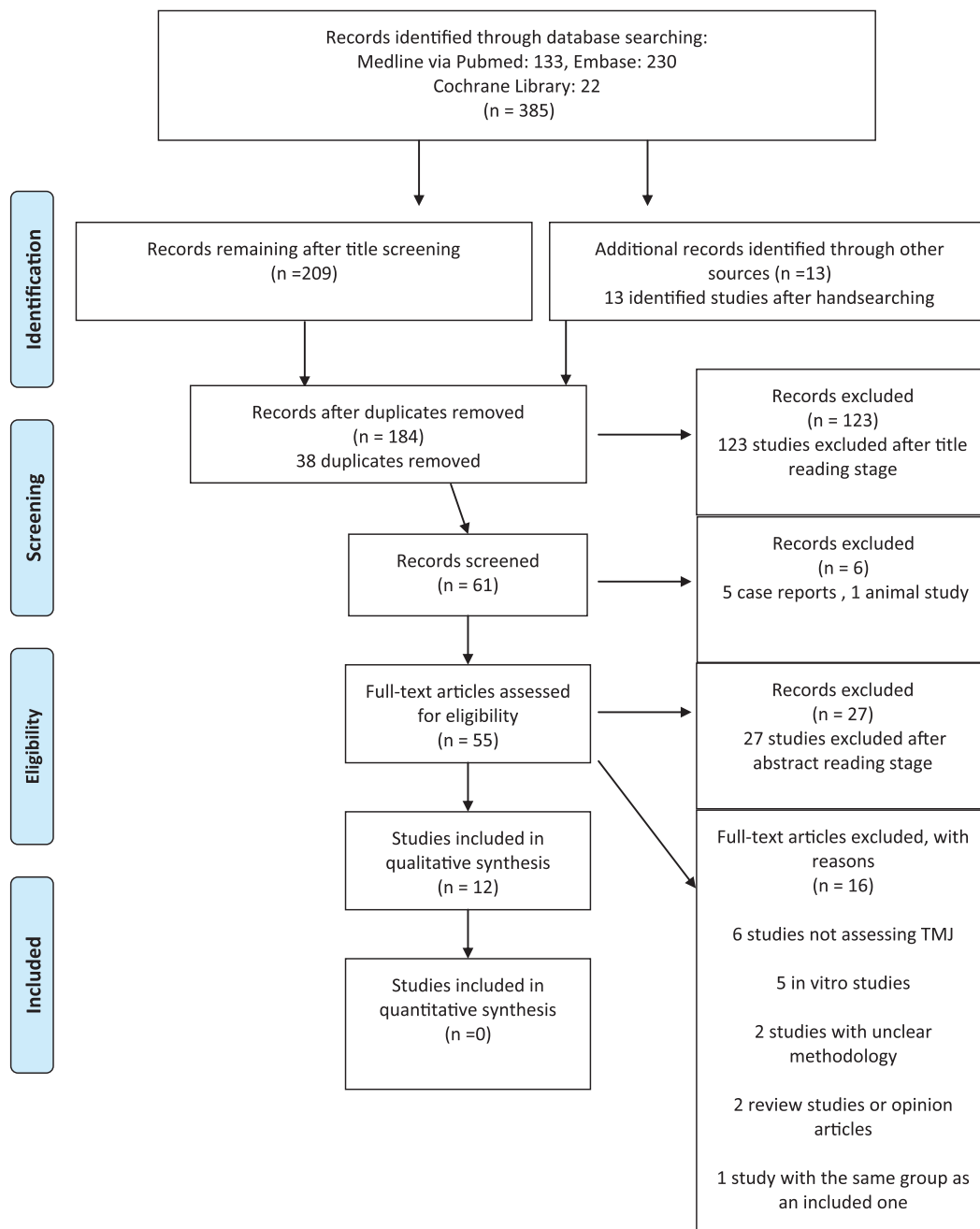
Figure 1. Study flow diagram. From Moher *et al.* (50). For more information, visit www.prima-statement.org (date last accessed, 26 September 2013).

underwent no significant change in patients treated with chin-cup and thus no adverse effect on the TMJ disc position and configuration could be detected.

The third study found no cephalometric differences between the different groups (55). Permutation tests showed highly significant differences in mandibular shapes (more rectangular mandibular configuration, forward condyle orientation, condyle neck compression, gonial area compression, symphysis narrowing) before and after treatment period and compared with the control group. These results implied that the chin-cup significantly affected the mandibular shape.

The results of the fourth study stated that the chin-cup group showed improvement of the skeletal Class III pattern (slightly increase of SNA, slightly decrease of SNB, decreased gonial angle) (54). The effective mandibular length increased significantly less in

Table 1. Quality assessment

Study	Study design	Definitive grade
Gökalp and Kurt (31)	Prospective	High risk
Gökalp *et al.* (58)	Prospective	High risk
Deguchi *et al.* (59)	Prospective	Low risk
Arat *et al.* (60)	Prospective	High risk
Alarcon *et al.* (55)	Retrospective	B
Deguchi and McNamara (54)	Retrospective	B
Mimura and Deguchi (61)	Prospective	High risk
Fukazawa *et al.* (51)	Prospective	High risk
Fukazawa *et al.* (52)	Prospective	High risk
Mukaiyama *et al.* (53)	Prospective	High risk
Imai *et al.* (56)	Retrospective	C
Gavakos and Witt (57)	Retrospective	C

Table 2. Materials and methods of included studies

Author	Study title	Number/gender/age of patients	Inclusion criteria	Type of orthodontic intervention	Comparison or control group	Magnitude and duration of force (g)	Diagnostic means	Observation period	Study design	Study district	Sampling method
Gökalp and Kurt (31)	MRI of the condylar growth pattern and disk position after chin cup therapy: a preliminary study	13 (10 female, 3 male) 9.06 years	Mandibular prognathism, clinically symptom-free subjects (TMJ)	Chin-cup	7 (6 female, 1 male)	600 g, 18 h/day	Cephalometry, hand wrist films, MRI	Treatment group 1.66 years, control group 1.88 years	Prospective	Not reported	Not reported
Gökalp et al. (58)	The changes in TMJ disc position and configuration in early orthognathic treatment: an MRI evaluation	15 (10 female, 5 male) 5–11 years	Prognathic facial structures, clinically symptom-free subjects (TMJ)	Chin-cup	10 (6 female, 4 male)	600 g, 16h/day	MRI	16 months	Prospective	Not reported	Not reported
Deguchi et al. (59)	Clinical evaluation of TMD in patients treated with chin-cup	160 (112 female, 48 male) 10 years, 1 month	Anterior cross-bite	Chin-cup with or without lingual arch appliance	No	400–500 g, 7–14 h/day	Questionnaire (presence of TMD signs and symptoms)	6 months to 4 years	Prospective	Department of Orthodontics, Matsumoto Dental College Hospital	University patients
Arat et al. (60)	Long-term effects of chin-cap therapy on the TMJs	32 (18 female, 14 male) 18.4 years	Skeletal Class III malocclusion	Chin-cup	Skeletal Class II group (untreated) 34 (14 female, 20 male), normal occlusion group 53 (29 female, 24 male)	500 g, 14h/day	Functional examination (TMD)	5.6 years	Prospective	Not reported	Not reported
Alarcon et al. (55)	Chin-cup treatment modifies the mandibular shape in children with prognathism	50 (25 female, 25 male) 8.5 ± 0.5 years	Skeletal Class III malocclusion due to mandibular prognathism	Chin-cup	40 (20 female, 20 male)	300 g, 14h/day	Cephalometry, superimposition (Procrustes)	36 months	Retrospective	Orthodontic Clinic of the School of Dentistry, University Complutense, Madrid	University patients
Deguchi and McNamara (54)	Craniofacial adaptations induced by chin-cup therapy in Class III patients	22 (22 females) 9 years, 4 month	Skeletal Class III malocclusion	Chin-cup (occipital-pull) and during initial stage of correction of anterior cross-bite lingual arch appliance	20 (all female)	400–500 g, 7–9h/day	Cephalometry, profilograms	1 year, 9 months	Retrospective	Department of Orthodontics, Matsumoto Dental Hospital and Private Clinic	University and private practice patients
Mimura and Deguchi (61)	Morphologic adaptation of TMJ after chin-cup therapy	19 (11 female, 8 male) 10 years, 2 month	True, mild skeletal Class III malocclusion with anterior cross-bite	Chin-cup and 0.018-inch edgewise appliance (Mershon's lingual arch appliance)	16 (12 females, 4 male)	Not reported	Cephalometry, sagittal arthrotomogram	2 years, 1 months	Prospective	Not reported	Not reported

(*Continued*)

Table 2. (*Continued*)

Author	Study title	Number/gender/age of patients	Inclusion criteria	Type of orthodontic intervention	Comparison or control group	Magnitude and duration of force (g)	Diagnostic means	Observation period	Study design	Study district	Sampling method
Fukazawa et al. (51)	Changes of frontal facial form occurred after correction of anterior reversed occlusion in children with TMJ dysfunction	22 (13 female, 9 male) 7 years, 8 month	Anterior cross-bite with normal function of TMJ at pre-treatment stage	Chin-cup with or without minor intraoral mechanotherapy	28 (14 female, 14 male)	200–450 g, 8–22 h/day	Posterior–anterior X-ray, morphological measurements	Not reported	Prospective	Hospital orthodontic department of the Tohoku University School of Dentistry	University patients
Fukazawa et al. (52)	Evaluation on facial pattern of early childhood patients with TMJ dysfunction occurred after anterior cross-bite correction	22 (13 female, 9 male) 7 years, 8 month	Anterior cross-bite with normal function or without of TMJ at pre-treatment stage	Chin-cup with or without minor intraoral mechanotherapy	28 (14 female, 14 male)	200–450 g, 8–22 h/day	Cephalometry and posterior–anterior X-ray, morphological measurements	Not reported	Prospective	Hospital orthodontic department of the Tohoku University School of Dentistry	University patients
Mukaiyama et al. (53)	Prevalence of TMD for 6- to 10-year-old Japanese children with chin-cap orthodontic treatment	108 (63 female, 45 male) 6–10 years	Anterior reversed occlusion	Chin-cup with or without minor intraoral mechanotherapy	None	14.5 h/day	TMJ examination (noise, and/or pain, abnormal jaw movements, pain complaint on palpation at masticatory muscles)	12.2 months	Prospective	Hospital orthodontic department of the Tohoku University School of Dentistry	University patients
Imai et al. (56)	A clinical study on the prevalence of TMD in orthodontic patients	129 (gender not reported) 13.1 years	Class III malocclusion	129 chin-cup, 1 chin-cup, and multibracket appliance	Not reported	500 g, 11 h/day	Symptoms of TMJ dysfunction (joint sounds, pain in the joints and muscles, restricted mandibular opening movement (<35 mm))	Not reported	Retrospective	Dental Hospital of Hokkaido University	University patients
Gavakos and Witt (57)	The functional status of orthodontically treated prognathic patients	30 (17 female, 13 male) 18.5 years	Class III malocclusion, more than 1 year out of retention	Chin-cup	30 (22 female, 8 male)	300–500 g, 12 h/day	Three indices introduced by Helkimo: (1) anamnestic dysfunction index, (2) clinical dysfunction index, and (3.) occlusal state)	Not reported	Retrospective	Not reported	Not reported

MRI, magnetic resonance imaging; TMD, temporomandibular disorders; TMJ, temporomandibular joint.

Table 3. Results of the included studies (morphological adaptation)

Study	Outcome assessed	Results
Gökalp and Kurt (31)	Mandibular corpus length, condylar head angle and morphology, bending of condylar head, condylar growth pattern, disc position, condyle position relative to glenoid fossa	Mandibular corpus length increased, condylar head angle decreased, positive correlation between activation of maxillary and mandibular growth and bending of condylar head. Induced alteration of condylar growth pattern
Gökalp *et al.* (58)	Disc position and configuration	Different condylar head angle at the beginning and end of the study, condylar head angle decreased, no significant changes in disc position and configuration
Alarcon *et al.* (55)	Mandibular shape changes (21 landmarks representing mandibular morphology)	Highly significant difference in mandibular shape (more rectangular mandibular configuration, forward condyle orientation, condyle neck compression, gonial area compression, symphysis narrowing)
Deguchi and McNamara (54)	Craniofacial adaption (posterior displacement of the structures comprising TMJs (e.g. mandibular condyle and glenoid fossa))	Slightly increase of SNA, slightly decrease of SNB, decreased gonial angle, mandibular length increased significantly less in the treated group, cranial base angles (N-S-Ba and N-S-Ar) showed no statistical difference, no posterior displacement of the glenoid fossa
Mimura and Deguchi (61)	Morphologic changes of TMJ	Change of direction of growth of the mandible, mandibular neck was relatively more slender than in control group, the condylar heads were bent forward, the glenoid fossa was deepened and widened and the clearance between condyle and fossa was decreased

TMJ, temporomandibular joint.

the treated group in comparison to the controls. The cranial base angles (N-S-Ba and N-S-Ar) showed no statistical difference between the two groups. Chin-cup treatment did not cause a posterior displacement of the structures comprising TMJs and therefore did not induce a posterior displacement of the glenoid fossa.

Mimura and Deguchi (1996) found out that chin-cup therapy changed the direction of growth in the mandible, especially the ramus swing-back (61). The therapy showed also a relatively more slender mandibular neck and in addition the condylar heads were bent forward, the glenoid fossa was deepened and widened and the clearance between condyles and fossae was decreased by the orthopaedic force of the chin-cup appliance. It was found that the chin-cup altered the direction of growth of the mandible.

Qualitative synthesis and chin-cup influence on TMD

Seven studies were identified for this evaluation (51–53, 56, 57, 59, 60). Evidence of TMD was found in the first study in 16% of the patients during chin-cup use, in 10% during active treatment, and in 6% after active treatment (59). In total, 32% individuals had one or more symptom(s) of TMD. Spontaneous pain occurred most often during active treatment, while clicking (sound) was less frequent, with the same incidence observed both during and after active treatment. These results showed little relation between chin-cup therapy and the incidence of TMD (Table 4).

In the second study, the symptomatic group consisted of individuals having at least one sign or symptom (clicking, pain, or deviation) (60). The distribution of symptomatic subjects was 25% in the treatment group, 23% in the Class III malocclusion group, and 41.5% in the control group. The occurrence of pain, which was regarded as a subjective sign, was different between the treatment (37.5%) and control group (54.5%) (*P* = 0.01), and the occurrence rate of pain was higher in the normal occlusion group than in the skeletal Class III malocclusion group (33%). The event of clicking and deviation did not differ among the groups. These findings indicated that chin-cup treatment did not have any effect on TMD development or prevention.

Mukaiyama *et al.* (1988) reported that 42% of the patients showed symptoms of TMD including 23.1% with noise during jaw movement, 20.4% with mandibular displacement during jaw opening, and pain on palpation (6.5% muscles and 19.4% TMJ) (53). Various symptoms were compound in 17.6% and a single symptom was found in 29.6% of the total samples. There was no significant difference between chin-cup single therapy and chin-cup with intraoral orthodontic therapy. TMD seemed to occur more often during the first 6 months with chin-cup treatment, and chin-cup use for more than 16 hours per day seemed to cause higher incidence for dysfunction. The results indicated a high incidence of TMD in 6- to 10-year-old children who were treated by chin-cup therapy.

Imai *et al.* (1990) found out that the frequency of occurrence of clinical symptoms for patients treated with a chin-cup was 10.9 and 6.7% for those treated with a multibracket appliance (56). In the chin-cup group, nine patients developed clinical symptoms within 1 year after the beginning of treatment and five developed clinical symptoms within 1–3 years. Clinical symptoms continued in four patients who continued to use the appliance under same conditions, whereas nine patients who discontinued the use of chin-cup or changed the conditions of use (shorter wearing time with lighter force of traction) became free from clinical symptoms. The results indicated a high occurrence of clinical TMD signs when a chin-cup is used after the pubertal growth period.

The authors of the fifth study identified that in both groups, 76% reported to have no symptoms (57). The clinical dysfunction index indicated that 13.3% of the chin-cup group and 6.6% of the control group were clinically symptom-free. Most of the patients (66.6% chin-cup group, 73.3% control group) had mild clinical symptoms, 20% of the chin-cup group and 10% of the control group had moderate clinical symptoms, and 10% of the control group suffered from severe clinical symptoms. None of the chin-cup group was affected. The evaluation of the occlusal state showed that only 20% of the patients in each group had a morphologically normal occlusion. The frequency of severe disorders was high (60% in chin-cup group, 43.3% in control group). Although the static occlusion was better in

Table 4. Results of the included studies (occurrence of TMD)

Study	Outcome assessed	Results
Deguchi *et al.* (59)	Incidence and types of TMD in 'chin-cup patients' during and after treatment and to study the effect of retreatment in TMD cases after chin-cup therapy	28 patients of 86 (160) showed 1 or more symptom(s) of TMD, 9 (28) had 2 or 3 symptoms during active treatment; 14 (86) showed symptoms during chin-cup use only, 9 (86) showed symptoms during active treatment, 5 (86) showed symptoms after active treatment
Arat *et al.* (60)	Signs and symptoms of TMD (clicking, pain, deviation)	Distribution of symptomatic subjects was 25% (treatment group), 23% (Class III group), and 41.5% (normal group), occurrence of pain was 37.5% (treatment group), 33% (Class II group), and 54.5% (normal group), chin-cup therapy is neither a risk factor for nor a prevention of TMD
Fukazawa *et al.* (51)	Facial pattern of early childhood patient with clicking after cross-bite correction with chin-cup	TMJ dysfunction often found 6 months after cross-bite correction, facial pattern showed asymmetry at T1 and the same trend of asymmetry pattern after cross-bite correction
Fukazawa *et al.* (52)	Facial pattern of early childhood patient with clicking after cross-bite correction with chin-cup	TMJ dysfunction often found 6 months after cross-bite correction, no significant difference between TMJ group and control group from lateral facial pattern, upper and middle facial skeleton were symmetrical in both groups, maxillary alveolar region of TMJ group was significant from anteroposterior view, high incidence of TMD in mandibular asymmetry cases
Mukaiyama *et al.* (53)	Prevalence of TMJ dysfunction with chin-cup therapy	47.2% have symptoms of any one of TMJ dysfunction, no significant difference between female/male, 23.1% noise during jaw movement, 20.4% mandibular displacement (deviation) during jaw opening, pain on palpation (6.5% muscles and 19.4% TMJ), various symptoms in 17.6%, single symptom in 29.6%, no significant difference between chin-cup single therapy and chin-cup with intraoral orthodontic therapy, Higher incidence of TMD found during the first 6 months of therapy and when chin-cup was used for more than 16 h/day.
Imai *et al.* (56)	Prevalence of TMJ dysfunction during orthodontic treatment and correlation between TMJ dysfunction occurrences and orthodontic appliances	Frequency of occurrence of clinical symptoms was 10.9 and 6.7% with multibracket appliance, nine developed clinical symptoms within 1 year after the beginning of treatment and five developed clinical symptoms within 1–3 years, clinical symptoms continued in four patients who continued to use the appliance under same conditions, nine patients who stopped using chin-cup or changed the conditions of use (shorter wearing time with lighter force of traction) became free from clinical symptoms
Gavakos and Witt (57)	Investigated the functional status of orthodontically treated prognathic patients after retention, ascertain the influence of chin-cup upon the function of the masticatory system	Anamnestic dysfunction index (76% in each group have no symptoms), clinical dysfunction index (13.3% clinically symptom-free, 66.6% with mild symptoms, 20% moderate symptoms), index for occlusal state (20% with normal occlusion in both groups, moderate: 20%, severe: 60%), functional aspect (no significant difference between both groups): no functional risk

TMD, temporomandibular disorders; TMJ, temporomandibular joint.

the control group, there was no significant difference in the findings concerning functional aspects. These findings indicated that the chin-cup did not seem to present a functional risk.

The last two studies, published by the same author, showed that in many cases (81.8%), TMD signs and symptoms (clicking, pain, or deviation) were found to commence about 6 months after cross-bite correction (51, 52). It was also cleared that the frontal facial pattern of the TMD-group showed asymmetry at pre-treatment stage, however there was no significant difference between the TMJ group and the control group from the lateral facial pattern. These findings indicated that high incidence of TMD was found in mandibular asymmetry cases.

Quantitative synthesis of the included studies

Before illustrating the reason of why a meta-analysis was not feasible in this review, it could be helpful to distinguish between different types of heterogeneity. Clinical heterogeneity refers to variability in the participants, interventions, and outcomes studied. Variability in study design and risk of bias may be described as methodological heterogeneity. Finally, major differences in the intervention effects being evaluated in different studies is known as statistical heterogeneity and is a consequence of clinical or methodological diversity, or both, among the studies (48). In the present review, the lack of standardized protocols on the influence of chin-cup therapy on the TMJ regarding morphological adaptation and appearance of TMD was evident. The analysis of the methodology of the included studies revealed substantial differences with respect to sample size, inclusion criteria (severity of Class III malocclusion), type of interventions, diagnostic means, and time points of outcome assessment. Moreover, the included studies were of various designs and of different quality. Consequently, clinical along with methodological heterogeneity of included studies impeded meta-analysis.

Discussion

Whether mandibular growth can be decelerated, reduced, or redirected by the use of chin-cup therapy has been a matter of ongoing debate in literature, and the mechanism by which a chin-cup treatment results in improvement of a skeletal Class III malocclusion has not yet been clarified. It is well known that mandibular growth is affected mainly by condylar growth. However, it must be highlighted that the condylar growth is not a unique factor in growth and development of the craniofacial complex (62). Therefore, it would be an oversimplification to attribute mandibular growth solely to condylar growth (62–66). With chin-cup therapy, a posterosuperior orthopaedic force is applied on the TMJ, with pressure directed from the chin to the condyle. Morphologic and biologic alterations of the mandible from orthopaedic chin-cup forces have been investigated both in cephalometric and experimental studies (34–36, 67, 68). The relationship between orthodontic treatment and TMD has also been discussed extensively in the past (43, 47, 69). Although short-term chin-cup wear may be applied not only to the anterior cross-bite correction, but also to skeletal Class III profile treatment, a risk of this therapy consists in the posterior displacement of the condyle in the glenoid fossa, which may cause anterior dislocation of the articular disc with clicking during mandibular movement (10, 59), whereas this issue has not been unequivocally defined (44–46).

Expanding on the disagreement between the authors, this systematic review aimed to evaluate the results of as many studies as possible to obtain information on the influence of chin-cup therapy on the TMJ regarding morphological adaptation and prevalence of TMD.

As outlined above, any observed heterogeneity may be of methodological, clinical, or statistical aetiology. These sources of heterogeneity were apparent in all studies with regard to treatment modality and duration, which rendered standardization an unrealizable task. The large range concerning the level of evidence of the included studies and the application of different study designs in regard to treatment duration, controls and force applied, made the comparison and quantitative synthesis of all included studies impossible. Data regarding age, magnitude and duration of force, length of treatment, and clinical outcomes of the treatment are illustrated in Tables 1, 3, and 4. Because of the vast variation of the assessed outcome, a comparison of observed morphological adaption was challenging.

Despite the lack of consistency in methodological approaches, and taking into account that the available evidence derived from studies, which command a low to medium level of evidence, the qualitative analysis of the included studies revealed the following:

1. Four out of five studies on morphological adaption investigated the condylar head angle (angle between the condyle and collum) and all of them reported a decrease of this particular angle. It is essential to indicate that the sample size of these studies varied quite a lot and all of them have rather small sample sizes. As a matter of course, the results may vary according to this specific parameter and therefore results should be evaluated with caution, not relying solely on *P* values. Chin-cup reportedly altered mandibular shape in all of the included studies. Further craniofacial adaptations such as posterior displacement of the glenoid fossa or alteration of disc position remain subject to controversy.

2. Based on the pertinent literature, it must be assumed that chin-cup therapy is neither a risk factor nor may prevent TMD.

Similar results were reported in comprehensive historical reviews by Reynders (1990) and Tallents *et al.* (69, 70). Forces that are applied in an upward and backward direction have been long assumed to be the main reason for the appearance of TMD (43, 47, 71). Some components of the TMJ complex, such as the temporomandibular ligament (TML), have always been ignored in these evaluations (72). But when a force is applied to the mandible in a posterosuperior direction, the expected upward and backward movement of the condyle is inhibited by the horizontal portion of the TML. The data relative to morphological adaptation suggest that chin-cup use does not decrease the overall mandibular growth, rather it contributes to changing of the direction of growth, eventually modifying the form of the mandible. Orthopaedic chin-cup force is directed from the chin to the condyle posterosuperiorly. Because it is known that stress concentration may be enhanced by specific geometries of the tissues, such as the condylar neck, which presents a high rate of fractures in cases of maxillofacial injuries (73), this site is speculated to be most responsive to mandibular orthopaedic force. The condylar head is bent forward (reduction of condylar head angle) after chin-cup therapy, an observation in accordance to a study by Levi *et al.* who visualized the direction of application of orthopaedic force by the chin-cup using a three-dimensional photoelastic model (37). Their result illustrated that stresses emanating from the chin-cup action are translated through the mandibular body, to the angle, and retromolar triangle of the mandible, radiating in a posterosuperior fashion, and concentrated at the neck of the condyle. Kanematsu's histological investigation in non-human primates revealed that chin-cup application inhibited the bone deposition on the condylar neck and stimulated apposition on the posterior border of the ramus, consequently reducing the gonial angle. The same group also described bone resorption on the roof of the fossa and posterior surface of the condyle and bone deposition on the anterior surface of the condyle. Although no description of the forward bending of the condyle was made, the human condyle is more slender than that of the animal model used in this study and as a result, the remodelling described by this author may occur (74).

With regard to the TMD, age seems to be a critical factor in differentiating the effects imposed by chin-cup on TMJ (71, 75–77). Based on studies that psychological factors may be seen as cause of TMD, it is suggested that stress plays an important role in the occurrence of TMD (78–80). An age-related peak in patients with TMD, particularly females, is seen between 20 and 45 years of age (81). A possible explanation for this phenomenon may relate to the emotional aspects and stressful lifestyle that characterize this age period (82). The study that showed high incidence of TMD in chin-cup therapy, however, found no significant difference between genders. The question about TMD signs and symptoms and their time of appearance (during and/or after chin-cup use), the influence of other orthodontic appliances which may be used simultaneously, the effect of magnitude and the duration of force, and the influence of the age (prepubertal/after pubertal growth) still remains an open question and should be evaluated in further studies.

Conclusions

The available evidence supports that there are craniofacial adaptations induced by chin-cup therapy for Class III malocclusion. In regard to the incidence of TMD, it can be concluded from the available data that chin-cup therapy seems to constitute no risk factor for the development of TMD.

In summary, the lack of high level evidence in the reviewed literature cannot be generalized to the orthodontic population. Because of limited comparative evidence, high-quality clinical trials are essential to further investigate both the influence of chin-cup treatment on morphological adaption and the development and prevalence of TMD.

Supplementary material

Supplementary material is available at *European Journal of Orthodontics online*.

Funding

References

1. Kang, H.K. and Ryu, Y.K. (1991) A study on the prevalence of malocclusion of Yonsei University students in 1991. *Korean Journal of Orthodontics*, 22, 691–701.

2. Chang, H.P. (1985) Components of Class III malocclusion in the Chinese. *The Kaohsiung Journal of Medical Sciences*, 1, 144–155.

3. Tang, E.L. (1994) The prevalence of malocclusion amongst Hong Kong male dental students. *British Journal of Orthodontics*, 21, 57–63.

4. Susami, R., Asai, Y., Hirose, K., Hosoi, T. and Hayashi, I. (1972) Prevalence of malocclusion in Japanese school children. 4. The frequency of mandibular overjet. *The Journal of Japan Orthodontic Society*, 31, 319–324.

5. McNamara, J.A. Jr. (1987) An orthopedic approach to the treatment of Class III malocclusion in young patients. *Journal of Clinical Orthodontics: JCO*, 21, 598–608.

6. Lin, H.C., Chang, H.P. and Chang, H.F. (2007) Treatment effects of occipitomental anchorage appliance of maxillary protraction combined with chincup traction in children with Class III malocclusion. *Journal of the Formosan Medical Association*, 106, 380–391.

7. Thilander, B. and Myrberg, N. (1973) The prevalence of malocclusion in Swedish schoolchildren. *Scandinavian Journal of Dental Research*, 81, 12–21.

8. Jacobson, A., Evans, W.G., Preston, C.B. and Sadowsky, P.L. (1974) Mandibular prognathism. *American Journal of Orthodontics*, 66, 140–171.

9. Graber, L.W. (1977) Chin cup therapy for mandibular prognathism. *American Journal of Orthodontics*, 72, 23–41.

10. Deguchi, T. and Kitsugi, A. (1996) Stability of changes associated with chin cup treatment. *The Angle Orthodontist*, 66, 139–145.

11. Mitani, H. (2002) Early application of chincap therapy to skeletal Class III malocclusion. *American Journal of Orthodontics and Dentofacial Orthopedics*, 121, 584–585.

12. Yoo, Y.K., Kim, N.I. and Lee, H.K. (1971) A study on the prevalence of malocclusion in 2378 Yonsei University students. *Korean Journal of Orthodontics*, 2, 35–40.

13. Mitani, H., Sato, K. and Sugawara, J. (1993) Growth of mandibular prognathism after pubertal growth peak. *American Journal of Orthodontics and Dentofacial Orthopedics*, 104, 330–336.

14. Lee, S.J., Kim, T.W. and Suhr, C.H. (1994) Study of recognition of malocclusion and orthodontic treatments. *Korean Journal of Orthodontics*, 24, 367–394.

15. Ko, Y.I., Baek, S.H., Mah, J. and Yang, W.S. (2004) Determinants of successful chincup therapy in skeletal class III malocclusion. *American Journal of Orthodontics and Dentofacial Orthopedics*, 126, 33–41.

16. Chang, H.P., Liu, P.H., Chang, H.F. and Chang, C.H. (2002) Thin-plate spline (TPS) graphical analysis of the mandible on cephalometric radiographs. *Dento Maxillo Facial Radiology*, 31, 137–141.

17. Turley, P.K. (1988) Orthopedic correction of Class III malocclusion with palatal expansion and custom protraction headgear. *Journal of Clinical Orthodontics: JCO*, 22, 314–325.

18. Chang, H.F., Tsai, C.W., Chang, H.P., Yao, C.C., Chen, K.C. and Chen, Y.J. (2004) Skeletal changes in patients with maxillary deficiency following face-mask therapy with or without a palatal expander. *Chinese Journal of Dental Research*, 3, 15–27.

19. Chang, H.P., Lin, H.C., Liu, P.H. and Chang, C.H. (2005) Geometric morphometric assessment of treatment effects of maxillary protraction combined with chin cup appliance on the maxillofacial complex. *Journal of Oral Rehabilitation*, 32, 720–728.

20. Fränkel, R. (1970) Maxillary retrusion in Class 3 and treatment with the function corrector 3. *Report of the congress. European Orthodontic Society*, pp. 249–259.

21. Abu Alhaija, E.S. and Richardson, A. (1999) Long-term effect of the chincap on hard and soft tissues. *European Journal of Orthodontics*, 21, 291–298.

22. Pearson, L.E. (1978) Vertical control in treatment of patients having backward-rotational growth tendencies. *The Angle Orthodontist*, 48, 132–140.

23. Pearson, L.E. (1986) Vertical control in fully-banded orthodontic treatment. *The Angle Orthodontist*, 56, 205–224.

24. Pearson, L.E. (1991) Case report KP. Treatment of a severe openbite excessive vertical pattern with an eclectic non-surgical approach. *The Angle Orthodontist*, 61, 71–76.

25. Hirose, H., Mochizuki, M., Matsuura, T., Sasakura, H. and Hanada, K. (1981) Cephalometric evaluation on the orthopedic therapy applied to the skeletal open bite patients during the growth periods. *The Journal of Japan Orthodontic Society*, 40, 356–377.

26. Mitani, H. (2007) Recovery growth of the mandible after chin cup therapy: fact or fiction. *Seminars in Orthodontics*, 13, 186–199.

27. Deguchi, T., Kuroda, T., Minoshima, Y. and Graber, T.M. (2002) Craniofacial features of patients with Class III abnormalities: growth-related changes and effects of short-term and long-term chincup therapy. *American Journal of Orthodontics and Dentofacial Orthopedics*, 121, 84–92.

28. Sugawara, J. and Mitani, H. (1997) Facial growth of skeletal Class III malocclusion and the effects, limitations, and long-term dentofacial adaptations to chincap therapy. *Seminars in Orthodontics*, 3, 244–254.

29. Allen, R.A., Connolly, I.H. and Richardson, A. (1993) Early treatment of Class III incisor relationship using the chincap appliance. *European Journal of Orthodontics*, 15, 371–376.

30. Arman, A., Toygar, T.U. and Abuhijleh, E. (2004) Profile changes associated with different orthopedic treatment approaches in Class III malocclusions. *The Angle Orthodontist*, 74, 733–740.

31. Gökalp, H. and Kurt, G. (2005) Magnetic resonance imaging of the condylar growth pattern and disk position after chin cup therapy: a preliminary study. *The Angle Orthodontist*, 75, 568–575.

32. Liu, Z.P., Li, C.J., Hu, H.K., Chen, J.W., Li, F. and Zou, S.J. (2011) Efficacy of short-term chincup therapy for mandibular growth retardation in Class III malocclusion. *The Angle Orthodontist*, 81, 162–168.

33. Sakamoto, T., Iwase, I., Uka, A. and Nakamura, S. (1984) A roentgenocephalometric study of skeletal changes during and after chin cup treatment. *American Journal of Orthodontics*, 85, 341–350.

34. Mitani, H. and Sakamoto, T. (1984) Chin cap force to a growing mandible. Long-term clinical reports. *The Angle Orthodontist*, 54, 93–122.

35. Sugawara, J., Asano, T., Endo, N. and Mitani, H. (1990) Long-term effects of chincap therapy on skeletal profile in mandibular prognathism. *American Journal of Orthodontics and Dentofacial Orthopedics*, 98, 127–133.

36. Mitani, H. and Fukazawa, H. (1986) Effects of chincap force on the timing and amount of mandibular growth associated with anterior reversed occlusion (Class III malocclusion) during puberty. *American Journal of Orthodontics and Dentofacial Orthopedics*, 90, 454–463.

37. Levy, A.J., Chaconas, S.J. and Caputo, A.A. (1976) Orthopedic effect of the extraoral chin cup appliance on the mandible. *American Journal of Orthodontics*, 69, 29–41.

38. Yamada, I., Hata, S., Nakashima, S., Itoh, T. and Matsumoto, M. (1978) Transformation of craniofacial complex by chin cap appliance–strain gauge measurements of *Macaca fusata* (author's transl). *The Journal of Japan Orthodontic Society*, 37, 205–216.

39. Janzen, E.K. and Bluher, J.A. (1965) The cephalometric, anatomic, and histologic changes in *Macaca mulatta* after application of a continuous-acting retraction force on the mandible. *American Journal of Orthodontics*, 51, 823–855.

40. Ritucci, R. and Nanda, R. (1986) The effect of chin cup therapy on the growth and development of the cranial base and midface. *American Journal of Orthodontics and Dentofacial Orthopedics*, 90, 475–483.

41. Agronin, K.J. and Kokich, V.G. (1987) Displacement of the glenoid fossa: a cephalometric evaluation of growth during treatment. *American Journal of Orthodontics and Dentofacial Orthopedics*, 91, 42–48.

42. Wyatt, W.E. (1987) Preventing adverse effects on the temporomandibular joint through orthodontic treatment. *American Journal of Orthodontics and Dentofacial Orthopedics*, 91, 493–499.

43. Tanne, K., Tanaka, E. and Sakuda, M. (1996) Stress distribution in the temporomandibular joint produced by orthopedic chincup forces applied in varying directions: a three-dimensional analytic approach with the finite element method. *American Journal of Orthodontics and Dentofacial Orthopedics*, 110, 502–507.

44. Dibbets, J.M. and van der Weele, L.T. (1987) Orthodontic treatment in relation to symptoms attributed to dysfunction of the temporomandibular joint. A 10-year report of the University of Groningen study. *American Journal of Orthodontics and Dentofacial Orthopedics*, 91, 193–199.

45. Dibbets, J.M. and van der Weele, L.T. (1991) Extraction, orthodontic treatment, and craniomandibular dysfunction. *American Journal of Orthodontics and Dentofacial Orthopedics*, 99, 210–219.

46. Dibbets, J.M. and van der Weele, L.T. (1992) Prevalence of structural bony change in the mandibular condyle. *Journal of Craniomandibular Disorders: Facial & Oral Pain*, 6, 254–259.

47. Wyatt, W.E. (1988) Preventing adverse effects on the temporomandibular joint through orthodontic treatment. *International Journal of Orthodontics*, 26, 10–12.

48. Higgins, J.P.T. and Green, S. (eds.) *Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0* [updated March 2011]. The Cochrane Collaboration, 2011. www.cochrane-handbook.org.

49. Bondemark, L., *et al.* (2007) Long-term stability of orthodontic treatment and patient satisfaction. A systematic review. *The Angle Orthodontist*, 77, 181–191.

50. Moher, D., Liberati, A., Tetzlaff, J. and Altman, D.G.; PRISMA Group. (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Medicine*, 6, e1000097.

51. Fukazawa, H., Endo, N., Kurita, S. and Mitani, H. (1990) Changes of frontal facial form occurred after correction of anterior reversed occlusion in children with TMJ dysfunction. *The Journal of Japan Orthodontic Society*, 49, 199–206.

52. Fukazawa, H., Mukaiyama, T., Kurita, T., Urano, J. and Mitani, H. (1989) Evaluation on facial pattern of early childhood patients with T.M.J. dysfunction occurred after anterior crossbite correction. *Nihon Ago Kansetsu Gakkai Zasshi*, 1, 66–78.

53. Mukaiyama, T., Fukazawa, H., Mizoguchi, I. and Mitani, H. (1988) Prevalence of temporomandibular joint dysfunction for 6-10-year old Japanese children with chincap orthodontic treatment. *The Journal of Japan Orthodontic Society*, 47, 425–432.

54. Deguchi, T. and McNamara, J.A. (1999) Craniofacial adaptations induced by chincup therapy in Class III patients. *American Journal of Orthodontics and Dentofacial Orthopedics*, 115, 175–182.

55. Alarcón, J.A., Bastir, M., Rosas, A. and Molero, J. (2011) Chincup treatment modifies the mandibular shape in children with prognathism. *American Journal of Orthodontics and Dentofacial Orthopedics*, 140, 38–43.

56. Imai, T., Watanabe, F. and Nakamura, S. (1990) Clinical study on the prevalence of temporomandibular joint dysfunction in orthodontic patients. *Dentistry in Japan*, 27, 97–99.

57. Gavakos, K. and Witt, E. (1991) The functional status of orthodontically treated prognathic patients. *European Journal of Orthodontics*, 13, 124–128.

58. Gökalp, H., Arat, M. and Erden, I. (2000) The changes in temporomandibular joint disc position and configuration in early orthognathic treatment: a magnetic resonance imaging evaluation. *European Journal of Orthodontics*, 22, 217–224.

59. Deguchi, T., Uematsu, S., Kawahara, Y. and Mimura, H. (1998) Clinical evaluation of temporomandibular joint disorders (TMD) in patients treated with chin cup. *The Angle Orthodontist*, 68, 91–94.

60. Arat, Z.M., Akçam, M.O. and Gökalp, H. (2003) Long-term effects of chin-cap therapy on the temporomandibular joints. *European Journal of Orthodontics*, 25, 471–475.

61. Mimura, H. and Deguchi, T. (1996) Morphologic adaptation of temporomandibular joint after chincup therapy. *American Journal of Orthodontics and Dentofacial Orthopedics*, 110, 541–546.

62. Koski, K. (1968) Cranial growth centers: facts of fallacies? *American Journal of Orthodontics*, 54, 566–583.

63. Ricketts, R.M. (1971) Facial and denture changes during orthodontic treatment as analyzed from the temporomandibular joint. *Journal of Maxillofacial Orthopedics*, 4, 26–28.

64. Bjork, A. (1963) Variations in the growth pattern of the human mandible: longitudinal radiographic study by the implant method. *Journal of Dental Research*, 42(Pt 2), 400–411.

65. Solow, B. (1980) The dentoalveolar compensatory mechanism: background and clinical implications. *British Journal of Orthodontics*, 7, 145–161.

66. Moss, M.L. and Salentijn, L. (1969) The primary role of functional matrices in facial growth. *American Journal of Orthodontics*, 55, 566–577.

67. Sakamoto, T. (1981) Effective timing for the application of orthopedic force in the skeletal class III malocclusion. *American Journal of Orthodontics*, 80, 411–416.

68. Wendell, P.D., Nanda, R., Sakamoto, T. and Nakamura, S. (1985) The effects of chin cup therapy on the mandible: a longitudinal study. *American Journal of Orthodontics*, 87, 265–274.

69. Reynders, R.M. (1990) Orthodontics and temporomandibular disorders: a review of the literature (1966-1988). *American Journal of Orthodontics and Dentofacial Orthopedics*, 97, 463–471.

70. Tallents, R.H., Catania, J. and Sommers, E. (1991) Temporomandibular joint findings in pediatric populations and young adults: a critical review. *The Angle Orthodontist*, 61, 7–16.

71. Riolo, M.L., Brandt, D. and TenHave, T.R. (1987) Associations between occlusal characteristics and signs and symptoms of TMJ dysfunction in children and young adults. *American Journal of Orthodontics and Dentofacial Orthopedics*, 92, 467–477.

72. Okeson, J.P. (ed.) (2007) Chapter 12: Diagnosis of Temporomandibular Disorders. In: *Management of Temporomandibular Disorders and Occlusion*. Sixth Edition. Elsevier Mosby, St Louis Missouri.

73. Haskell, R., Bradley, J., Row, N., Williams, J., Grattan, E. and Hobbs, J. (1985) *Applied Surgical Anatomy. Maxillofacial Injuries*. Churchill Livingstone, pp. 1–42.

74. Kanematsu, S. (1988) Dentofacial changes produced by extraoral posterior force on the mandible of *Macaca irus*. *The Journal of Japan Orthodontic Society*, 47, 1–36.

75. Egermark-Eriksson, I., Carlsson, G.E., Magnusson, T. and Thilander, B. (1990) A longitudinal study on malocclusion in relation to signs and symptoms of cranio-mandibular disorders in children and adolescents. *European Journal of Orthodontics*, 12, 399–407.

76. Egermark-Eriksson, I., Carlsson, G.E. and Ingervall, B. (1981) Prevalence of mandibular dysfunction and orofacial parafunction in 7-, 11- and 15-year-old Swedish children. *European Journal of Orthodontics*, 3, 163–172.

77. Dibbets, J.M., van der Weele, L.T. and Uildriks, A.K. (1985) Symptoms of TMJ dysfunction: indicators of growth patterns? *The Journal of Pedodontics*, 9, 265–284.

78. Stockstill, J.W. and Callahan, C.D. (1991) Personality hardiness, anxiety, and depression as constructs of interest in the study of temporomandibular disorders. *Journal of Craniomandibular Disorders: Facial & Oral Pain*, 5, 129–134.

79. Shiau, Y.Y. and Chang, C. (1992) An epidemiological study of temporomandibular disorders in university students of Taiwan. *Community Dentistry and Oral Epidemiology*, 20, 43–47.

80. Steed, P.A. and Wexler, G.B. (2001) Temporomandibular disorders–traumatic etiology vs. nontraumatic etiology: a clinical and methodological inquiry into symptomatology and treatment outcomes. *Cranio: The Journal of Craniomandibular Practice*, 19, 188–194.

81. Mohlin, B. (1983) Prevalence of mandibular dysfunction and relation between malocclusion and mandibular dysfunction in a group of women in Sweden. *European Journal of Orthodontics*, 5, 115–123.

82. Athanasiou, A.E. (2001) *Orthodontics and Craniomandibular Disorders*. W. B. Saunders Company, Philadelphia, PA.