CECILIA ABRAHAMSSON

MASTICATORY FUNCTION AND TEMPOROMANDIBULAR DISORDERS IN PATIENTS WITH DENTOFACIAL DEFORMITIES

Studies before and after orthodontic and orthognathic treatment
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PREFACE ........................................................................................................... 9
ABSTRACT ......................................................................................................... 10
   Key conclusions and clinical implications .................................................. 12
POPULÄRVETENSKAPLIG SAMMANFATTNING .......... 13
   Klinisk betydelse: ..................................................................................... 15
ABBREVIATIONS AND DEFINITIONS ........................................ 16
INTRODUCTION ................................................................. 18
   Dentofacial deformities ................................................................. 18
      Definition ......................................................................................... 18
      Prevalence ....................................................................................... 19
      Aetiology .......................................................................................... 19
      Treatment strategies ......................................................................... 20
   Temporomandibular disorders .......................................................... 21
      Definition .......................................................................................... 21
      Prevalence ........................................................................................ 22
      Aetiology ............................................................................................ 23
      Research Diagnostic Criteria for TMD (RDC/TMD) .................. 24
   Malocclusion and TMD ........................................................................... 25
   Orthognathic treatment and TMD ..................................................... 25
   Dentofacial deformities and mastication ......................................... 26
SIGNIFICANCE ...................................................................................... 28
AIMS ......................................................................................................... 29
   Paper I ................................................................................................. 29
   Paper II ............................................................................................... 29
<table>
<thead>
<tr>
<th>Page</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>Paper III</td>
</tr>
<tr>
<td>29</td>
<td>Paper IV</td>
</tr>
<tr>
<td>30</td>
<td>HYPOTHESES</td>
</tr>
<tr>
<td>30</td>
<td>Paper I</td>
</tr>
<tr>
<td>30</td>
<td>Paper II</td>
</tr>
<tr>
<td>30</td>
<td>Paper III</td>
</tr>
<tr>
<td>30</td>
<td>Paper IV</td>
</tr>
<tr>
<td>31</td>
<td>MATERIALS AND METHODS</td>
</tr>
<tr>
<td>31</td>
<td>SUBJECTS</td>
</tr>
<tr>
<td>32</td>
<td>Ethical considerations</td>
</tr>
<tr>
<td>33</td>
<td>METHODS</td>
</tr>
<tr>
<td>33</td>
<td>Paper I</td>
</tr>
<tr>
<td>36</td>
<td>Paper II-IV</td>
</tr>
<tr>
<td>38</td>
<td>Paper III-IV</td>
</tr>
<tr>
<td>39</td>
<td>Paper IV</td>
</tr>
<tr>
<td>40</td>
<td>Statistical analyses</td>
</tr>
<tr>
<td>43</td>
<td>RESULTS</td>
</tr>
<tr>
<td>43</td>
<td>Systematic review – Paper I</td>
</tr>
<tr>
<td>43</td>
<td>Dentofacial deformities and frequency of TMD</td>
</tr>
<tr>
<td>43</td>
<td>The effect of orthognathic surgery on TMD</td>
</tr>
<tr>
<td>44</td>
<td>Quality analysis</td>
</tr>
<tr>
<td>44</td>
<td>New literature search</td>
</tr>
<tr>
<td>47</td>
<td>Paper II</td>
</tr>
<tr>
<td>47</td>
<td>Anamnestic findings</td>
</tr>
<tr>
<td>47</td>
<td>TMD diagnoses</td>
</tr>
<tr>
<td>48</td>
<td>Paper III</td>
</tr>
<tr>
<td>48</td>
<td>TMD diagnoses</td>
</tr>
<tr>
<td>48</td>
<td>TMD diagnoses in relation to different kinds of dentofacial deformities</td>
</tr>
<tr>
<td>49</td>
<td>Symptoms of TMD</td>
</tr>
<tr>
<td>50</td>
<td>Mandibular movement capacity</td>
</tr>
<tr>
<td>51</td>
<td>Occlusal interferences</td>
</tr>
<tr>
<td>52</td>
<td>Patients’ satisfaction with treatment</td>
</tr>
<tr>
<td>52</td>
<td>Level of anxiety</td>
</tr>
<tr>
<td>52</td>
<td>Paper IV</td>
</tr>
<tr>
<td>52</td>
<td>Self estimated masticatory ability</td>
</tr>
<tr>
<td>52</td>
<td>Factors influencing the self estimated masticatory ability</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Masticatory performance</td>
<td>53</td>
</tr>
<tr>
<td>Factors influencing MPI</td>
<td>53</td>
</tr>
<tr>
<td>Correlations</td>
<td>54</td>
</tr>
<tr>
<td>Occlusion</td>
<td>55</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td>58</td>
</tr>
<tr>
<td>Systematic review</td>
<td>59</td>
</tr>
<tr>
<td>Methodological aspects</td>
<td>60</td>
</tr>
<tr>
<td>Paper I-III</td>
<td>60</td>
</tr>
<tr>
<td>Paper IV</td>
<td>63</td>
</tr>
<tr>
<td>Anamnestic findings</td>
<td>64</td>
</tr>
<tr>
<td>Frequency of TMD</td>
<td>64</td>
</tr>
<tr>
<td>Masticatory ability and performance</td>
<td>66</td>
</tr>
<tr>
<td>Future research</td>
<td>67</td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td>69</td>
</tr>
<tr>
<td>Key conclusions and clinical implications</td>
<td>70</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>71</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>75</td>
</tr>
<tr>
<td>PAPERS I – IV</td>
<td>87</td>
</tr>
</tbody>
</table>
To Jonas, Klara, Alva and Henrik
This thesis is based on the following papers, which are referred to in the text by their Roman numerals.


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About 30% of individuals in the Swedish population will at some stage during life have treatment with orthodontic appliances. In more severe cases, when orthodontic treatment is not considered sufficient enough to correct the malocclusion, the orthodontic treatment is combined with orthognathic surgery. For these cases, a satisfying jaw relation is achieved by surgically moving the maxilla and/or the mandible into a pre-planned position.

Patients due to be treated with orthognathic surgery often suffer from an impaired masticatory function, symptoms from the masticatory muscles or temporomandibular joints (temporomandibular disorders), headaches as well as dissatisfaction with their facial aesthetics.

Since orthognathic treatment is expensive, in many cases arduous to the patient and not without complications, it is important to assess the treatment outcome and if this is satisfying for the patients. Previous studies that have examined the outcome after orthognathic treatment have had diverging study designs and have come to different conclusions with regard to both temporomandibular disorders and masticatory function.

The overall aim of this thesis was to assess and compare the frequencies of temporomandibular disorders and the masticatory function in patients with dentofacial deformities before and after orthognathic treatment.

The thesis is based on the following studies:

**Paper I** is a systematic literature review aiming to, in an evidence-based approach, answer the question whether orthognathic treat-
ment affects the prevalence of signs and symptoms of temporomandibular disorders. The review encompasses the period from January 1966 to April 2006 and was further extended to May 2013 in the frame story of this thesis.

Conclusions in Paper I and the complementary survey
- There is insufficient scientific evidence for a decrease of subdiagnoses of temporomandibular disorders after orthognathic treatment.
- There is limited scientific evidence for a reduction of masticatory muscle pain on palpation after orthognathic treatment.
- There is insufficient scientific evidence for an effect on temporomandibular joint pain on palpation and temporomandibular joint sounds from orthognathic surgery.
- Further controlled, well-designed studies assessing temporomandibular disorders before and after orthognathic treatment are needed to consolidate strong evidence considering treatment outcomes.

Papers II and III are studies comparing frequencies of temporomandibular disorders in patients with dentofacial deformities with a control group. The patients were referred for a combined orthodontic and orthognathic treatment to correct their malocclusion. The control group comprised individuals with normal occlusion or minor malocclusion traits not in need of orthodontic treatment. In Paper III, temporomandibular disorders were longitudinally analysed by assessing and comparing frequencies before and after orthognathic treatment. All individuals in the studies were diagnosed according to the research diagnostic criteria for temporomandibular disorders.

Conclusions in Papers II and III
- Patients due to be treated with orthognathic surgery had more signs and symptoms of temporomandibular disorders and a higher frequency of diagnosed temporomandibular disorders compared with the age- and gender matched control group.
- Patients with dentofacial deformities, corrected by orthodontic treatment in conjunction with orthognathic surgery, had a positive treatment outcome in respect of myofascial pain and arthralgia.
After treatment the frequency of temporomandibular disorders in the treatment group was low and at an equivalent level of that in the control group.

**Paper IV** evaluates the self-estimated masticatory ability and the masticatory performance before and after orthognathic treatment in the same individuals as in Paper II and III.

**Conclusions in Paper IV**

- Masticatory ability and performance increased after orthognathic treatment.
- The number of occlusal contacts and severity of overall symptoms of TMD influenced both the masticatory ability and performance.
- Open bite had a negative effect on masticatory performance.

**Key conclusions and clinical implications:**

Patients with dentofacial deformities diagnosed with temporomandibular disorders do in most cases benefit from orthognathic treatment. In addition, masticatory ability and performance, which is impaired in patients with dentofacial deformities, improve after treatment. Thus, patients with dentofacial deformities that are to be treated with orthodontics in combination with orthognathic surgery can be recommended the treatment in order to relieve symptoms of TMD and impaired mastication.
Populärvetenskaplig sammanfattning

Ca 30 % av Sveriges befolkning genomgår någon gång i livet behandling med tandreglering. I de fall där bettavvikelsen är mer omfattande är enbart tandreglering inte tillräckligt för att uppnå ett bra bett. Istället kombinerar man tandregleringen med en kirurgisk förflyttningslandning av käkarna s.k. ortognat kirurgi. Dessa patienter besväras ofta, före behandling, av smärta och funktionsstörningar i käkar och tuggmuskler och är dessutom ofta missnöjda med sitt utseende. Då denna behandling är omfattande, kostsam och inte helt utan komplicationer är det av stort intresse att undersöka utfallet av behandlingen och om denna motsvarar förväntningarna hos patienterna.

Tidigare studier som har utvärderat utfallet av tandreglering i kombination med ortognat kirurgi har kommit fram till motsägelsefulla slutsatser vad gäller hur behandlingen har påverkat förekomsten av smärta och funktionsstörningar i käkar och tuggmuskulatur.

Det övergripande syftet med denna avhandling är att i en serie studier, före och efter ortognat kirurgi, utvärdera och jämföra förekomsten av smärta och käkfunktionsstörningar hos patienter med stora bettavvikelser.

Avhandlingen är baserad på följande studier:
Delarbete 1 är en systematisk litteraturoversikt med följande frågeställning:

Påverkar ortognat kirurgi förekomsten av smärta och funktionsstörningar i käkleder och tuggmuskulatur?

**Slutsatser i delarbete I**

- Det finns ett otillräckligt vetenskapligt underlag för om förekomsten av diagnostiserad smärta och funktionsstörning i käkleder och tuggmuskler minskar efter ortognat kirurgi.
- Det vetenskapliga underlaget är begränsat när det gäller en minskning av palpationsömhet i tuggmuskler efter ortognat kirurgi.
- Det finns ett otillräckligt vetenskapligt underlag för om förekomsten av käkledsljud påverkas av ortognat kirurgi.
- Det behövs ytterligare studier som är av hög eller medelhög kvalitet för att på ett evidensbaserat sätt kunna styrka behandlingsutfallet av ortognat kirurgi när det gäller smärta och funktionsstörningar i käkleder och tuggmuskler.

**Delarbetena II och III** är kontrollerade studier som undersöker förekomsten av smärta och funktionsstörningar i käkleder och tuggmuskler hos patienter med stora bettavvikelser, i jämförelse med personer med eller utan små bettavvikelser (ej i behov av tandreglering). Patienterna var remitterade för behandling med ortognat kirurgi. I delarbete III, som är en longitudinell uppföljningsstudie, analyseras hur förekomsten av smärta och funktionsstörningar i käkleder och tuggmuskler påverkas av behandlingen.

**Slutsatser i delarbete II och III**

- Patienter som ska behandlas med ortognat kirurgi har mer smärta och funktionsstörningar i käkleder och tuggmuskler jämfört med kontrollgruppen.
- Patienter som genomgått ortognat kirurgi har ett positivt behandlingsutfall avseende smärta från käkleder och tuggmuskler.
- Efter behandling är förekomsten av smärta och funktionsstörningar i käkleder och tuggmuskler låg och i nivå med den i kontrollgruppen.
Delarbete IV utvrderar den sjlvupplevda tuggförmågan och den testade tuggprestationen före och efter ortognat kirurgi hos samma individer som i studie II och III.

Slutsatser i delarbete IV

- Patienter med stora bettavvikler har innan ortognat kirurgi en sämre sjlvupplevd tuggförmåga och testad tuggprestation jämfört med kontrollgruppen.
- Efter behandling förbättras både den sjlvupplevda tuggförmågan och tuggprestationen.

Klinisk betydelse:
Patienter som har stora bettavvikler och dessutom smärta och funktionsstörningar i känleder och tuggmuskler har oftast ett positivt behandlingsutfall efter ortognat kirurgi. Dessutom förbättras den sjlvupplevda tuggförmågan och den testade tuggprestationen efter behandlingen. Patienter med stora bettavvikler som ska behandlas med tandreglering i kombination med ortognat kirurgi kan därför rekommenderas behandlingen för möjlighet till minskade besvär från tuggmuskler och käleder samt förbättrad tuggförmåga.
ABBREVIATIONS AND DEFINITIONS

ANB  The angle between point A in the maxilla and point B in the mandible in relation to nasion - describing the sagittal relation between the jaws
BSSO  Bilateral Sagittal Split Osteotomy
CI  Confidence Interval
DC/TMD  Diagnostic Criteria for TMD
EMG  Electromyography
IVRO  Intraoral Vertical Ramus Osteotomy
ICP  Intercuspation position
RCP  Retruded contact position
Masticatory ability  Self evaluated masticatory function
Masticatory performance  Tested masticatory function
ML  Mandibular plane (extending from gnathion to gonion)
ML/NSL  The angle between ML and NSL
MPI  Masticatory Performance Index
MeSH  Medical Subject Heading
NIH  National Institutes of Health
NSL  Nasion-Sella line (extending from Nasion to Sella)
Orthognathic Treatment  Orthodontic treatment in conjunction with orthognathic surgery
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q</td>
<td>Percentiles</td>
</tr>
<tr>
<td>RDC/TMD</td>
<td>Research Diagnostic Criteria for TMD</td>
</tr>
<tr>
<td>RCT</td>
<td>Randomized Controlled Trial</td>
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<td>SBU</td>
<td>The Swedish Council on Health Technology Assessment</td>
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<tr>
<td>TMD</td>
<td>Temporomandibular Disorders</td>
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<td>TMJ</td>
<td>Temporomandibular Joint</td>
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<tr>
<td>VAS</td>
<td>Visual Analogue Scale</td>
</tr>
</tbody>
</table>
**INTRODUCTION**

**Dentofacial deformities**

Definition

Malocclusion has been defined as a deviation in intramaxillary and/or intermaxillary relations of teeth that presents a hazard to the individual’s well being. (1)

More severe forms of malocclusion have been termed **dentofacial deformities** (Figure 1). The suggested definition of dentofacial deformities is a malformation of the dentofacial complex with resulting disabling disharmony in size and/or form (1) or as clearly described in PubMed (2); An abnormality of the jaws or teeth affecting the contour of the face.

![Figure 1. Different kinds of dentofacial deformities a) Open bite b) Deep bite c) Class II d) Class III](image)

1a

1b

1c

1d
Prevalence

Deviations from a normal occlusion are common and it has been estimated that about 74 % of Swedish schoolchildren have some form of malocclusion. (3)

The most prevalent malocclusions, according to Thilander and Myrberg 1974(3), are:

- Postnormal occlusion (14 percent)
- Prenormal occlusion (4 percent)
- Open bite (4 percent)
- Deep bite (8 percent)
- Cross-bite: uni- and bilateral (11 percent)
- Anterior Cross bite (11 percent)
- Overjet ≥ 6 mm (8 percent)

These prevalence figures for malocclusions include the prevalence figures for dentofacial deformities. Assessing the prevalence of severe skeletal malocclusions requiring orthognathic surgery is difficult (4) since dentofacial deformities can merely be regarded as a more severe form of malocclusion. (4) It has been estimated that 5 % of all Class II, 33 % of Class III and 25 % of all open bites needs orthognathic treatment. (5)

Aetiology

Malocclusion and dental deformities are in most cases caused by moderate distortions from normal development. They are the result from a complex interaction among multiple factors and it is in most cases not possible to describe a specific factor. In a population it has been reported that, about one third has a normal occlusion, 60 % has a malocclusion with unknown cause and 5 % has a malocclusion with a known cause. (6)

Skeletal growth disturbances such as Pierre Robin sequence and hemifacial microsomia are known to cause mandibular deficiencies. (6) Another factor known to affect craniofacial growth is muscle dysfunction. Muscular dystrophy, one kind of muscle dysfunction, leads to a decrease in muscle tonus allowing the mandible to drop downward, resulting in an increased facial height and development of an open bite. (7)
Other more well-known and common causes of malocclusion are oral habits such as sucking on fingers or pacifiers. (8)

Genetics has a strong influence on facial appearance and certain types of malocclusion like a Class III malocclusion runs in families e.g. the Habsburg jaw. (6) The relative influence of environment and heritability in the development of malocclusions with both skeletal and dental components is unclear. (6) However, it has been suggested that the heritability is high for craniofacial characteristics but low for dental characteristics. (9) So, it is therefore likely that a hereditary component is present in the aetiology of dentofacial deformities.

Treatment strategies
In Sweden, the reported need for orthodontic treatment in individuals between 8 and 20 years of age varies between 24 and 46 %. (10-12) In cases, when there is a good skeletal jaw relationship, the malocclusion can be corrected by orthodontic treatment using orthodontic appliances. In more severe cases, when a skeletal jaw discrepancy is involved, there are three treatment possibilities; a) growth modification, i.e. dentofacial orthopaedics that is applicable on growing individuals; b) camouflage treatment (orthodontic positioning of the teeth to compensate for the jaw discrepancy), not always resulting in an acceptable dental occlusion or satisfying facial aesthetics; c) orthodontic treatment in conjunction with orthognathic surgery in order to reposition the jaws, or the dentoalveolar segments, or both.(4)

Orthognathic surgery can be done either in the maxilla or in the mandible separately, or as bimaxillary surgery involving both jaws. Maxillary osteotomies are primarily performed as a LeFort I osteotomy, which allows the maxilla to be moved in both vertical and sagittal directions (Figure 2).

Bilateral sagittal split osteotomy is used for mandibular advancement in Class II cases or for setback in both Class II and Class III cases. The vertical ramus osteotomy is an alternative to sagittal split osteotomy when treating Class III deformities. A lower incidence of neural damage and fewer complaints of TMD are mentioned as some of the advantages with the vertical ramus osteotomy.(4, 13, 14)
The indications for treatment of dentofacial deformities by orthognathic surgery are mainly facial aesthetics, functional problems and temporomandibular disorders (TMD). The importance of the various individual indications varies between genders and between different parts of the world due to cultural differences and economical aspects. (15, 16) During 2012, 97 patients underwent orthognathic surgery in Lund University hospital. Unfortunately, there is a lack of data regarding the total number of orthognathic treatments performed per year in Sweden, which makes it impossible to validate the impact in oral health care.

Figure 2. A patient, diagnosed with an open bite, before and after orthognathic treatment.

Temporomandibular disorders
Definition
TMD is a collective term describing musculoskeletal disorders arising from the masticatory structures (Figure 3), (17) and has been identified as “a major cause of nondental pain in the orofacial region and are a sub-classification of musculoskeletal disorders”. (17)

The most important feature of TMD is chronic musculoskeletal pain. Palpation tenderness of the muscles of mastication and the temporomandibular joints is also frequently reported. Impaired range of motion (leading to difficulties when eating, e.g. apples or hamburgers) and various joint sounds elicited by mandibular excursions are associated with certain types of TMD. (19) Patients with TMD often also describe a feeling of fatigue of the jaws and symptoms of pain and dysfunction affecting ears, eyes and/or throat and headaches. (20)
Prevalence
The prevalence of TMD has been found to be high, albeit of a mild character, already in childhood. (21, 22) It then seems to increase, in a fluctuating pattern, from adolescence(23) to middle age and then to decrease in old age. (24) TMD is therefore primarily seen as a condition of young and middle-aged adults. (25)

TMD pain is common, occurring in about 10-14 % of the population over the age of 18 (25, 26) and is about twice as common in women as in men. (25)

TMJ clicking is even more prevalent and is found in 20-30 % of the adult population. (17, 25, 27, 28) There is evidence that TMJ sounds alone are frequent and a natural phenomenon in the general population and that they fluctuate longitudinally, but they are also recognized as a sub diagnosis of TMD. (19) Disc displacement with reduction diagnosed according to Research Diagnostic Criteria for TMD (RDC/TMD) (19) is present in 12-18 % of the adult population.(26)
In a meta-analysis by Al-Jundi et al.(29) it was estimated that the treatment need for TMD in adults, is in the region of 16 %, which indicates that TMD can be considered as a major health problem.

**Aetiology**

There is uncertainty as to the actual underlying aetiology of TMD. (25) Even if there are similarities with musculoskeletal disorders and pain disorders in general, the stomatognathic system is also unique with the upper and lower jaw, and occluding teeth, between bilaterally functioning temporomandibular joints, which has led to a need for a multifactorial etiologic approach. (30)

Contributing factors are often discussed in respect of the aetiology of TMD. These factors are divided as predisposing, initiating and perpetuating. Predisposing factors can increase the risk of developing a condition, initiating factors can cause the onset of the condition and perpetuating factors contribute to the maintenance or persistency of the condition.(30)

**Psychosocial and biomedical factors**

Every time a pain signal reaches the central nervous system the information in the impulse is processed and influenced by different areas of the brain, for example the limbic system, thalamus and cortex. (30) Beside age and gender, psychosocial factors like stress, depression and the presence of multiple somatic symptoms are therefore seen as possible risk factors in the development of TMD. (25, 31) Actually, psychological disorders have been shown to be a major contributing factor in chronic TMD. (30)

It has also been argued that biomechanical factors such as functional impairments of the TMJ’s, muscles and occlusion are involved in the aetiology of TMD. (20) Also behavioural factors such as tooth clenching or grinding have been discussed, (23) together with the possible influence from occlusion, (31-33) external trauma including whiplash injury(34) and micro-trauma due to overloading of the masticatory system.(30)

The various factors involved have led to a multidimensional perspective regarding TMD with an appreciation that a combination of physical, psychological and social factors can contribute to the overall presentation of this disorder. According to NIH Consensus
Conference (1997) it is hypothesized that the two cardinal features of TMD are pain and dysfunction, incorporating individual variability (Figure 4).

**Figure 4. Aetiological factors in TMD. The cardinal features of temporomandibular pain and dysfunction.** (20)

*Dysfunctional central pain modulation*

It has been emphasized that the development of chronic musculoskeletal pain in the case of the TMD diagnoses myofascial pain and arthralgia starts with peripheral trigeminal pain and inflammation, which has been proceeded by long-standing, repetitive muscular load. (35) This pain and inflammation in turn leads to a peripheral nociceptive hyper-excitability in the dorsal horn neurons in the spinal cord, i.e. primary hyperalgesia. This condition is normally reversible but in some individuals a central sensitization may develop due to functional (neurochemical) and structural (neuroanatomical) changes in the dorsal horn neurons and in other parts of the central nervous system as a consequence of the repeated and/or continuing peripheral noxious output. The condition can then result in a long-standing and refractory pain disorder, i.e. secondary hyperalgesia. (35) The structural changes can include development of dendrites and activation of latent synapses, which may cause spread, and referral of pain often seen in patients with TMD. (35)

**Research Diagnostic Criteria for TMD (RDC/TMD)**

The RDC/TMD were introduced in 1992 and was primarily developed for research purposes. There was a need for standardized research methods to enable comparisons of findings between different clinical investigators. The RDC/TMD has, since then, been
used in a large number of studies and it is now a well-accepted diagnostic tool. The diagnostic system in RDC/TMD is non-hierarchical and allows for the possibility of multiple diagnoses for a given subject. (19)

**Malocclusion and TMD**

An association with TMD and certain malocclusions has been reported. In a case-control study Henrikson et al (33) found more TMD among girls with a Class II malocclusion compared with controls with a normal occlusion. (33) This finding was confirmed in a study by Miller et al (36) who concluded that severe retrognathia was a risk factor for TMJ pain disorders in women.

Other malocclusions that have been suggested to be of importance in the development of TMD in some individuals, are unilateral cross-bite (32, 37) and crowding (38). There is however a general consensus that occlusal variables alone are not considered etiologic factors of TMD and that their role should not be overstated. (20, 30, 39, 40) In a systematic review by The Swedish Council on Health Technology Assessment (SBU) it was concluded that there is insufficient scientific evidence for an association between specific malocclusions and TMD. (12, 41)

**Orthognathic treatment and TMD**

Even though the occlusion does not seem to have a major role in the TMD aetiology, TMD are one of the main complaints among patients that are referred for orthognathic treatment. (15, 42) Can it be that individuals with dentofacial deformities are more susceptible to TMD than the population in general?

The frequency of TMD in patients with dentofacial deformities referred for orthognathic surgery, have been reported to vary between 43 and 73 %. (13, 43-45) These existing studies are not population based and therefore, sound epidemiologic data on the prevalence of TMD in individuals with dentofacial deformities is limited.

It has been agreed that orthodontic treatment does not seem to have a negative impact on the frequency of TMD. (12, 33, 38, 46)

Several studies have investigated whether orthodontic treatment in combination with orthognathic surgery has an influence on TMD.
Some of these studies indicated that orthognathic treatment does not affect frequencies of TMD at all. (45, 47, 48) On the other hand, Pahkala et al (49) concluded that patients diagnosed with TMD of myogenous origin benefited more from treatment compared with those diagnosed with TMD of arthrogenous origin. This conclusion was based on the findings that TMJ clicking decreased whereas crepitations were found to increase. These findings were confirmed by Rodrigues-Garcia et al(50) who in Class II patients found a decrease in TMD pain and TMJ clicking, but an increase in TMJ crepitus after treatment. The finding of decreased TMD pain after treatment, especially when of myogenous origin, has been confirmed in other studies.(43, 44)There are also reports indicating an overall decrease in TMD after treatment. (13, 42, 51)

Taken together, the cited articles above show a broad spectrum of different study designs and results, reflecting the divergence of the available literature. Therefore no consensus can be reached at this point in time with regard to treatment outcomes of TMD after combined orthodontic and orthognathic treatment.

Dentofacial deformities and mastication

Mastication is one of the most important functions of the digestion process. During mastication the food particles are reduced in size, thereby increasing the surface area and facilitating enzymatic processing. Saliva is produced to moisten and lubricate the food for swallowing.

Mastication can be assessed as masticatory ability - an individual’s self-estimated masticatory capacity or as masticatory performance – the tested defragmentation of food after a certain number of chewing strokes.

The number of chewing cycles before swallowing depends on the volume(52, 53) and the characteristics of the food, such as consistency and the percentage content of water and fat. (54, 55) Swallowing thresholds for hard food products, like carrots, are further affected by the masticatory performance and maximum bite force. (54)

The number and size of the occlusal contacts have been proposed as one determinant of self estimated masticatory ability(56) and masticatory performance since the contacts between occluding
pair of teeth determine the area available for shearing and grinding the food. (57) Compared to individuals with a closer to “ideal” bite, individuals with malocclusions have fewer occlusal contacts. Malocclusions have also been found to negatively affect an individual’s masticatory performance and self estimated masticatory ability. (57, 58)

Masticatory performance has also been reported to be affected by the maximum bite force (54). Individuals with an open bite or a Class III occlusion have demonstrated less maximum isometric bite force compared with controls. (53, 59) One explanation for this, at least in patients with open bite, can be that they exhibit thinner masticatory muscles. (53)

It has also been shown that there are gender differences in both thickness and activities of the masticatory muscles, with men having thicker masseter muscles (60) and higher EMG activity (61) compared with women.

Masticatory ability, an individual’s own assessment of their mastication, is an important factor in oral-health related quality of life and general health. It may therefore possibly reflect the impact of mastication on food choice and enjoyment of meals. (56)
Orthognathic surgery and its effect on TMD and mastication have been examined in several studies. However, most of the existing studies were designed as case-series and diverging in both study-design and results. This means that based on previous literature it is difficult to evaluate and comprehend the treatment effects of orthognathic surgery. Therefore, a systematic literature review in an evidence-based manner could increase the understanding in this field of research.

The consequences for patients with impaired masticatory function and pain from the masticatory muscles or joints often include difficulties in speaking, chewing and swallowing. These types of problems can probably affect the individual in daily activities such as in the choice of food and even in the everyday social intercourse.

The indications for orthognathic treatment typically reflect the patient complaints. Besides symptoms of TMD and dissatisfaction with facial aesthetics, treatment is therefore primarily performed due to the need to correct functional problems like mastication. The available literature unfortunately does not bring clarity, neither to whether patients with TMD benefit from orthognathic treatment, nor if their mastication is improved. Since orthognathic treatment is arduous for the patient, not without complications, time consuming and expensive for the society and sometimes also for the individual, it is of outmost importance to evaluate if the treatment meets the expectations from the patients, the profession and the society.

This thesis is based on a series of studies, unique in the way that they in a prospective longitudinal design assess TMD and masticatory function, in patients with dentofacial deformities, before and after orthognathic treatment in comparison with a control group.
Aims

Paper I
- To accomplish a systematic review of the present literature in order to evaluate whether orthognathic surgery affects the prevalence of signs and symptoms of TMD.

Paper II
- To evaluate whether TMD are more common in individuals referred for orthognathic surgery than in a control group.

Paper III
- To investigate whether correction of dentofacial deformities by orthognathic treatment alters the frequency of TMD.
- To compare and monitor the frequency of TMD in an untreated normal group over the same period of time.

Paper IV
- To evaluate the self estimated masticatory ability and masticatory performance in patients with dentofacial deformities before and after orthognathic treatment; in comparison to an age- and gender matched control group.
- To investigate possible factors that can have an impact on self estimated masticatory ability and masticatory performance.
HYPOTHESES

Paper I
- The scientific evidence based on currently available literature is insufficient to clarify if orthognathic treatment can affect the frequency of TMD.

Paper II
- Neither frequency of signs and symptoms of TMD or diagnosed TMD according to Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) would differ between the patient and control group.

Paper III
- Patients with dentofacial deformities benefit from treatment, in respect of TMD.
- Post-treatment, the frequency of TMD is similar to that in the control group.

Paper IV
- Patients with dentofacial deformities have impaired self-estimated masticatory ability and masticatory performance compared to a control group.
- For patients with dentofacial deformities the self estimated masticatory ability and masticatory performance is improved by orthognathic treatment.
MATERIALS AND METHODS

SUBJECTS
Paper II-IV
The treatment group comprised 121 consecutive patients (51 males and 70 females) with dentofacial deformities, referred to the Department of Oral Maxillofacial Surgery, Malmö University Hospital, Sweden for orthognathic treatment. The mean age at the start of the trial was 22.5±7.4 years. All patients with Class II, Class III, open bite or deep bite diagnoses were included and recruited during two periods, between 1992–1995 and 2000–2002. Patients with such severe dentofacial deformities are entitled to subsidized treatment under the Swedish National Health Service. The exclusion criteria were craniofacial syndromes, systemic arthritic and muscular diseases, and a dentition of fewer than 24 teeth. There were 98 patients that completed the follow-up examination (Paper III and IV, Figure 5); 38 males and 60 females, mean age 22.4 ± 7.5 years.

The control group comprised 56 subjects, 23 males and 33 females, mean age 23.4 ±7.4 years, age and gender matched with the subjects in the treatment group. They were recruited from general dental patients at the Faculty of Odontology, Malmö University, Sweden, and the Public Dental Health Clinic in Oxie, County Skane, Sweden. The inclusion criteria for the controls were normal occlusion, or minor malocclusions for which neither orthodontic treatment nor orthognathic surgery was indicated.

The same exclusion criteria applied to the control group as to the treatment group. Three years after the initial examination a follow-up questionnaire was sent to the individuals in the control group. They were contacted by telephone 2 to 3 weeks later, and asked to participate in the follow-up examination. Thirty-eight
of the 56 individuals (68 %) in the control group underwent the clinical follow-up examination in Paper III (Figure 5).

Analysis of those who withdrew from the treatment and control groups, (n = 23, 19 %, and n = 18, 32 %, respectively) showed no significant differences compared with the final samples with respect to age, gender, self-rated level of anxiety, pain in the jaws and related muscles, diagnosed TMD, self-estimated masticatory ability or performance reported at baseline. Thus, the participants who completed the study were considered to be representative of the initial study sample.

Ethical considerations
The study was approved by the Ethics Committee of Lund University, Sweden (Ref. No. LU-241-01), which follows the guidelines of the declaration of Helsinki.

Figure 5. Flow chart showing the participants in Paper III.
METHODS

Search strategy
To identify all studies that examined orthognathic surgery and its effect on TMD in patients with severe malocclusions, a literature survey was performed using the PubMed (www.ncbi.nlm.nih.gov) and the Cochrane Library electronic databases (www.cochrane.org). The search covered the period from January 1966 to April 2006.

The terms used in the search were malocclusion (MeSH-term), retrognathia (MeSH-term), prognathia, open bite (MeSH term), and deep bite in various combinations with craniomandibular disorders (MeSH-term), temporomandibular disorders, temporomandibular dysfunction, temporomandibular joint dysfunction, temporomandibular joint pain, and orthognathic surgery (MeSH-term), surgical-orthodontic treatment, and surgery (MeSH-term).

Selection criteria
Controlled human studies published as full-length articles, comparing symptoms and signs of TMD before and after orthognathic surgery in patients with malocclusion, were included. Articles concerning treatment of syndromes, e.g. cleft lip and palate were not considered. Three reviewers independently assessed all the article abstracts that appeared to meet the inclusion criteria. The article abstracts were collected irrespectively of the language in which they were published, after that the retrieved articles were read in their entirety and independently by the three reviewers. The reference lists of the retrieved articles were also hand-searched for relevant studies not found in the database search. Any inter-examiner conflicts were resolved by discussion to reach a consensus.

Data collection and analysis
Data were extracted on the following items: author, year of publication, study design, sample size, gender and age, surgical treatment methods, follow-up time, methods to determine TMD, outcomes, and authors’ conclusions. In addition, to document the methodological soundness of each article, a quality evaluation modified by the methods described by Antczak et al (62) and Jadad et al (63) was performed with respect to pre-established characteristics. The following variables were evaluated:
1. Study design; RCT = 3 points, prospective study = 2 points, retrospective study = 1 point
2. Adequate sample size = 1 point,
3. Adequate selection description = 1 point
4. Valid measurement methods = 1 point
5. Use of method error analysis = 1 point
6. Adequate statistics provided = 1 point
7. Consequences of confounders discussed in analysis = 1 point

By summarizing the scores for these seven variables, a study could achieve a quality score ranging from zero to a maximum of 9. A study’s quality was then categorized as low (0 to 4 points), medium (5 to 7 points), or high (8 or 9 points). To increase the objectivity of the analysis, four evaluators independently assessed the data extraction and quality scoring from each article. For each article, any inter-examiner disagreements were resolved by discussion to reach a consensus.

**Supplemental search**

Paper I was supplemented with a new literature search extending from April 2006 to May 2013 in the PubMed database and the Cochrane Collaboration Library for reviews and clinical trials. The same search terms as previously were used, and with the addition of the MeSH term ”dentofacial deformities” in combination with the original terms. The same selection criteria, data collection and analysis as described in Paper I were used, the only exception being that only three evaluators assessed the quality of the retrieved articles.

The grading and the final level evidence, based on the evaluated studies, were estimated according to the SBU (Tables 1 and 2). (38, 64-66)
Table 1. Criteria for grading of assessed studies.(66)

**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 test 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 2. Definitions of the evidence levels.(66)

<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 that two grade “B” studies</td>
</tr>
</tbody>
</table>
Paper II-IV

Questionnaire

In the questionnaire, the individuals reported:

- Reasons for seeking treatment (impaired chewing capacity, symptoms from the masticatory muscles, TMJs, headaches, and aesthetic reasons)
- State of general health
- Use of painkillers for headaches and TMD (yes/no)
- Awareness of oral parafunctions as tooth grinding (yes/no), or tooth clenching (yes/no)
- Frequency of TMD pain, jaw fatigue, TMJ clicking, and headache (never/once or twice a month/once a week/once or twice a week/daily)
- Pain at rest (yes/no) and during mandibular movements (yes/no) and reported TMJ clicking (yes/no)
- Ability to masticate different kinds of food; meat (yes/no), carrots (yes/no), toffee (yes/no), French loaf (yes/no) or cold cuts of ham, cheese and cucumber (yes/no).

A visual analogue scale (VAS) (67) 0-100 mm, was used to register severity of overall symptoms of TMD (Paper II) with the endpoints none = 0 and severe = 100 and on a verbal scale as follows: 0 = no or minimal discomfort, 1 = slight discomfort, 2 = moderate discomfort, 3 = severe discomfort, 4 = very severe discomfort (Paper III, IV). The VAS was also used for registration of the individuals self-estimated ability to masticate food with the end points “good” = 0 mm and “bad” =100 mm and the level of anxiousness with the endpoints “calm” = 0 and “nervous/anxious” = 100.

The follow-up questionnaire in Paper III included questions about treatment satisfaction, including whether the pre treatment information had been adequate (yes/no), whether treatment met expectations (yes/no) and whether, post-treatment, the subjects had perceived any alterations in masticatory capacity, aesthetics and TMD symptoms (better, unchanged, worse).

Clinical examination

Before the orthognathic treatment was started, two calibrated specialists in stomatognathic physiology conducted the clinical
examination at the Department of Stomatognathic Physiology at Malmö University. The extraoral examination preceded the intraoral examination.

The examination included measurement of mandibular movements, pain during non-guided mandibular movements, registration of TMJ sounds (clicking and crepitation), and tenderness of the TMJs and related muscles. The clinical registrations were improved by calibrating the examination techniques of the two examiners before the start of the study. The calibration was performed by examining 8 patients, not included in the study, and was achieved after discussion. The 8 subjects were also examined regarding occlusal interferences with an observer error that was found to be acceptable. The specialists conducting the examinations were not informed whether the subject belonged to the treatment or control group at the follow-up.

The functional occlusion was assessed by methods previously described and investigated for observer error. Mediotrusion interferences within a lateral excursion of 3 mm, laterotrusion interferences, protrusion interferences, and the distance and the direction of the slide between retruded contact position (RCP) and the intercuspal contact position (ICP) were registered.

Sub-diagnoses of TMD
Diagnoses according to RDC/TMD (19) are divided into three groups (Paper II):
- Muscle disorders: (a) myofascial pain, (b) myofascial pain with limited opening
- Disc displacements: (a) disc displacement with reduction; (b) disc displacement without reduction, with limited opening; (c) disc displacement without reduction, without limited opening
- Arthralgia, arthritis, arthrosis: (a) arthralgia, (b) osteo-arthritis of the TMJ, (c) osteoarthrosis of the TMJ

In Paper III the criteria for diagnosis of disc displacement were modified:

Disc displacement was diagnosed if, upon opening and closing from maximum intercuspation, a click was noted audible or by palpation. Osteoarthrosis was diagnosed as registered crepitations by palpation of the TMJ.
Sub-diagnoses of dentofacial deformities
Morphologic occlusion according to Björk et al (69) was registered by intraoral examination. For the patient group, further data were obtained from dental study casts, lateral cephalograms, and a cephalometric analysis. (70) An open bite was classified as an NSL/ML angle of $\geq 40^\circ$ and a deep bite as an NSL/ML angle of $\leq 26^\circ$. A Class II skeletal relationship between the dental arches was classified as an ANB angle of $\geq 6^\circ$ and a Class III skeletal relationship as an ANB angle of $\leq 0^\circ$. Consequently, the diagnoses in the treatment group were separated into sagittal and vertical discrepancies (Table 4).

Paper III-IV
In the treatment group, TMD and masticatory function was assessed by means of a questionnaire and a clinical examination before (baseline) and 18 months after surgery. The interval between the two examinations was approximately 3 years depending on the length of the orthodontic treatment. The questionnaire and the clinical examination were performed after treatment planning. The control group was similarly assessed, on two occasions, at an interval of at least 3 years.

Treatment methods
All subjects in the treatment group underwent pre- and postsurgical orthodontic treatment with fixed orthodontic appliances in both arches. Ten specialists carried out the orthodontic treatment; the duration varied between 18 and 24 months.

Four maxillofacial surgeons at the Department of Oral Maxillofacial Surgery, Malmö University Hospital, Sweden, performed the orthognathic surgery. Vertical deformities was corrected in the maxilla with a one piece Le Fort I osteotomy or a segmental maxillary osteotomy (Table 4). (71) Sagittal adjustments were made either by sagittal split osteotomy, to advance the mandible (72) or by intraoral vertical ramus osteotomy, to correct mandibular prog- nathism (Table 4). (71) When bimaxillary surgery was indicated, maxillary osteotomies were combined with either sagittal split or vertical ramus osteotomies (Table 4). Maxillo-mandibular fixation was used for 4 weeks after intraoral vertical ramus osteotomies. In all other cases, rigid intra jaw fixation was used.
Paper IV

Self-estimated masticatory ability
Assessed by a questionnaire, as described previously (p. 42).

Masticatory performance test
For assessment of the masticatory performance (73), the individuals were instructed to chew round tablets of silicon impression material (Optosil®, Bayer, Germany) with a standardized weight (Figure 6). The test involves chewing of 5 separate tablets for 20 strokes. The chewed sample was expectorated into a plastic cup. The mouth was then rinsed with water until all particles were removed from the mouth. The rinse water was also collected in the cup and then filtered. The chewed material from each of the tablets was fractionated in a system of sieves with coarse, medium and fine meshes (Figure 6). Essentially, the more efficient the mastication was, the greater the quantity of material that passed through the finest sieve. The quantity of material was estimated by weight.

A masticatory performance value, by proportion of weight, was calculated for each test portion, and the mean of the best four values out of five was used as the masticatory performance index (MPI). (73) The index ranges from 0 to 100 - the highest number corresponds to the highest performance value. Data of the MPI test was lost from 1 patient at baseline and another 6 patients at follow-up in the treatment group. In the control group the MPI test was only performed at baseline.

Figure 6. Showing the Optosil® tablett and the sievesystem.
Tooth contacts
The number of tooth contacts was recorded in habitual intercuspal position during maximal isometric biting force. The indication of contacts was registered in the maxilla by means of a thin double folded plastic-foil (GHM occlusion foil® 8 μm, Hanel –Ghm Dental, Germany). The markings by the foil were registered as follows: single dot = one contact; line = two contacts; region of several small markings = three contacts (Figure 7). The evaluation of the methodological error for measuring the number of occlusal contacts has been described earlier and was found to be low. (58)

Figure 7. Registration of tooth contacts. 1) Single dot – one contact, 2) Line – two contacts, 3) Region of several small markings – three contacts.

Statistical analyses
All statistical analyses were performed using the Statistical Package for the Social Scenes (SPSS) versions 13-20 for Windows (IBM). The criterion for significance (alpha) was set at .05. The tests were 2-tailed, which means that an effect in either direction was recognized. When necessary, statistical consultations were made with a statistician at the Department of statistics, Lund University, Sweden.
Sample size calculation (Paper II-IV)
With the proposed sample size of 35 in the treatment and control groups, the study had a power of 89.8% to yield a statistically significant result. This computation assumed that the difference in proportions was 0.30 (specifically, 0.05 versus 0.35) in the prevalence of TMD pain. This difference was selected as the smallest effect that would be important to detect, in that any smaller effect would not be of clinical or substantive significance.

Descriptives
Mean and standard deviations were calculated for all continuous, numerical variables (Paper II-IV) and medians and percentiles (Q) for continuous, ordinal variables (Paper II-IV).

Differences between groups
Pearson’s chi-square test with Yate’s correction for continuity was used when 2 x 2 cross tabulations were applicable. When the expected cell value was less than 5, Fisher’s exact test was used (Paper II-IV).

Mann-Whitney rank sum test was used to compute the difference between ranks and groups with ordinal data (Paper II-IV).

Two-sample t-statistics was used when comparing means of numerical variables (Paper II-IV).

Analysis of variances (ANOVA) was used when comparing means between sub groups of sagittal and vertical discrepancies (Paper IV).

Differences within groups (Paper III-IV)
McNemar exact test was used to analyse dichotomous data before and after treatment.

Wilcoxon signed ranks test was used to analyse ordinal data before and after treatment.

Paired t-test was used to compare the means of maximum mandibular opening capacity.
Multivariate analysis
Linear regression analysis, with the enter method, adjusted for age and group belonging, was used for multivariate analysis of masticatory ability and MPI (Paper IV).

Bivariate analysis
Bivariate correlation with Pearson correlation coefficient was performed on numerical variables (thesis).
RESULTS

Systematic review – Paper I
The search strategy resulted in 467 articles. After analysis according to the inclusion/exclusion criteria, three articles (43-45) were included for further analysis. All of the included studies were controlled, prospective and longitudinal.

An agreement of more than 90 % was found between the reviewers in assessing the data extraction and decisions of quality scores of the included articles.

Dentofacial deformities and frequency of TMD
When comparing signs and symptoms of TMD before treatment, none of the included studies (43-45) found any significant differences between patients and control groups or between different kinds of malocclusion.

The effect of orthognathic surgery on TMD
The reported findings after orthognathic treatment were contradictory. Two of the studies(43, 44) found a statistically significant decrease in muscle palpation tenderness after surgery, whereas in one study, (45) no such change was found. (Table 3) One study(43) also reported a significant decrease in TMJ palpation tenderness (Table 3). Consequently the authors’ conclusions for the studies also diverged with two of the studies(43, 44) declaring that both signs and symptoms related to TMD had improved significantly, whereas one study, (45) reported that TMD symptoms did not always show improvement after surgical correction, and for some patients, the symptoms even changed for the worse.
Quality analysis
According to the quality assessment of the included articles there were two studies (44, 45) of medium and one (43) of low quality. All of the studies used valid and well-known methods for measurements and provided adequate statistics. The general shortcomings were inadequate selection description, no method error analysis and no discussion of consequences of confounders. One study was also found to have an inadequately small control sample. (43) It is also notable that no study (43-45) reported a prior estimate of the sample size.

New literature search
The complementary literature search of studies published April 2006-May 2013 resulted in 234 articles. Only one study met the inclusion criteria. (74) The reasons for exclusion and number of excluded articles were:

- Studies not concerning the objectives of this review (analysis of surgery technique, treatment of arthritis and osteoarthritis, treatment of syndromes as cleft lip or palate treatment) 218
- Case reports, case series 10
- Review articles 5

Total 233

Treatment effects
The only included study in the new search was a prospective, longitudinal and controlled trial (Paper III in this thesis). (74) The findings revealed a decrease of both myofascial pain, arthralgia and disc displacements. The results also indicated an increase in osteoarthritis (Table 3). The conclusions from the study were that for patients with dentofacial deformities orthognathic surgery has a positive treatment outcome in respect of TMD pain. After treatment the frequency of TMD was lower and comparable to that of a control group.(74)
Quality Analysis

The research quality/methodological soundness for the included study was estimated as high. (74) Adequate sample size, in advance calculated by a power analysis, and selection description was provided. The study used a valid and well-known measurement method, method error analysis and adequate statistics. Confounders were discussed in the analysis. The only, but major, shortcoming was that the study design was not a RCT.

Evidence for differences in frequency of TMD before and after orthognathic treatment

Only one study used RDC/TMD as a diagnostic tool when assessing frequencies of TMD. (74) Therefore, according to the definitions of evidence level by SBU (61) there is insufficient evidence for an effect on diagnosed TMD from orthognathic treatment.

The majority of the included studies in the systematic review, instead assessed signs and symptoms of TMD. The result from Paper I and the complementary search revealed that there is limited evidence for a decrease in pain on palpation in the masticatory muscles after orthognathic treatment. (44, 74)

There was insufficient scientific evidence, partly due to contradictory results, (44, 45, 74) to support an effect on TMJ sounds and TMJ pain on palpation from orthognathic treatment.
Table 3. Results of the quality analysis and the treatment outcome of the studies included in Paper I and the new literature search.

<table>
<thead>
<tr>
<th>Study</th>
<th>Quality</th>
<th>Score</th>
<th>Number of patients</th>
<th>Type of dentofacial deformity</th>
<th>Follow-up after surgery</th>
<th>Subdiagnoses of TMD</th>
<th>Pain on palpation of the masticatory muscles and TMJs</th>
<th>TMJ sounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onizawa et al, 1995</td>
<td>Moderate</td>
<td>5</td>
<td>30</td>
<td>Various</td>
<td>6 months</td>
<td>no</td>
<td>Unchanged</td>
<td>Unchanged</td>
</tr>
<tr>
<td>Panula et al, 2000</td>
<td>Low</td>
<td>4</td>
<td>60</td>
<td>Various</td>
<td>29 months</td>
<td>no</td>
<td>Decrease in both muscle and joint pain on palpation</td>
<td>Unchanged</td>
</tr>
<tr>
<td>Dervis et al, 2002</td>
<td>Moderate</td>
<td>5</td>
<td>50</td>
<td>Various</td>
<td>24 months</td>
<td>no</td>
<td>Decrease in muscle pain on palpation, joint pain on palpation unchanged</td>
<td>Unchanged</td>
</tr>
<tr>
<td>Abrahamsson et al 2013</td>
<td>High</td>
<td>8</td>
<td>121</td>
<td>Various</td>
<td>18 months</td>
<td>yes (RDC/TMD) Decrease in myofascial pain, arthralgia and disc displacement</td>
<td>Decrease in both muscle and joint pain on palpation</td>
<td>Joint clicking decreased, crepitations increased</td>
</tr>
</tbody>
</table>
**Paper II**

*Anamnestic findings*

The self-rated level of anxiousness was similar in the treatment and control groups, with median VAS scores of 19.5 (Q1 = 7, Q3 = 47) and 19.0 (Q1 = 6, Q3 = 43), respectively. Furthermore, there were no differences between the groups with regard to reported weekly headaches or awareness of para-functional habits such as tooth clenching and tooth grinding. No subject in either of the two groups reported heart or joint disease. No significant differences were found between the groups regarding frequencies of allergies, stomach and dermatologic diseases.

The severity of the overall symptoms of TMD was rated higher on a verbal scale in the treatment group compared with the control group (P = .001).

The reasons for seeking treatment reported by the patients were (more than one answer was possible):

- impaired mastication (75 %)
- symptoms from masticatory muscles, TMJs, and headaches (72 %)
- aesthetic reasons (66 %)

*TMD diagnoses*

The treatment group had a significantly higher frequency of myofascial pain, disc displacement with reduction (DDR), and arthralgia compared with the control group (Figure 8). The frequency of myofascial pain with limited opening, osteoarthritis, and osteoarthrosis was low, with no differences found between the two groups.

There were no significant differences in the frequency of diagnosed TMD(19) between the different malocclusion traits, shown in Table 4.
Figure 8. Percentage distribution of TMD diagnoses according to RDC/TMD in the treatment group (n = 121) and the control group (n = 56) before treatment.

Table 4. Distribution of different kinds of malocclusions and performed surgery in the treatment group.

<table>
<thead>
<tr>
<th>Dentofacial Deformities</th>
<th>Maxillary osteotomy</th>
<th>Bilateral Sagittal Split Osteotomy (BSSO)</th>
<th>Intraoral Vertical Ramus Osteotomy (IVRO)</th>
<th>LeFort I and BSSO</th>
<th>LeFort I and IVRO</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class II</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Class III</td>
<td>6</td>
<td>0</td>
<td>29</td>
<td>0</td>
<td>7</td>
<td>42</td>
</tr>
<tr>
<td>Open bite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in combination with orthognathic jaws</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>1</td>
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</tr>
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<td></td>
<td></td>
</tr>
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</tr>
<tr>
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<td>0</td>
<td>1</td>
<td>2</td>
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<td></td>
<td></td>
<td></td>
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</tbody>
</table>

Paper III
TMD diagnoses
After treatment, the frequencies of myofascial pain, disc displacement and arthralgia were significantly reduced in the treatment group, but at the same time, there was a significant increase in osteoarthrosis (Figure 9). At baseline, significantly more patients in the treatment group had myofascial pain and arthralgia compared with the control group, whereas there was no difference post-treatment
(Figure 10). For the treatment group the number of patients with at least one TMD pain diagnosis had decreased with 42%.

The only TMD diagnosis, in the treatment group, with a significant gender difference was myofascial pain. Before treatment ($P = .015$); it was more common in women (32%) than in men (12%), but at follow-up, no gender-related differences were found for this or any other of the TMD diagnoses.

TMD diagnoses in relation to different kinds of dentofacial deformities

After treatment, there were significantly decreased frequencies of myofascial pain ($P = .022$) and arthralgia ($P = .031$) in Class III patients (with a normal vertical jaw relationship). None of the other subgroups showed significant differences in TMD diagnoses between baseline and follow-up.

![Figure 9. Percentage distribution of TMD diagnoses in the treatment group (n=98) before and after treatment.](image-url)
Figure 10. Percentage distribution of TMD diagnoses in the treatment group (n=98) and control group (n=56) after treatment.

Symptoms of TMD
In the treatment group, both self-evaluated severity of overall symptoms of TMD and pain from the masticatory muscles and TMJs, decreased significantly from baseline to follow-up (P < .001). No such difference was found in the control group (Figures 11-13).

Figure 11. Self-evaluated overall symptoms of TMD, in the treatment group (n=97), at baseline and follow-up (P < .001). For one patient no answer was registered.
Figure 12. Self-evaluated overall symptoms of TMD, in the control group, at baseline and follow-up (P = NS).

Figure 13. Reported pain from the masticatory muscles and TMJs during rest, wide opening and/or mastication, in the treatment (n=97) and control group (n=38), before and after treatment. For one patient in the treatment group no answer was registered.

Mandibular movement capacity
At both baseline and follow-up, the maximum mandibular opening capacity in the treatment group was lower than in the control group (P = .005, P < .001 respectively). The opening capacity in the treatment group had decreased at follow-up, from 50 ± 8 mm to 48 ± 7 mm (P = .009). For the control group, no significant changes in mandibular opening capacity were recorded from baseline to follow-up examinations (mean 54±5 mm and 53±6 mm, respectively).
Occlusal interferences
At baseline, the treatment group had significantly more interferences (P < .05) than the control group, except for lateral deviation between RCP and ICP. At follow-up, the number of subjects in the treatment group with interferences had decreased significantly (P < .05) and no inter-group differences were disclosed.

Patients’ satisfaction with treatment
When asked about their satisfaction with the treatment, 82% of the patients in the treatment group reported improved aesthetics, 80% reported improved masticatory comfort and 61% reported fewer symptoms of TMD after treatment. Ninety-two percent were satisfied with the information received before treatment. Sixty-eight percent reported their experience of treatment to be as they had expected, or less burdensome than expected. There were no gender differences with regard to treatment satisfaction.

Level of anxiety
The median self-evaluated level of anxiety registered on a VAS decreased from 19 to 11 after treatment (P = .001). The corresponding figures for the control group were 20 at baseline and 25 at follow-up examination (P = .871).

Paper IV
Self estimated masticatory ability
At baseline, the patients rated their masticatory ability significantly lower (mean = 52.2 ± 29.5) than the control group (mean = 85.7 ± 17.4, P < .001). They also found it more difficult to chew meat (P < .001), raw carrots (P = .019), toffee (P = .002), French loaf (P < .001) and cold cuts of ham, cheese and cucumber (P < .001). At follow-up, the masticatory ability had significantly improved in the treatment group (mean = 83.9 ± 19.2, P < .001) and reached a level similar to that of the control group with no significant difference between the groups.

Factors influencing the self estimated masticatory ability
The only factors significantly associated with the masticatory ability in the treatment group were the number of occlusal contacts during
maximum biting pressure and self-estimated overall symptoms of TMD. When the treatment group and control group were merged a significant association between TMD pain and masticatory ability was found (Table 5).

In a linear regression analysis adjusted for age, factors like number of occlusal contacts during maximal biting pressure, severity of overall symptoms of TMD and study group belonging explained 45% of the total variation of the masticatory ability. Fewer occlusal contacts during maximal biting pressure, a higher severity of the overall symptoms of TMD and belonging to the treatment group all had a negative association with the masticatory ability.

When subgroups of dentofacial deformities were assessed it was found that patients with a Class II relation (n = 27) rated their masticatory ability higher (mean = 68.7, ± 25.9) compared with patients with Class III and normal sagittal relations (n = 71, mean = 46.5, ±28.7, P = .002, 95% CI 8.4-35.9). No significant differences were found between separate vertical jaw relations.

**Masticatory performance**

There were large individual variations of the masticatory performance index (MPI), within the groups. At baseline, the treatment group had a lower MPI than the control group (mean 10.4 ± 10.4 versus mean 37.3 ± 16.8). For the treatment group, the MPI increased at follow-up (mean 21.0 ± 19.2) but was still low compared with the baseline level in the control group (P < .001).

After stratifying the material into sagittal and vertical deformities it was found that the MPI improved after treatment in patients with:

- Class III malocclusion (normal vertical relation)
  - *Mean*: 12.8 ± 11.0 to 23.7 ± 18.5 (P < .001)
- Open bite (normal sagittal relation)
  - *Mean*: 6.3 ± 6.0 to 19.9 ± 19.9 (P = .038)
- Class III combined with open bite
  - *Mean*: 7.9 ± 8.4 to 24.7 ± 20.6 (P = .003)

No significant differences after treatment were found in patients with deep bite or Class II malocclusion.

**Factors influencing MPI**
When the treatment group and control group were analysed altogether the variables gender; number of occlusal contacts during maximal biting pressure; self reported severity of overall symptoms of TMD and TMD pain diagnoses were all found to significantly have an influence on the MPI at baseline, (Table 6). When the treatment group and control group were analysed separately only gender and occlusal contacts had an influence on the MPI in the treatment group whereas gender and a TMD pain diagnosis influenced the MPI in the control group. No association was found between age and MPI for any of the groups (Table 6).

A linear regression analysis, adjusted for age and group belonging, explained 37 % of the total variation of MPI. The number of occlusal contacts during maximal biting pressure was the factor that had the highest influence on MPI, with increased MPI with a higher number of contacts. Open bite was the only kind of dentofacial deformity with a significant influence on MPI, showing a negative effect on MPI.

Patients with an open bite (n = 41) were also found to have an impaired masticatory performance (mean = 6.7, SD 6.8) compared with patients with deep bite or a normal vertical relation (n = 57, mean = 13.2, SD 11.8, P = 0.01, 95 % CI 2.7-10.2). No significant differences were found between separate sagittal relations.

**Correlations**

Before treatment, significant correlations were found between:

- Self-estimated masticatory ability and masticatory performance (0.483, P < .001).
- Self-estimated masticatory ability and number of occlusal contacts during maximum biting pressure (0.428, P < .001).
- Masticatory performance and number of occlusal contacts during maximum biting pressure (0.509, P < .001).
Occlusion

Before treatment, there were no significant differences in number of teeth between the treatment (mean = 28 ± 1.9) and the control group (mean = 29 ± 2.0). During treatment teeth were extracted in some of the patients and at follow-up there were significant differences between the two groups (mean = 27 ± 2.1 and 29 ± 2.0 respectively, \( P = .002 \)).

The treatment group had significantly fewer occlusal contacts during maximum biting pressure than the control group (mean = 13 ± 6.4 versus 18 ± 5.5, \( P < .001 \)). After treatment the number of contacts increased (Mean = 16 ± 6.1, \( P < .001 \)) and did not significantly differ from the control group.

When subgroups of sagittal and vertical discrepancies were assessed before treatment, the 41 patients with open bite had significantly fewer occlusal contacts during maximum biting pressure compared with the 48 patients with normal vertical relation (mean = 14 ± 5.8, \( P = .014 \)) and the 9 patients with deep bite (mean = 10 ± 5.0 versus 19 ± 9.5, \( P < .001 \)) and the 48 patients with normal vertical relation (mean = 14 ± 5.8, \( P = .014 \)). No significant differences between sagittal discrepancies were found before treatment. After treatment there were no significant differences between any of the subgroups.
Table 5. Statistically significant differences of the Mean self-evaluated masticatory ability by levels of Occlusal factors and TMD in the whole study group (Both Treatment and Control group) \( n = 153 \) and the two groups separately. Twelve patients were not asked for their masticatory ability before treatment.

| Influencing binary parameters | Patient group | | | | | | Control Group | | | | | | Both groups | | | |
|-----------------------------|---------------|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|                             | n  | MPI | SD | P  | 95% CI | n  | MPI | SD | P  | 95% CI | n  | MPI | SD | P  | 95% CI |
| Female                      | 50 | 57.1 | 31.5 | NS | | 33 | 86.6 | 15.3 | NS | | 83 | 68.8 | 30.7 | NS | |
| Male                        | 36 | 45.4 | 25.4 | NS | | 23 | 84.3 | 14.9 | NS | | 59 | 60.6 | 29.1 | NS | |
| Number of occlusal contacts during maximal biting pressure | | | | | | | | | | | | | | | |
| < 10                        | 28 | 38.7 | 25.5 | NS | | 3 | 63.7 | 8.1 | NS | | 31 | 43.1 | 27.8 | NS | |
| ≥ 10                        | 58 | 58.7 | 29.3 | .003 | .71 – 32.9 | 53 | 85.8 | 17.8 | NS | | 111 | 71.6 | 27.9 | .000 | 17.4 – 39.8 |
| One diagnose of TMD pain    | | | | | | | | | | | | | | | |
| No                          | 59 | 56.4 | 28.4 | NS | | 50 | 87.5 | 13.3 | NS | | 109 | 79.7 | 27.5 | NS | |
| Yes                         | 27 | 43.1 | 30.4 | NS | | 6 | 70.3 | 35.8 | NS | | 33 | 46.0 | 32.6 | .000 | 11.3 – 33.9 |
| Severity of overall symptoms of TMD | | | | | | | | | | | | | | | |
| Insignificant-light         | 60 | 60.1 | 26.8 | NS | | 51 | 88.0 | 13.2 | NS | | 101 | 74.2 | 25.2 | NS | |
| Moderate-very severe        | 36 | 41.2 | 29.9 | .003 | 6.7 – 31.2 | 5 | 61.8 | 34.5 | NS | | 41 | 43.7 | 30.8 | .000 | 20.7 – 40.4 |
Table 6. Statistically significant differences of the mean Masticatory Performance Index (MPI) by levels of Occlusal factors and TMD in the whole study group (Both Treatment and Control group) n = 153 and the two groups separately.

<table>
<thead>
<tr>
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<th>Control Group</th>
<th>Both groups</th>
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</thead>
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</tr>
<tr>
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<td></td>
<td></td>
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<tr>
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<tr>
<td>≥ 10</td>
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<td>One diagnose of TMD pain</td>
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<td>11.5</td>
<td>11.0</td>
</tr>
<tr>
<td>Moderate-very severe</td>
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DISCUSSION

This thesis is based on a series of studies evaluating TMD and masticatory function in patients with dentofacial deformities referred for orthognathic surgery. The first part of the thesis (Paper I) reviewed previous literature to determine whether there was evidence for a positive or negative outcome with respect to TMD after orthognathic treatment. The clinical studies (Paper II-IV) were unique as they provided a longitudinal comparison of a patient group with a control group that had no or minor malocclusions. Studies with a controlled and longitudinal study design are scarce in this field of research.

The main finding of the initial systematic review (Paper I) was that there are very few controlled studies that longitudinally assess TMD in patients treated with orthognathic surgery. Thus, it was very difficult to draw any conclusions regarding treatment outcomes. This lack of studies may reflect the difficulties in performing these kind of clinical trials.

The main findings of the clinical studies (Paper II-IV) were that patients with dentofacial deformities and referred for orthognathic surgery had more TMD than a normal population. These patients also estimated their masticatory ability lower and was tested having lower masticatory performance than the control group. After treatment the frequency of TMD had been reduced in the treatment group and were similar to the levels found in the control group. Also the masticatory ability and the masticatory performance had improved, although the masticatory performance was still lower compared to the control group.
Systematic review

In 1992 Davidoff et al(75) estimated that dedicated health care professionals would have to read and critically review about 17 original articles every day to keep up to date with the recent published science. Today the figures are probably even higher, and consequently this task is obviously impossible to implement for most clinicians, making systematic reviews valuable.

In a systematic review a well-formulated question is addressed by analysing all available evidence. It includes an objective search of the literature, critically appraising what is found to be relevant. Then data is extracted, synthesized and summarized. The process is aimed at minimizing bias in order to have a more reliable basis for clinical decision-making. (76, 77) There is also the view that systematic reviews should always precede new research projects in order to improve study designs, and consequently to produce new trials with a higher impact. (78)

In the present systematic review the formulated question was “Does orthognathic surgery affect the prevalence of signs and symptoms of TMDs?” and the inclusion criteria were:

- Studies comparing signs and symptoms of TMD before and after orthognathic surgery in patients with malocclusion.
- Randomized controlled trials (RCTs) or controlled, prospective or retrospective studies.

The result of the literature search in the initial and the complementary review revealed a limited number of studies that corresponded to the inclusion criteria. (43-45, 79) Furthermore, neither of these studies were RCTs. In research, a well-designed and properly executed RCT, is claimed to provide the highest level of evidence on the efficacy of health care interventions and is therefore considered the gold standard(80-82). Unfortunately, often due to ethical reasons, it is not possible to perform randomised trials, instead leaving observational studies like cohort or case-control studies as the only choice. Considering patients with dentofacial deformities, scheduled for orthognathic surgery, it can be considered unethical to randomize one group of patients for treatment and postpone treatment for another group of patients for one or two years. With this in mind, it was even more surprising that there were so few
observational studies with a well-defined control group as it is well known that studies without a control group only provide low scientific evidence.

The methodology for data extraction and the quality assessment used in the present systematic review was partly adopted from Antczak et al (62) and partly from SBU. (64)

It can be discussed whether the scoring criteria were too ambitious since RCT can be difficult to implement in this type of research. Even so, one study (Paper III in this thesis) was judged as high value of evidence, confirming that well-designed observational studies can reach as high level of evidence equivalent to RCTs. (64, 81)

When grading studies as high, medium or low value of evidence, there is always the possibility of subjective impact on the assessment. All of the retrieved articles in Paper I was therefore independently analysed by all four authors. Consensus was then reached through discussion.

The systematic review, complemented with the new literature survey, found limited scientific evidence for a decrease in pain on palpation of the masticatory muscles and insufficient evidence for alterations of TMJ pain and sounds after treatment. Only one study (74) used TMD diagnoses according to RDC/TMD(19) when assessing treatment outcomes, consequently the evidence for alterations of TMD after orthognathic treatment was insufficient. One more study estimated as high, or two studies estimated as moderate value of evidence (66), confirming the results of Paper III in this thesis, are needed for implementation in clinical decision-making.

**Methodological aspects**

**Paper II-III**

RCTs are, as discussed earlier, the golden standard in evidence-based research. In the present study, due to ethical reasons, an observational design in the form of a case-control study was the preferred choice. It has been argued that observational studies can exaggerate treatment results but there are also reports showing no differences in the treatment outcome between RCTs and observational studies. (81) Because of the case-control design the present study cannot present epidemiologic figures with regard to the prevalence of TMD in individuals with dentofacial deformities in the population, since these types of trials should be population-based.
The number of patients included in our study, exceeded the power-calculations, with the intention to have the possibility to subgroup the material for different kinds of dentofacial deformities. Obviously, some of the subgroups, most notably deep bite, became too small and could not be statistically calculated with any significance. What could have been done differently in this regard? The size of the subgroups could conceivably have been set before the collection of patients started. However, the data collection was carried out during two time periods 1992-1995 and 2000-2002, a period of totally 7 years. It would have taken many more years to get sufficient subgroups, especially for the deep bite diagnoses.

Another methodological issue was the choice of definitions for the subgroups. In both Paper II and III it was decided to subgroup the different dentofacial deformities as a combination of vertical and sagittal discrepancies resulting in relatively well defined but small groups. Another possibility for classification, which was used in Paper IV, was to separate the dentofacial deformities in vertical and sagittal discrepancies. This meant that the treatment outcome was related to sagittal discrepancies and to vertical discrepancies independently. Every patient had both a sagittal and a vertical diagnosis. This alternative created larger subgroups but implies a higher risk of biases, in form of overlap between different kinds of malocclusion.

In the early 1990’s, when this study was initiated, the RDC/TMD (19) had recently been introduced and accepted in TMD research but not yet been established as a diagnostic tool worldwide. Therefore, the individuals in this study were assessed for signs and symptoms of TMD according to an examination form used at the time in the clinic, at the department of Stomatognathic Physiology in Malmö. The RDC/TMD diagnoses for myofascial pain disorders and arthritic disorders were thereafter implicated. Since the measurements of reciprocal clicking had not been assessed exactly as prescribed in the RDC/TMD it was, in Paper III, deliberately chosen, not to use RDC/TMD diagnoses for disc displacements with reduction. The RDC/TMD has been found to demonstrate sufficiently high reliability for the most common TMD diagnoses, supporting its use in clinical research and decision-making.(83)The validity of the RDC/TMD has in a review(84)been estimated to range from poor to extremely
good, depending on the diagnosis to be tested. Myofascial pain (limited opening included) was found to have acceptable sensitivity and extremely good specificity. The authors concluded that individuals where unlikely to be over-diagnosed when using the RDC/TMD. (84) Recently there has been a revision of the RDC/TMD and a new index, the diagnostic criteria for TMD (DC/TMD), (85) is claimed to be more suitable for routine clinical implementation, since psychological and biological data are better integrated. (84)

When assessing frequencies of TMD, it could be argued that the results of the present study are biased, since patients are prone to highlight physical disorders, like TMD to gain attention in the financially subsidized health care system. In order to avoid this phenomenon, the stomatognathic examination was performed at a separate occasion and in a department separate from the one in which the orthognathic treatment was performed in. Furthermore the specialists that performed the examinations were not involved in the decision-making regarding the orthognathic treatment of the patients.

Some of the participants in the initial sample withdrew at follow-up (Paper III and IV). In spite of this, both the treatment and control group included a sufficient number of participants according to the initial power calculation. An analysis of the drop-outs revealed no significant differences with respect to age, gender, self-reported anxiety, pain in the jaws and related muscles, diagnosed TMD or masticatory ability and performance compared to the remaining participants. Therefore, both the treatment and control group were considered having sufficient participants to ensure reliability between the baseline and follow-up examinations.

The strength of the studies was that the patients were consecutively included, with the size of the study groups calculated beforehand by a power analysis, and a low-rate of dropouts. A control group was included, with the aim to, as far as possible, reflect a normal population. The specialists conducting the stomatognathic examinations were calibrated and blinded to the extent that was possible; as to they were not informed whether the individual belonged to the treatment or the control group. Despite this, there were obviously for some of the patients before treatment, anatomical features that could be detectable.
Before the analysis of the results in Paper III, the sub-diagnoses of different kinds of dentofacial deformities were rechecked with the surgery protocols. There were three patients diagnosed with “open bite and normal vertical relation” in Paper II and one patient diagnosed with “open bite and Class II relation” that were re-diagnosed as “open bite with a Class III relationship”. When frequencies of TMD were analysed with the correct diagnosis of dentofacial deformity no significant differences could be found compared with the results in Paper I.

Furthermore, the sub-diagnoses of TMD were rechecked between Paper II and Paper III, and one patient was found to have osteoarthritis at baseline, which had not been registered for Paper II.

**Paper IV**

The self-estimated masticatory ability in Paper IV was assessed by a questionnaire. A shortcoming was that the questions involving masticatory ability were limited. Since the present study was initiated in 1992, a Jaw Function Limitation Scale (JFLS) has been developed. (86) This scale has been shown to exhibit good reliability and validity in assessing limitations in mastication, jaw mobility and verbal and emotional expression (86). Since, the questionnaire in Paper IV focused solely on mastication, it would have been interesting to extend it according to the JFLS to have the possibility to assess also if patients with dentofacial deformities are limited in their daily life when talking, swallowing, making facial expressions etc.

In the present study it was chosen to test the masticatory performance by methods developed by Edlund and Lamm.(73) The advantages of using Optosil® tablets were the standardization of size and texture of the tablets, together with the water and age resistance. (73) Unfortunately, the weight composition of the Optosil® material was changed by the manufacturer over the years, and therefore it was decided for the control group not to perform the masticatory performance test at the follow-up examination. The follow-up tests for the treatment group were performed using the former variant of the Optosil® tablets, and the collected data were checked for inconsistencies.
Anamnestic findings
The questionnaire in Paper II revealed no anamnestic differences between the treatment and control group. Neither were there any differences for self-estimated level of anxiety, reported on a VAS. The VAS is a rough instrument for assessing psychological variables but the result still gave an indication that the treatment group did not differ from the control group in respect of self-perception.

For the patients with dentofacial deformities, impaired masticatory function, symptoms from the masticatory muscles, TMJs and headaches followed by aesthetics were the most common reasons for seeking treatment, which is in line with other studies (15, 87-89). However, in our study (Paper II) the aesthetic reasons were rated relatively low compared with earlier studies reporting that facial appearance was the most important reason for seeking treatment. (90, 91) Cultural differences and financial aspects probably explain this divergence in results. (15, 87) Facial appearance has been suggested to be one of four dimensions in Oral-Health-related quality of life (92) and a new scale, the Oral Esthetical Scale (OES) has been developed, which has shown satisfying reliability and validity. (93) The use of such a scale would have been beneficial to assess the perception of aesthetics of the patients and individuals in this thesis.

Frequency of TMD
In Paper II the most common diagnoses of TMD were myofascial pain, disc displacement and arthralgia. These results are in accordance with other studies. (19, 28, 83) These diagnoses were also significantly more common in the treatment group compared with the control group. Consequently, the hypothesis of Paper II, that there are no differences in the frequency of TMD between patients with dentofacial deformities and a normal control group, was rejected. This finding is diverging from previous controlled studies(43-45) that did not find any differences in frequency of TMD between the treatment groups and control groups at the baseline examination. Probable causes for the diverging results between these studies and the present study are differences in measurement methods and the sizes of the control groups. It is well accepted that signs and symptoms of TMD are common in a population and therefore sub
diagnoses of TMD according to RDC/TMD are more suitable when assessing TMD. (19)

After treatment; myofascial pain, disc displacement and arthralgia was significantly reduced in the treatment group, while osteoarthritis increased. Taken together, despite the increase in frequency of osteoarthritis, the present study clearly revealed a positive treatment outcome considering TMD pain and disc displacements and thereby the first hypothesis of Paper III was confirmed.

The second hypothesis yielded that there would be no differences between the treatment group and the control group after treatment and since no significant differences were found also this hypothesis was confirmed.

The increase of osteoarthritis in the TMJs after orthognathic treatment has also been observed in studies by Rodrigues-Garcia et al (50) and Pahkala et al(94) and has been suggested to be a result of post-surgical changes of the condylar position in the glenoid fossa. (95) The results may also have been affected by the uncertainty in differentiating a specific joint sound (i.e. crepitus) from clicking or even from soft tissue sounds during digital palpation. Only marginal validity is reported for these signs due to low sensitivity and high specificity for crepitus. (84)

The present study also investigated the maximum mandibular opening capacity, which was significantly lower in the treatment group, compared with the control group, and also decreased after treatment. A reduction in opening capacity has also been noted in other studies. (47, 96) However, the posttreatment decrease of 2 mm in the present study was not considered clinically important. In a recent review (97) it was proposed that the opening capacity will increase gradually during the first years after orthognathic surgery. There was also a general understanding that the impaired lateral excursions that most patients experience after surgery improves over time and that most patients regain the full range of motion two years after surgery.(97)

The present study did not find any subgroup of dentofacial deformities that, separately, was significantly associated with TMD before treatment. Anyhow, it should be remembered, that most of the subgroups were too small to detect any statistical significance, as indicated by the power analysis. An interesting finding was that
patients with Class III bite in combination with normal vertical relation showed less myofascial pain and arthralgia after treatment. All of the Class III patients had intraoral vertical ramus osteotomy (IVRO) for setback of the mandible. A positive treatment outcome for patients with TMD has been an argument for using IVRO, instead of bilateral sagittal split osteotomy (BSSO), for correction of a protrusive mandible.(6, 14)

**Masticatory ability and performance**

The results of Paper IV supported the hypothesis that patients with dentofacial deformities has an impaired self estimated masticatory ability and masticatory performance in comparison with a control group without dentofacial deformities before treatment, which is in consistency with other controlled studies. (57, 58)

The masticatory ability improved after orthognathic treatment and at follow-up no differences were found between the treatment and the control group. However, there seems to be an overestimation of the masticatory ability, which was rated high compared with the tested masticatory performance, which also improved but not as much as the masticatory ability. This was particularly evident in Class II patients who reported significant higher levels of masticatory ability, compared with patients with other dentofacial deformities, properties that were not confirmed in the masticatory performance test. In a study by Henrikson et al, (58) involving 11-15 year old girls with Class II malocclusions, the same overestimation of the masticatory ability was found.(58)

The reason for the modest improvement in masticatory performance in the present study may be the relatively short follow-up period (18 months). It has been suggested that a follow-up period of 5 years is more appropriate and beneficial for the masticatory performance, since the musculature needs a relatively long time to readapt before regaining full strength. (98, 99)

The factors that were found to have an association with the masticatory ability and the masticatory performance differed slightly between the treatment and control groups. The number of occlusal contacts during maximal biting pressure affected both the masticatory ability and performance in the treatment group, but had no association with mastication in the control group. This result is
strengthened by the finding that patients with an open bite, the only type of dentofacial deformity associated with masticatory performance, had fewer occlusal contacts compared with patients with deep bite and normal vertical relations.

The masticatory performance was found to be significantly higher in men than in women. This result can be explained by the fact that men have a higher EMG activity of the masticatory muscles together with a higher muscle thickness, especially for the masseter muscle. (60, 61)

**Patient satisfaction**

The patients were in general satisfied with the treatment. The variables most frequently reported as improved were masticatory function and aesthetics, followed by symptoms of TMD. In a study by Öland et al(89) it was shown that the pre-treatment motives correlated with the satisfaction after treatment. They also found that patients that, at baseline, rated oral function highest also expressed the lowest degree of treatment satisfaction, which is contradictory to our results (Paper III). In a study by Trovik et al(88) it was noticed that peer comments about appearance after treatment affected both self-esteem and quality of life.

A positive finding was that a great majority of the patients (92 %) were satisfied with the information that they had received before the treatment. It should be remembered though, that 32 % of the patients experienced the treatment as more difficult than they had expected, which should be taken into consideration when presurgical information is given.

**Future research**

The results of this thesis showed that frequencies of TMD decreased after orthognathic treatment. However, as indicated by the systematic review (Paper I) and the supplementary literature survey further research is required. A stronger evidence base to be able to evaluate whether orthognathic treatment alters frequencies of TMD would require one more study of high, or two more studies of medium value of evidence, assessing alterations of sub-diagnoses of TMD according to RDC/TMD.
It should also be noted that in the present study we found an increase in the number of patients with osteoarthrosis 18 months post treatment. As it is well known that TMD fluctuates over time it would be valuable to carry out a 5 years follow-up to assess how the treatment outcome of TMD persists in the long run.

Moreover, since oral-health-related quality of life has been associated with both TMD and masticatory function in previous studies (56, 92, 100) it would be of interest to investigate how the psychosocial well-being is affected after orthognathic treatment by using the Swedish version of the Oral Health Impact Profile (OHIP-S). (100) Such a study is planned and will be presented in the future.
CONCLUSIONS

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

- There is insufficient evidence for a decrease in TMD sub diagnoses after orthognathic treatment.
- There is low scientific evidence for an improvement of masticatory muscle pain on palpation after orthognathic treatment.
- There is insufficient evidence considering alterations of TMJ pain on palpation and TMJ sounds after orthognathic surgery.
- Further controlled, well-designed studies assessing TMD before and after orthognathic treatment are needed to secure strong evidence considering treatment outcomes.

In the cross-sectional, case-control study comparing frequencies of TMD in patients referred for orthognathic treatment with a control group it was concluded that:

- Patients with dentofacial deformities have higher frequencies of signs and symptoms of TMD and diagnosed TMD compared with a normal group.

In the controlled, longitudinal, follow-up study comparing frequencies of TMD before and after orthognathic treatment, it was concluded that in patients with dentofacial deformities:

- Frequencies of TMD decrease after orthognathic treatment.
- Frequencies of TMD were after orthognathic treatment comparable in the patient group and control group.
In the controlled, longitudinal, follow-up study before and after orthognathic treatment of patients with dentofacial deformities, it was concluded that:

- Masticatory ability and masticatory performance increased after orthognathic treatment.
- The number of occlusal contacts and severity of overall symptoms of TMD influenced both the masticatory ability
- and performance.
- Open bite had a negative effect on masticatory performance.

**Key conclusions and clinical implications:**
Patients with dentofacial deformities diagnosed with TMD do in most cases benefit from orthognathic treatment. In addition, masticatory ability and performance, which is impaired in patients with dentofacial deformities, improve after treatment. Thus, patients with dentofacial deformities that are to be treated with orthodontics in combination with orthognathic surgery can be recommended the treatment in order to relieve symptoms of TMD and impaired mastication.
The work with this project has taken many years to accomplish. It started already in the 1990s when one of my supervisors, Thor Henrikson was curious and enthusiastic enough to gather specialists from different disciplines of odontology to formulate a research programme in a field that at the time was not studied by many. About a decade later I gratefully got the opportunity to be a part of that research group and to complete the project.

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Alterations of Temporomandibular Disorders before and after Orthognathic Surgery
A Systematic Review
Cecilia Abrahamsson*a; Ewa Carin Ekbergb; Thor Henriksonc; Lars Bondemarkd

ABSTRACT
Objective: To answer the question whether orthognathic surgery does affect the prevalence of signs and symptoms of temporomandibular disorders (TMDs).

Materials and Methods: A literature survey in the PubMed and Cochrane Library electronic databases was performed and covered the period from January 1966 to April 2006. The inclusion criteria were controlled, prospective or retrospective studies comparing TMDs before and after orthognathic surgery in patients with malocclusion. There were no language restrictions, and three reviewers selected and extracted the data independently. The quality of the retrieved articles was evaluated by four reviewers.

Results: The search strategy resulted in 467 articles, of which 3 met the inclusion criteria. Because of few studies with unambiguous results and heterogeneity in study design, the scientific evidence was insufficient to evaluate the effects that orthognathic surgery had on TMD. Moreover, the studies had problems with inadequate selection description, confounding factors, and lack of method error analysis.

Conclusion: To obtain reliable scientific evidence, additional well-controlled and well-designed studies are needed to determine how and if orthognathic surgery alters signs and symptoms of TMD.

KEY WORDS: Temporomandibular disorders; Malocclusion; Orthognathic surgery; Systematic review

INTRODUCTION
Temporomandibular disorders (TMDs) embrace different signs and symptoms of the temporomandibular joint (TMJ), masticatory muscles, and related structures.1 These include orofacial pain, joint sounds, reduced or asymmetric mandibular movement, and pain on palpation of the TMJ and related muscles.2 Different kinds of occlusal factors are sometimes claimed to be associated with TMD; however, the opinion as to whether this association has been proven differs between different studies.3–9 It has been indicated that orthodontic treatment does not, except for mild signs, increase prevalence of TMD10 and that orthodontic treatment, of some kinds of malocclusion, in children and adolescents may even reduce prevalence of signs and symptoms of TMD.11,12

In severe malocclusions with major skeletal discrepancies, orthodontic treatment in combination with orthognathic surgery is sometimes needed. Orthognathic surgery and its effect on TMD have been examined in several studies during the past decades, and a systematic review of the present knowledge is motivated. In view of this and because evidence-based medicine has grown in importance,13 a systematic review of the present knowledge seems desirable. Systematic reviews try to locate, appraise, and synthesize evidence from scientific studies to provide informative answers.
to scientific questions by including a comprehensive summary of the available evidence.

The aim of this systematic review was to answer the question of whether orthognathic surgery affects the prevalence of signs and symptoms of TMDs.

MATERIALS AND METHODS

Search Strategy

To identify all studies that examined orthognathic surgery and its effect on TMD in patients with severe malocclusion, a literature survey was performed using the PubMed (www.ncbi.nlm.nih.gov) and the Cochrane Library electronic databases (www.cochrane.org). The search covered the period from January 1966 to April 2006. The terms used in the search were malocclusion, retrognathia, prognathia, open bite, and deep bite in various combinations with craniofacial disorders, temporomandibular disorders, temporomandibular dysfunction, temporomandibular joint dysfunction, temporomandibular joint pain and orthognathic surgery, surgical-orthodontic treatment, and surgery.

Selection Criteria

Inclusion Criteria

• Studies comparing symptoms and signs of TMDs before and after orthognathic surgery in patients with malocclusion

• Randomized clinical trials (RCT) or prospective, retrospective, controlled human studies.

Exclusion Criteria

• Animal studies

• Case reports, case series, and preliminary reports

• Reviews, discussions, interviews

• Treatment of patients with syndromes; cleft lip or palate treatment (or both)

Three reviewers independently assessed all the article abstracts that appeared to meet the inclusion criteria. The article abstracts were collected irrespective of the language in which they were published, and the retrieved articles were read in their entirety. The reference lists of the retrieved articles were also checked for relevant studies not found in the database search. Any interexaminer conflicts were resolved by discussion to reach a consensus.

Data Collection and Analysis

Data were extracted on the following items: author, year of publication, study design, sample size, gender and age, surgical treatment methods, follow-up time, methods to determine TMD, outcomes, and authors’ conclusions. In addition, to document the methodolog-
and examined at only one time. In the study by Panula et al.,17 the control sample was composed of patients that had refused orthognathic treatment after the first information, and in the study by Dervis et al.,18 the control group was composed of individuals without dento-facial deformities. In all of the studies,16–18 there were few or no dropouts. Panula et al.,17 reported five dropouts who were deleted from the study. Dervis et al.18 and Onizawa et al.16 did not report dropouts. However, in the study by Onizawa et al.,16 there was a decrease in the number of class III patients from the initial to the final examination, on which the authors only partly commented.

The orthognathic surgical method was described in two of the studies.16,17 Both studies used bilateral split osteotomy only or in combination with Le Fort I osteotomy. In the study by Dervis et al.,18 no description of the surgical method was given.

In the study by Onizawa et al.,16 evaluation of TMD was assessed before and 6 months after surgery, whereas Dervis et al.18 and Panula et al.17 evaluated signs and symptoms 2 and 4 years, respectively, from the initial preoperative examination.

All studies16–18 used a questionnaire and performed a clinical examination before and after surgery when assessing the patients’ signs and symptoms of TMD. Controls were examined with the same methods at two different occasions except in the study by Onizawa et al.,16 in which the control group was examined on only one occasion. In addition, Panula et al.17 and Dervis et al.18 also evaluated the frequency of headache.

**Orthognathic Surgery and Its Effect on TMD**

When comparing signs and symptoms of TMD before treatment, neither study found any significant differences between patients and control group or type of malocclusion. After treatment, two of the studies17,18 concluded that both signs and symptoms related to TMD could be significantly improved (Table 2). On the other hand, Onizawa et al.16 declared that TMD symptoms did not always show improvement after surgical correction, and for some patients, the symptoms changed for the worse (Table 2). When considering specific signs of TMD, Panula et al.17 and Dervis et al.18 found a statistically significant decrease in muscle palpation tenderness after surgery, whereas in the study by Onizawa et al.,16 there was no such change found. Furthermore, Panula et al.17 also reported a significant decrease in joint palpation tenderness. Onizawa et al.16 reported a significant decrease in maximal mouth opening capacity, which was not observed by the other studies.17,18

**Quality Analysis**

A quality analysis of the three involved studies is presented in Table 3. The research quality and meth-
Table 3. Quality Evaluation of the Three Retrieved Studies

<table>
<thead>
<tr>
<th>Authors</th>
<th>Study Design</th>
<th>Sample Size</th>
<th>Selection Description</th>
<th>Valid Measurement Methods</th>
<th>Method Error Analysis</th>
<th>Adequate Statistics Provided</th>
<th>Consequences of Confounders Discussed</th>
<th>Judged Quality Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onizawa et al, 1995</td>
<td>Prospective, longitudinal, controlled clinical trial</td>
<td>Adequate</td>
<td>Inadequate</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Medium (5 points)</td>
</tr>
<tr>
<td>Panula et al, 2000</td>
<td>Prospective, longitudinal, controlled clinical trial</td>
<td>Inadequate, small control sample</td>
<td>Inadequate</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Low (4 points)</td>
</tr>
<tr>
<td>Dervis et al, 2002</td>
<td>Prospective, longitudinal, controlled clinical trial</td>
<td>Adequate</td>
<td>Inadequate</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Medium (5 points)</td>
</tr>
</tbody>
</table>

a Maximum nine points were possible to reach.

odological standard was low in one study\(^{17}\) and medium in two studies.\(^{16, 18}\) The reasons for the low quality standard were mainly inadequate sample selection or description and no method error analysis. In addition, the authors had not discussed the influence of confounding factors on the results. Moreover, Panula et al\(^{17}\) had an inadequate control sample size.

DISCUSSION

The aim of this systematic review was to answer the question of whether orthognathic surgery affects the prevalence of signs and symptoms of TMDs in patients with malocclusion. However, no conclusion could be drawn because of the few studies located and their unambiguous results. Moreover, the included studies had problems with insufficient or lack of sample selection description, no discussion of confounding factors, and no method error analysis.

The outcome or authors’ conclusion differed between the articles. One of the reasons could be the disparity of follow-up time between the study of Onizawa et al\(^{16}\) and the other two studies.\(^{17, 18}\) The short follow-up time (6 months) used by Onizawa et al\(^{16}\) may not be enough for the patients to fully recover from the surgery. Orthognathic surgery is usually combined with presurgery and postsurgery orthodontic treatment. However, the description of the orthodontic treatment and its length of application was sparse\(^{17}\) or lacking.\(^{16, 18}\) In Onizawa et al,\(^{16}\) there may have been a potential risk that the occlusion had not yet settled in some of the patients since the postsurgery orthodontic treatment may have been ongoing or recently completed. When comparing the treatment outcome between these three studies, one should also be aware of the heterogeneity in surgical methods and fixation, which could have influenced the outcome. Stomatognathic treatment before surgery could have been a confounding factor in the study by Panula et al\(^{17}\) and might also have affected the results of this study and thereby affected the treatment outcome.

It is well known that uncontrolled studies and case reports imply low scientific evidence, and this was the reason why such studies were excluded. As signs and symptoms of TMD have been proven to fluctuate over time\(^{19}\) and because symptom frequencies appear to be age dependent,\(^{20}\) it is important to include an age- and gender-matched\(^{21}\) nonpatient control group as comparison to diminish the risk that the results after treatment show only the normal fluctuation in prevalence of TMD. The study by Panula et al\(^{17}\) was the only study in which efforts were made to use an appropriate control group (ie, a control group consisting of patients with severe malocclusions and who refuse orthognathic surgery treatment). However, the control sample size was judged to be too small and thereby inadequate. Furthermore, no sample size calculation was presented to prove that the control sample size was sufficient. Nevertheless, in all of the studies, it seems it was difficult for the researchers to enroll appropriate control groups. However, in this kind of clinical controlled trial, it might be very difficult to find a control group with severe skeletal jaw discrepancy. It would be unethical not to offer treatment to those kinds of controls either conservatively, orthodontically, or by surgical-orthodontic treatment.

In all of the studies,\(^{16-18}\) the methods of assessing signs and symptoms of TMD were valid and well known. However, in two studies,\(^{17, 18}\) the Helkimos index\(^{22}\) was used, and it remains to be determined whether the Helkimos index is an appropriate method.
to determine TMD patients. Broad-based symptom scales (eg, the Helkimo indices) have often been used in the past. However, advances in classification mandate that future epidemiological studies use working definitions that include patterns of signs and symptoms of TMD and focus on more narrowly defined disease groups.23 Furthermore, Storey24 stated that although TMD was viewed as one syndrome, current research supports the view that TMDs are a cluster of related disorders in the masticatory system that have many common symptoms. Today, it is more suitable to use the research diagnostic criteria for TMD, which is a valid instrument with good reliability among adults to subdiagnose TMD.25,26 From a methodological point of view, it was notable that none of the articles declared the use of blinding in measurements. However, the explanation for this may be that even if the extraoral stomatognathic examination is performed before the intraoral one, the blinding concerning test and control fails because the test individuals often are externally affected by their skeletal malocclusion.

Today, the systematic literature search, data extraction, and subsequent quality assessment of included articles are well-established measures in evidence-based medicine/dentistry. However, the precise methods for the process can differ between various systematic reviews. The methodology used in this review was adopted from and based on the criteria for assessing study quality from the Centre for Reviews and Disseminations in York, United Kingdom.27 Many articles were excluded: the main reason was the lack of a control group. Other excluded articles were those based on evaluation after the intervention without any registrations or analyses before the intervention started.

Several methods and scales to incorporate quality into systematic reviews have been proposed.14,15,27,28 However, many items were clearly not applicable, for example, placebo appearance/taste or patient or observer blinded to treatment. Instead, the quality of the articles was judged as low, medium, or high according to the scoring system based on the characteristics given in Table 3.

The restrictions on the number of databases used when searching the literature might imply that some articles were not identified. However, studies that are difficult to find are often of lower quality. The strength of the evidence in a systematic review is probably more dependent on assessing the quality of the included studies than on the degree of comprehensiveness.29

CONCLUSIONS

• No conclusions could be drawn because of the few studies identified, heterogeneity in study design, and unambiguous results. To obtain reliable scientific evidence, additional well-controlled and well-designed studies are needed to determine if and how orthognathic surgery alters signs and symptoms of TMD and headache.

REFERENCES

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ORIGINAL ARTICLE

TMD in Consecutive Patients Referred for Orthognathic Surgery

Cecilia Abrahamsson; Ewa Carin Ekberg; Thor Henrikson; Maria Nilner; Bo Sunzel; Lars Bondemark

ABSTRACT
Objective: To answer the question whether temporomandibular disorders (TMD) were more common in a group of individuals referred for orthognathic surgery than in a control group. The null hypothesis was that neither the frequency of signs and symptoms of TMD or diagnosed TMD would differ between the patient group and a control group.

Materials and Methods: A sample of 121 consecutive patients referred for orthognathic surgery at the Department of Oral Maxillofacial Surgery, Malmö University Hospital, Sweden, was interviewed and examined regarding signs and symptoms of TMD and headaches. A control group was formed by 56 age- and gender-matched individuals attending the Department of Oral Diagnosis, Faculty of Odontology, Malmö University, Sweden, and Public Dental Health Clinic in Oxie, County of Skane, Sweden. TMD diagnoses were used according to Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD).

Results: The patient group showed more myofascial pain without limited opening, disc displacement with reduction, and arthralgia according to RDC/TMD than the control group. The patient group also had more symptoms and signs of TMD in general.

Conclusions: The null hypothesis was rejected because patients who were to be treated with orthognathic surgery had more signs and symptoms of TMD and higher frequency of diagnosed TMD compared with the matched control group. (Angle Orthod. 2009;79:621–627.)

KEY WORDS: Temporomandibular disorders; Orthognathic surgery; Controlled study; Malocclusion

INTRODUCTION

An increased prevalence of temporomandibular disorders (TMD) from adolescence to adulthood has been reported in longitudinal studies, which also have shown a fluctuation of signs and symptoms of TMD over time, with both improvement and impairment on an individual basis. The most common subtypes of TMD are myofascial pain, disc displacements with reduction, and arthralgia. Factors that have shown associations with TMD are indirect or direct trauma to the masticatory system, anatomic, pathophysiologic, and psychosocial factors. The importance of the occlusion and its role in causing the onset or perpetuation of TMD, compared with other factors, has been studied and is still debated. Subjects with malocclusions have been suggested to have a significantly higher prevalence of signs and symptoms of TMD than others. These malocclusions include Angle Class II, anterior open bite, deep bite, posterior crossbite, and extreme maxillary overjet. In addition, severe mandibular retrognathism and a hyperdivergent skeletal pattern have been suggested to be risk factors for TMD. In a recent systematic review considering alterations of TMD before and after orthognathic surgery, heterogeneous study design and unambiguous results of the selected studies were found. Thus, no clear picture exists whether individuals re-
ferred for orthognathic surgery or with dentofacial deformities have higher prevalence of TMD than normal individuals.

The aim of this study was to investigate whether TMD was more common in a group of individuals referred for orthognathic surgery than in a control group. The null hypothesis was that neither frequency of signs and symptoms of TMD or diagnosed TMD according to Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) would differ between the patient and control group.

MATERIALS AND METHODS

Subjects

A sample of 121 consecutive patients, mean age 22.9 ± 7.4 years, 70 females and 51 males, with dentofacial deformities was included. All patients were referred to the Department of Oral Maxillofacial Surgery, Malmö University Hospital, Malmo, Sweden, between 1992 and 2002 for orthodontic treatment in combination with orthognathic surgery.

A control group of 56 individuals, mean age 23.4 ± 7.4 years, 33 females and 23 males, were recruited to match the patients in the treatment group, considering age and gender. These individuals were regular patients, with or without minor malocclusion traits that were not needed to be corrected with either orthodontic therapy or orthognathic surgery, attending the Department of Oral Diagnostics, Faculty of Odontology, Malmö University, Sweden, and Public Dental Health Clinic in Ocie, County Skane, Sweden.

The exclusion criteria for the 2 groups were craniofacial syndromes, systemic arthritic and muscle diseases, and a dentition of fewer than 24 teeth.

The study was approved by the Ethics Committee of Lund University, Sweden (Ref No LU-241-01).

Questionnaire and Clinical Examination

All individuals in the patient group and control group were assessed for signs and symptoms of TMD by means of a questionnaire and clinical examination.

In the questionnaire, the individuals reported reasons for seeking treatment (impaired chewing capacity/symptoms from the masticatory muscles, temporomandibular joints [TMJs], and headaches/esthetic reasons), the state of general health, use of painkillers for headache and TMD (yes/no), as well as awareness of oral parafunctions as tooth grinding (yes/no), or tooth clenching (yes/no). Frequency of TMD pain, tiredness of the jaws, TMJ clicking, and headache (never/once or twice a month/once or twice a week/daily) was registered as well as pain at rest (yes/no) and reported TMJ clicking (yes/no). The questionnaire also included questions about the severity of TMD discomfort on a visual analogue scale (VAS) with the endpoints none and severe and a verbal scale as follows: 0 = no or minimal discomfort, 1 = slight discomfort, 2 = moderate discomfort, 3 = severe discomfort, 4 = very severe discomfort. Furthermore, the individuals rated themselves on the VAS regarding their level of anxiousness with the endpoints calm and nervous/anxious.

Before the orthognathic treatment was started, the clinical examination was performed at the Department of Stomatognathic Physiology at Malmö University, by either one of two calibrated specialists. The examination included measurement of mandibular movements, pain during nonguided mandibular movements, examination of TMJ sounds, and tenderness of the TMJs and related muscles (Table 1). The reliability of the methods used for clinical registrations was improved by calibrating the examination technique between two examiners. Thus, before the study, eight subjects not included in the study were examined.21 Furthermore, the specialists conducting the examinations were not informed of the group to which the individual belonged, and the extraoral examination was performed before the intraoral one.

Subdiagnoses of TMD were used according to RDC/TMD.4 The diagnoses are divided into three groups:

1. Muscle disorders: (a) myofascial pain, (b) myofascial pain with limited opening
2. Disc displacements: (a) disc displacement with reduction; (b) disc displacement without reduction, with limited opening; (c) disc displacement without reduction, without limited opening
3. Arthralgia, arthritis, arthrosis: (a) arthralgia, (b) osteoarthritis of the TMJ, (c) osteoarthrosis of the TMJ

The functional occlusion was assessed by methods previously described and investigated for observer error.22,23 Nonworking side interferences within a lateral

Table 1. Clinical Examination and Registration of Temporomandibular Disorders and Related Muscles

| Measurement of mandibular mobility in millimeters |
| Maximum opening capacity without assistance |
| Maximum laterotrusion, left/right |
| Maximum protrusion |
| Maximum retrusion |
| Pain on movement of the mandible |
| Mandibular deviation ≥2 mm on opening |
| Temporomandibular joint (TMJ) clicking and crepitations registered by palpation and auscultation during opening and closing of the mandible |
| Tenderness on palpation of the TMJs; laterally and posteriorly and masticatory musculature; the origin and the insertion of the temporal muscles, the superficial and deep portion of the masseter muscles, and the insertion of the medial pterygoid muscle |

Angle Orthodontist, Vol 79, No 4, 2009
excursion of 3 mm, working side interferences, protrusion interferences, and the distance and the direction of the slide between retruded contact position (RCP) and the intercuspal contact position (ICP) were registered.

In both groups morphologic occlusion according to Björk et al. was registered by intraoral examination. The patient group was further analyzed by dental study casts, lateral cephalograms, and a cephalometric analysis. A hyperdivergent facial profile was classified as an NSL/ML angle of $\geq 40^\circ$ and a hypodivergent facial profile as an NSL/ML angle of $\leq 26^\circ$. A Class II skeletal relationship between the dental arches was classified as an ANB angle of $\leq 6^\circ$ and a Class III skeletal relationship as an ANB angle of $\leq 0^\circ$.

**Statistical Methods**

Power for test of the null hypothesis. One goal of the proposed study was to test the null hypothesis that the proportion positive was identical in the two populations. The criterion for significance (alpha) was set at .05. The test was 2-tailed, which means that an effect in either direction was interpreted.

With the proposed sample size of 35 in each subgroup, the study had a power of 89.8% to yield a statistically significant result. This computation assumed that the difference in proportions was $-0.30$ (specifically, $0.05$ vs $0.35$) in prevalence of TMD pain. This effect was selected as the smallest effect that would be important to detect, in the sense that any smaller effect would not be of clinical or substantive significance.

**Differences between groups and precision to estimate the effect size.** Pearson's chi-square test with Yate's correction for continuity was used when 2x2 cross-tabulations were applicable. When the expected cell value in a 2x2 table was less than 5, Fisher's exact test was used. To compute the difference between ranks and groups with ordinal data, the Mann-Whitney rank sum test was used.

A second goal of this study was to estimate the difference between the two groups. Based on these same parameters and assumptions, the study enabled us to report the difference in proportions with a precision (95% confidence level) of approximately $\pm 0.17$ points. Specifically, an observed difference of $-0.30$ would be reported with a 95% confidence interval of $-0.47$ to $-0.13$.

When comparing means in numerical variables, the two-sample t-statistic was used. Median value and percentiles (Q) were calculated when estimating reported anxiety on the VAS. All statistic procedures were performed with statistical software SPSS 13.0 for Windows (SPSS Inc, Chicago, IL).

**RESULTS**

**Anamnestic Findings**

Twenty-one percent in the patient group and 2% in the control group used painkillers for headache and/or TMD pain ($P < .001$). The self-rated level of anxiety on the VAS was similar in the two groups, with a median of 19.5 ($Q_1 = 7$, $Q_3 = 47$) and 19.0 ($Q_1 = 6$, $Q_3 = 43$). There were no differences between the groups concerning reported weekly headaches ($P = .373$) or awareness of parafunctional habits such as tooth clenching ($P = .665$) and tooth grinding ($P = .080$). When the patients registered their reasons for seeking treatment, 75% answered impaired chewing capacity and 72% symptoms from masticatory muscles, TMJs, and headaches. Sixty-six percent reported aesthetic reasons.

**Symptoms of TMD**

The patient group reported more subjective TMD discomfort on a verbal scale ($P < .001$) than did the control group (Figure 1). Also, pain in the TMJs and/or masticatory muscles during rest, wide opening, and chewing were significantly more commonly reported in the patient group than in the control group, as well as weekly TMD pain, weekly jaw tiredness, and weekly joint clicking (Table 2).

**Clinical Findings**

**Signs of TMD.** There were statistically significant differences between the patient group and the control group with regard to pain on palpation of the TMJs and related muscles, deviation during opening and/or closing of the mandible, and TMJ clicking (Table 3). However, no differences were found in registered reciprocal clicking or crepitations. During maximum opening, laterotrusion, and protrusion, the individuals in the control group had significantly larger mandibular movement capacity than the patient group did (Table 4).

**Occlusal interferences.** A sagittal and vertical distance of $\geq 1$ mm between RCP and ICP was significantly more common in the patient group than in the control group. Significantly more individuals in the patient group had interferences in laterotrusion, mediotrusion, and protrusion compared with the control group (Table 5).

**TMD diagnoses according to RDC/TMD.** The patient group had a significantly higher frequency of myofascial pain, disc displacement with reduction, and arthralgia compared with the control group (Table 6). The frequency of myofascial pain with limited opening, osteoarthritis, and osteoarthrosis was low, and no differences could be found between the two groups.
**Figure 1.** Reported temporomandibular disorder discomfort on a verbal scale.

**Subgrouping into different malocclusion traits.** The distribution of malocclusion traits is shown in Table 7. No certain malocclusion trait could be associated with symptoms of TMD or headache. No differences in the frequency of diagnosed RDC/TMD could be seen between different malocclusion traits.

**DISCUSSION**

The null hypothesis was rejected because patients who were to be treated with orthognathic surgery had more signs and symptoms of TMD and a higher frequency of diagnosed TMD compared with the matched control group.

Previous studies assessing the frequency of TMD in patients with dentofacial deformities have been heterogeneous in study design and have shown ambiguous results. However, neither of these studies used RDC/TMD as a diagnostic tool.

It is well known that signs and symptoms of TMD are common in a healthy population and do not have to be an indication of disease. Therefore, the use of the RDC/TMD is important since it allows standardization and replication of the most common forms of muscle- and joint-related TMD. The RDC/TMD demonstrates sufficiently high reliability for the most common TMD diagnoses, supporting its use in clinical research as well as in decision making. In the present study, all individuals were diagnosed according to RDC/TMD, and the patient group had a significantly higher frequency of myofascial pain, disc displacement with reduction, and arthralgia than the control group.

**Table 2. Percentage Distribution of Self-reported TMD Symptoms in the Patient Group (n = 121) and the Control Group (n = 56)**

<table>
<thead>
<tr>
<th>Symptoms of TMD</th>
<th>Patient Group</th>
<th>Control Group</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMJ/muscles, pain at</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rest</td>
<td>18</td>
<td>2</td>
<td>.003</td>
</tr>
<tr>
<td>Wide opening</td>
<td>34</td>
<td>11</td>
<td>.006</td>
</tr>
<tr>
<td>Chewing</td>
<td>50</td>
<td>11</td>
<td>.000</td>
</tr>
<tr>
<td>Rest, wide opening, and/or chewing</td>
<td>57</td>
<td>16</td>
<td>.000</td>
</tr>
<tr>
<td>Weekly TMD pain</td>
<td>38</td>
<td>5</td>
<td>.000</td>
</tr>
<tr>
<td>Weekly jaw tiredness</td>
<td>64</td>
<td>9</td>
<td>.000</td>
</tr>
<tr>
<td>Weekly TMJ clicking</td>
<td>47</td>
<td>8</td>
<td>.002</td>
</tr>
</tbody>
</table>

**Table 3. Percentage Distribution of Clinical Signs of TMD in the Patient Group (n = 121) and the Control Group (n = 56)**

<table>
<thead>
<tr>
<th>Signs of TMD</th>
<th>Patient Group</th>
<th>Control Group</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain on palpation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscle pain on palpation ≥ three sites</td>
<td>31</td>
<td>5</td>
<td>.000</td>
</tr>
<tr>
<td>TMJ pain on lateral and/or posterior palpation</td>
<td>21</td>
<td>5</td>
<td>.009</td>
</tr>
<tr>
<td>TMJ sounds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clicking during opening and/or closing</td>
<td>31</td>
<td>14</td>
<td>.021</td>
</tr>
<tr>
<td>Reciprocal clicking</td>
<td>19</td>
<td>11</td>
<td>.166</td>
</tr>
<tr>
<td>Crepitations</td>
<td>4</td>
<td>2</td>
<td>.422</td>
</tr>
<tr>
<td>Deviation on opening/closing of the mandible ≥ 2 mm</td>
<td>41</td>
<td>13</td>
<td>.000</td>
</tr>
</tbody>
</table>

° TMJ indicates temporomandibular disorder; TMJ, temporomandibular joint.
These TMD diagnoses were also the most prevalent in this material, as in the study by John et al.6

Because it is well known that signs and symptoms of TMD fluctuate over time3 and because symptom frequencies appear to be age dependent,28 it is important to include an age- and gender-matched nonpatient control group as a comparison when evaluating the frequency of TMD. In evidence-based research, usually a randomized controlled trial methodology is recommended. However, in this kind of clinical trial, it is often not possible for ethical or practical reasons to randomize and enroll subjects or patients into a treatment or a nontreatment group. Thus, the control group deliberately consisted of individuals with or without minor malocclusion traits. No limitations were done considering previous orthodontic treatment.

In this study, it was found that the patient group had more occlusal interferences than the control group did. In a recent review by Luther,29 it was concluded that neither static nor dynamic factors can be said to cause TMD, and this current study has not proven otherwise. However, it is interesting to assess whether occlusal interferences are altered by orthognathic surgery. Such a study has been commenced and will be presented later.

The clinical registration of signs of TMD, mandibular function, and functional occlusal interferences was performed by standardized methods, and the reliability of these methods has been evaluated and found to be acceptable.3,20,31 In addition, it was decided to perform the orthognathic surgery and the clinical TMD examination separately to ensure the objectiveness of the clinical TMD examination. Furthermore, the reliability of the methods used for clinical registrations was improved by calibrating the examination technique between the two examiners. Thus, before the study, eight subjects not included in the study were examined. In addition, the specialists were not informed which group their patients belonged to, and, moreover, the extraoral examination was carried out before the intraoral examination in an attempt of blinding.

Two studies30,31 have reported that patients declared an aesthetic motive to be the main reason for seeking orthognathic surgery treatment. This was not confirmed in this study. Instead, functional motives were the most frequent, albeit not significantly higher than aesthetic reasons. In fact, many of the patients reported more than one motive for seeking treatment. It can be pointed out that many other factors, such as social and psychological concerns, cultural values, cost of treat-

### Table 4. Mandibular Movement Capacity (in mm) in the Patient Group (n = 121) Compared with the Control Group (n = 56)

<table>
<thead>
<tr>
<th>Maximum Mandibular Movements</th>
<th>Patient Group</th>
<th>Control Group</th>
<th>95% CI</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum opening capacity</td>
<td>49.8 ± 8.0</td>
<td>54.3 ± 6.1</td>
<td>2.1–6.8</td>
<td>.000</td>
</tr>
<tr>
<td>Maximum laterotrusion, left</td>
<td>8.0 ± 2.6</td>
<td>9.7 ± 2.0</td>
<td>1.0–2.5</td>
<td>.000</td>
</tr>
<tr>
<td>Maximum laterotrusion, right</td>
<td>8.2 ± 2.6</td>
<td>9.7 ± 2.1</td>
<td>0.8–2.3</td>
<td>.000</td>
</tr>
<tr>
<td>Maximum protrusion</td>
<td>8.1 ± 3.1</td>
<td>9.9 ± 1.9</td>
<td>0.3–2.7</td>
<td>.000</td>
</tr>
</tbody>
</table>

### Table 5. Percentage Distribution of Occlusal Interferences in the Patient Group (n = 121) and the Control Group (n = 56)

<table>
<thead>
<tr>
<th>Occlusal Interferences</th>
<th>Patient Group</th>
<th>Control Group</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sagittal distance between RCP and ICP ≥ 1.0 mm</td>
<td>41/18</td>
<td>30/10</td>
<td>.002</td>
</tr>
<tr>
<td>Vertical distance between RCP and ICP ≥ 1.0 mm</td>
<td>39/16</td>
<td>19/5</td>
<td>.017</td>
</tr>
<tr>
<td>Lateral deviation between RCP and ICP ≥ 0.5 mm</td>
<td>23/20</td>
<td>21/5</td>
<td>.007</td>
</tr>
<tr>
<td>Laterotrusion interferences</td>
<td>27/9</td>
<td>3/0</td>
<td>.235</td>
</tr>
<tr>
<td>Laterotrusion interferences</td>
<td>80/18</td>
<td>0/2</td>
<td>.000</td>
</tr>
</tbody>
</table>

* RCP indicates retruded contact position; ICP, intercuspal contact position.

### Table 6. Percentage Distribution of Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) Diagnoses in the Patient Group (n = 121) and Control Group (n = 56)

<table>
<thead>
<tr>
<th>RDC/TMD Diagnosis</th>
<th>Patient Group</th>
<th>Control Group</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myofascial pain</td>
<td>30/4</td>
<td>1/0</td>
<td>.000</td>
</tr>
<tr>
<td>Myofascial pain with limited opening</td>
<td>1/0</td>
<td>1/0</td>
<td>.493</td>
</tr>
<tr>
<td>Disc displacement with reduction</td>
<td>19/5</td>
<td>5/5</td>
<td>.17</td>
</tr>
<tr>
<td>Arthralgia</td>
<td>21/5</td>
<td>5/5</td>
<td>.007</td>
</tr>
<tr>
<td>Osteoarthritis</td>
<td>3/0</td>
<td>2/0</td>
<td>.235</td>
</tr>
<tr>
<td>Osteoarthrosis</td>
<td>0/2</td>
<td>2/0</td>
<td>.140</td>
</tr>
<tr>
<td>At least one diagnosis (RDC/TMD)</td>
<td>51/18</td>
<td>18/2</td>
<td>.000</td>
</tr>
<tr>
<td>Having two or more diagnoses (RDC/TMD)</td>
<td>19/2</td>
<td>2/0</td>
<td>.002</td>
</tr>
</tbody>
</table>

### Table 7. Percentage Distribution of Diagnosed Malocclusion Traits in the Patient Group (n = 121)

<table>
<thead>
<tr>
<th>Skeletal Diagnosis</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mandibular prognathism</td>
<td>45</td>
</tr>
<tr>
<td>Mandibular retrognathism</td>
<td>7</td>
</tr>
<tr>
<td>Open bite in combination with: Orthognathic jaws</td>
<td>17</td>
</tr>
<tr>
<td>Mandibular prognathism</td>
<td>8</td>
</tr>
<tr>
<td>Mandibular retrognathism</td>
<td>16</td>
</tr>
<tr>
<td>Deep bite in combination with: Mandibular prognathism</td>
<td>4</td>
</tr>
<tr>
<td>Mandibular retrognathism</td>
<td>3</td>
</tr>
</tbody>
</table>

* RCP indicates retruded contact position; ICP, intercuspal contact position.
ment, recovery time, and perceived benefits, are involved and can encourage or discourage a patient to pursue surgery. An attempt was made to evaluate whether psychological stress could be a selection bias when comparing the frequency of TMD between the groups. However, no differences were found between the two groups when the subjects rated their level of anxiousness on the VAS. Even if the VAS is a raw tool to measure psychological distress, it can still give an indication of the level of anxiousness in a group of individuals.

In this study, it was convincingly demonstrated that consecutive patients referred for treatment with orthognathic surgery had a higher frequency of diagnoses according to RDC/TMD before this treatment compared with an age- and gender-matched control group. However, the question still remains whether orthognathic treatment in these patients significantly relieves signs and symptoms of TMD. Such information will be presented in a further study.

CONCLUSION

• The null hypothesis was rejected because patients who were to be treated with orthognathic surgery had more signs and symptoms of TMD and a higher frequency of diagnosed TMD according to RDC/TMD compared with the matched control group.

ACKNOWLEDGMENTS

We extend our sincere thanks to Ingrid Carlin and Birgitta Zahleé, Faculty of Odontology, Malmö University, and Ingela Nilsson at Department of Oral and Maxillofacial Surgery, Malmö University Hospital, for clinical assistance during this study. Furthermore, we would like to thank the Public Dental Health Clinic in Oxie for providing patients and treatment rooms. This study was supported by grants from the Swedish Dental Society and from Faculty of Odontology, Malmö University, Sweden.

REFERENCES

In patients with dentofacial deformities, the major indications for undergoing orthodontic treatment in conjunction with orthognathic surgery are function improvement and aesthetic considerations.\(^1\)\(^2\) Motivation for treatment may be influenced by many different factors, such as psychosocial concerns, cultural values, treatment costs, age at treatment, expected treatment outcomes and gender.\(^3\)

Orthodontic treatment in conjunction with orthognathic surgery is expensive, arduous and not without complications. It is therefore important that the treatment outcomes meet patient expectations. The aetiology of temporomandibular disorders (TMD) is complex\(^4\) and today most researchers and clinicians agree that the aetiology is multifactorial. Some studies have shown that compared to those with normal occlusion, subjects with malocclusions have a significantly higher prevalence of signs and symptoms of TMD.\(^5\)\(^6\)

It has also been suggested that alterations in facial morphology, such as a hyperdivergent facial profile may influence the development of TMD.\(^7\) On the other
hand, there are studies that have shown the opposite and the relative importance of the occlusion in the onset or perpetuation of the condition has been discussed.

A number of studies have shown that orthodontic correction of different types of malocclusion does not increase the risk of developing TMD. In cases of major skeletal jaw discrepancies (i.e. dentofacial deformities) orthognathic surgery is indicated in conjunction with orthodontic treatment to correct the dental relationship.

Two recent systematic reviews of changes in TMD after orthodontic treatment in conjunction with orthognathic surgery, disclosed lack of uniformity in study design and ambiguous results in the selected studies. The review by Abrahamsson et al. was limited to controlled studies only.

A well-designed study by Rodriguez-Garcia et al., albeit without a control group, reported positive treatment outcomes with respect to signs and symptoms of TMD. TMD symptoms fluctuate over time and the frequencies of symptoms appear to be age dependent. The importance of a control group should, therefore, not be underestimated.

The aims of the present study were twofold: to investigate whether correction of dentofacial deformities by orthodontic treatment in conjunction with orthognathic surgery alters the frequency of TMD, and over the same period of time, to compare and monitor the frequency of TMD in an untreated normal group (control group).

The hypothesis was that the patients with dentofacial deformities would benefit from treatment, in respect of TMD, and that post-treatment, the frequency of TMD would be similar to that in the control group.

Materials and methods

The study sample comprised 121 consecutive patients (51 males and 70 females) with dentofacial deformities, referred to the Department of Oral Maxillofacial Surgery, Malmö University Hospital, Malmö, Sweden for orthodontic treatment in conjunction with orthognathic surgery (the treatment group). The mean age was 22.5 ± 7.4 years. All patients were recruited during two periods, between 1992–1995 and 2000–2002. Under the Swedish National Health Service, patients with such severe deformities are entitled to subsidized treatment. The exclusion criteria were craniofacial syndromes, systemic articular and muscular diseases, and a dentition of fewer than 24 teeth. 23 patients were excluded. 98 patients (81%) met the inclusion criteria and the final sample comprised 38 males and 60 females, mean age 22.4 ± 7.5 years (Fig. 1).

The control group comprised 56 subjects, 23 males and 33 females, mean age 23.4 ± 7.4 years, age and gender matched with the subjects undergoing treatment. They were recruited from general dental patients at the Faculty of Odontology, Malmö University, Sweden, and the Public Dental Health Clinic in Oxie, County Skane, Sweden. The inclusion criteria were normal occlusion, or minor malocclusions for which neither orthodontic therapy nor orthognathic surgery was indicated. The same exclusion criteria applied to the control group as to the treatment group. Of the 56 recruits who underwent the initial clinical examination and completed the questionnaire, 38 (68%) presented for the follow-up clinical examination and 47 (84%) completed the follow-up questionnaire (Fig. 1).

In the treatment group, TMD was assessed by means of a questionnaire and a clinical examination before (baseline) and 18 months after surgery. The interval between the two examinations was approximately 3 years depending on length of orthodontic treatment. The questionnaire and the clinical examination were performed after treatment planning. The control group was similarly assessed, on two occasions, at an interval of at least 3 years.

The following issues were addressed in the baseline and follow-up questionnaires: frequency of TMD pain, jaw fatigue and temporomandibular joint (TMJ) clicking (never, once or twice a month, once a week, once or twice a week, daily); pain at rest (yes/no) and during mandibular movements (yes/no). The severity of discomfort associated with TMD was

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**Fig. 1. Flow chart: subjects included in the study.**
The estimated on the following scale: 0, little or none; 1, slight; 2, moderate; 3, severe; 4, very severe. The subjects rated their anxiety levels on a visual analogue scale (VAS) with the endpoints calm and anxious/uneasy. The follow-up questionnaire also included questions about treatment satisfaction, such as whether the pre-treatment information had been adequate (yes/no), whether treatment met expectations (yes/no) and whether, post-treatment, the subjects had perceived any alterations in masticatory capacity, aesthetics and TMD symptoms (better, unchanged, worse).

The clinical examinations were conducted at the Department of Stomatognathic Physiology at the Faculty of Odontology, Malmö University, by one of two calibrated specialists in stomatognathic therapy. The extra-oral examination preceded the intraoral examination. The examination included measurement of maximum mandibular opening capacity, registration of TMJ sounds (clicking and crepitation), and tenderness in the TMJs and related muscles. The clinical registrations were improved by calibrating the examination techniques of the two examiners before the start of the study. The calibration was performed by examining eight patients, not included in the study, and was achieved after discussion. Eight subjects not included in the study were examined regarding occlusal interferences with an observer error that was found to be acceptable. The specialists conducting the examinations were not informed whether the subject belonged to the test or control group at the follow-up.

Subdiagnoses for TMD pain followed the research diagnostic criteria (RDC) for TMD (Table 1). Disc displacement was diagnosed if, upon opening and closing from maximum intercuspation, a click was noted audible or by palpation. Osteoarthritis was diagnosed as registered crepitations by palpation of the TMJ.

Functional occlusion was assessed by previously described methods and investigated for observer error. Medioputricus interferences within a lateral excursion of 3 mm, latereutrinus interferences, protrusion interferences, and the distance and the direction of the slide between retruded contact position (RCP) and the intercuspal contact position (ICP) were registered.

Morphological occlusion according to Björk et al. was registered by intraoral examination. Further data were obtained from dental study casts, lateral cephalograms, and a cephalometric analysis. The diagnoses in the treatment group were also separated into sagittal and vertical discrepancies, according to a combination of morphological and cephalometric values (Table 2).

All subjects in the treatment group underwent pre- and postsurgical orthodontic treatment with fixed orthodontic appliances in both arches. Ten specialists carried out the orthodontic treatment; the duration varied between 18 and 24 months.

The orthognathic surgery was undertaken by four oral maxillofacial surgeons at the Department of Oral Maxillofacial Surgery, Malmö University Hospital, Malmö, Sweden. Vertical deformities was corrected in the maxilla with a one piece Le Fort I osteotomy or a segmental maxillary osteotomy. Sagittal adjustments were made either by sagittal split osteotomy, to advance the mandible, or by intraoral vertical ramus osteotomy, to correct mandibular prognathism. When bimaxillary surgery was indicated, in 27 patients, maxillary osteotomies were combined with either sagittal split or vertical ramus osteotomies. Maxillo-mandibular fixation was used for 4 weeks after intraoral vertical ramus osteotomies. In all other cases, rigid intrajaw fixation was used.

### Table 1. Clinical examination and diagnoses of temporomandibular pain according to RDC/TMD

<table>
<thead>
<tr>
<th>Diagnoses of TMD</th>
<th>Muscle disorders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myofascial pain</td>
<td>Osteoarthritis</td>
</tr>
<tr>
<td>1. Report of pain or ache in the jaw, temples, face, preauricular area, or inside the ear at rest or during function; plus</td>
<td></td>
</tr>
<tr>
<td>2. Pain reported by the subject in response to palpation of three or more of 20 muscle sites. At least one of the sites must be on the same site as the complaint of pain</td>
<td></td>
</tr>
</tbody>
</table>

### Statistical methods

One goal of the proposed study was to test the null hypothesis that the proportion of positive outcomes was identical in the two groups. Significance (alpha) was set at .05. The test was two-tailed (i.e., an effect in either direction was analysed). With the proposed sample size of 35 in each subgroup, the study had a power of 89.8% to yield a statistically significant result. This computation assumed that the difference in proportions in frequency of TMD pain was ~ .30 (specifically .05 vs .35). This was selected as the cut-off point for minimum detection; any effect below this level would not be of clinical relevance or of substantive significance.

A second goal of this study was to estimate the difference between the test and control groups and the precision in estimating the magnitude of the effect. Pearson’s χ² test with Yate’s correction for continuity was used when 2 × 2 cross tabulations were applicable. When the expected cell value in a 2 × 2 table was less than 5, Fisher’s exact test was used. The two-sample t-statistic was used to compare means in numerical variables. To estimate self-reported anxiety on the VAS, median values and percentiles (Q) were calculated.

To assess the differences within groups, McNemar exact test was used to analyse ordinal data before and after treatment. The paired t-test was used to compare the means of maximum mandibular opening capacity.
Table 3. Distribution of TMD diagnoses in the treatment and control groups. Each subject may have multiple TMD diagnoses.

<table>
<thead>
<tr>
<th>TMD diagnoses</th>
<th>Treatment group (n = 98)</th>
<th>Control group (n = 38)</th>
<th>Group differences *</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline (P1) n (%)</td>
<td>Follow up (P2) ~3 years</td>
<td>Baseline (C1) n (%)</td>
</tr>
<tr>
<td>Myofascial pain</td>
<td>29 (30)</td>
<td>17 (17)</td>
<td>4 (10)</td>
</tr>
<tr>
<td>Disc displacement</td>
<td>19 (19)</td>
<td>9 (9)</td>
<td>5 (13)</td>
</tr>
<tr>
<td>Arthralgia</td>
<td>16 (16)</td>
<td>4 (4)</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Osteoarthritis</td>
<td>1 (1)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Osteoarthrosis</td>
<td>1 (1)</td>
<td>9 (9)</td>
<td>1 (3)</td>
</tr>
<tr>
<td>At least one TMD</td>
<td>42 (43)</td>
<td>32 (33)</td>
<td>10 (26)</td>
</tr>
<tr>
<td>pain diagnosis</td>
<td>31 (32)</td>
<td>18 (18)</td>
<td>4 (10)</td>
</tr>
</tbody>
</table>

*NS: not significant.

Results

Analysis of those who withdrew from the treatment and control groups, (n = 23, 19%, and n = 18, 32%, respectively) showed no significant differences compared with the final study groups with respect to age, gender, self-rated level of anxiety on VAS, pain in the jaws and related muscles or diagnosed TMD reported at baseline. Thus, the participants who completed the study were considered to be representative of the initial study sample.

TMD diagnoses

At baseline, the most common diagnoses in both treatment and control groups were myofascial pain, disc displacement and arthralgia. At follow-up, the frequencies of these diagnoses were significantly reduced in the treatment group, but at the same time, the treatment group exhibited a significant increase in osteoarthritis post-treatment (Table 3). Compared with the control group, significantly more subjects in the treatment group had myofascial pain and arthralgia at baseline, but post-treatment these differences had been eliminated (Table 3). Myofascial pain was the only TMD diagnosis with a significant gender difference before treatment (P = .015); it was more common in women (32%) than in men (12%), but at follow-up, no gender-related differences were found for any of the TMD diagnoses. After stratifying the treatment group according to the type of dentofacial deformity (Table 2), those with a Class III relationship combined with a normal vertical relationship of the jaws having myofascial pain (n = 13) and/or arthralgia (n = 8) had significantly decreased after treatment (n = 4, P = .022 and n = 2, P = .031 respectively). None of the other subgroups showed significant differences in TMD diagnoses between baseline and follow-up.

Symptoms of TMD

In the treatment group, self-evaluated TMD discomfort, evaluated on a verbal scale, decreased significantly from baseline to follow-up (Fig. 2).

At baseline, the treatment group reported significantly more TMD symptoms than the control group (Table 4). With the exception of weekly jaw fatigue, there were no significant inter-group differences in TMD symptoms at follow-up. The treatment group experienced significantly fewer TMD symptoms at follow-up than at baseline, except for weekly TMJ clicking. In the control group, there were no differences in TMD symptoms in either group, at baseline or at follow-up.

Mandibular movement capacity

The maximum mandibular opening capacity in the treatment group had decreased at follow-up, from 50 ± 8 mm to 48 ± 7 mm (P = .009). At both baseline and follow-up, the opening capacity was lower in the treatment group than in the control group.
Table 4. Distribution of self-reported symptoms of TMD in the treatment (N = 98) and control groups (N = 38).

<table>
<thead>
<tr>
<th>Symptoms of TMD</th>
<th>Treatment group</th>
<th>Control group</th>
<th>Group differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline (P1)</td>
<td>Follow up (P2)</td>
<td>Baseline (C1)</td>
</tr>
<tr>
<td>Pain at</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rest</td>
<td>15 (15)</td>
<td>6 (6)</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Wide opening</td>
<td>32 (33)</td>
<td>17 (17)</td>
<td>6 (16)</td>
</tr>
<tr>
<td>Chewing</td>
<td>44 (45)</td>
<td>21 (21)</td>
<td>5 (13)</td>
</tr>
<tr>
<td>Rest, wide opening and/or chewing</td>
<td>51 (53)</td>
<td>31 (32)</td>
<td>8 (21)</td>
</tr>
</tbody>
</table>

NS: not significant.

control group (P = 0.005, P < 0.001 respectively). No significant changes in mandibular opening capacity were recorded in the control group from baseline to follow-up examinations.

Occlusal interferences

At baseline, the treatment group had significantly more interferences (P < 0.05) than the control group, except for lateral deviation between RCP and ICP. At follow-up, the number of subjects in the treatment group with interferences had decreased (P < 0.05) significantly. No inter-group differences were disclosed.

Patients’ satisfaction with treatment

82% of the subjects in the treatment group reported improved aesthetics, 80% reported improved masticatory comfort and 61% reported fewer symptoms of TMD after treatment. 92% were satisfied with the information received before treatment. 68% reported their experience of treatment to be as they had expected, or less burdensome than expected.

In the treatment group, the self-evaluated level of anxiety registered on the VAS decreased (P = 0.001) after treatment (median (M) of 19, 25th percentile (Q1) = 6, 75th percentile (Q3) = 36) to 11 (M = Q1 = 3, Q3 = 31). The corresponding figures for the control group were 20 M (Q1 = 8, Q3 = 43) at baseline and 25 M (Q1 = 13, Q3 = 48) at follow-up examination (P = 0.871).

Discussion

The frequency of diagnosed myofascial pain and arthralgia as well as signs and symptoms of TMD pain in the treatment group decreased after orthodontic treatment in conjunction with orthognathic surgery. At follow-up, there were no differences in TMD between the treatment and the control group. Thus, the hypothesis could not be rejected.

Only one previous study has applied the RDC/TMD as a diagnostic tool for assessing TMD in consecutive patients treated by a combination of orthognathic surgery and orthodontic treatment. Thus, comparative data are limited. In the study by Farella et al.,25 including Class III patients, none of the patients had myofascial pain or arthralgia at baseline, and throughout the entire study period. In contrast, the present study reports a significantly lower frequency of patients diagnosed with myofascial pain and arthralgia after treatment. Farella et al.,25 also found disc displacement with reduction in 7 of 14 patients before treatment, and no significant difference at follow-up. These findings are in accordance with the present study: from baseline to follow-up, patients with a Class III jaw relationship showed no significant changes in the frequency of diagnosed disc displacement.

Several factors in the study design may have contributed to inconsistencies in the results of the two studies. First, sample size, with a relatively small study group of 14 subjects in the study by Farella et al.25 Second, surgical approach, the patients in the study by Farella were treated by bilateral sagittal split osteotomy combined with a Le Fort I osteotomy, whereas in the present study, all Class III patients were treated by bilateral vertical ramus osteotomy, with or without maxillary osteotomy. Jung et al.26 analysed treatment outcomes for sagittal split osteotomy and vertical ramus osteotomy and reported that Class III patients treated by bilateral vertical ramus osteotomy experienced a decrease in TMJ sounds and pain.

In the present study, osteoarthrosis was not a concern in the treatment group at follow-up than at baseline. This is in accordance with Rodrigues-Garcia et al.,27 who found a significant increase of fine crepitus, from 4% to 15% in Class II patients treated by bilateral sagittal split osteotomy. The post-treatment increase in osteoarthrosis in Class II patients could be attributable to post-surgical changes in the condylar position in the glenoid fossa.27 The results may also have been affected by the uncertainty inherent in detecting and differentiating a specific joint sound (i.e. crepitus) from clicking or even from soft tissue sounds during digital palpation. Only marginal reliability is reported for these signs28 by showing low sensitivity and high specificity for crepitus.28 It has been proposed that imaging aids the diagnosis of osteoarthrosis/ osteoarthritises of the TMI.29 Imaging was not used as a diagnostic tool in this study. Tomography has been found to offer only minor advantages in the management of TMD.23 Limaichiana et al.30 showed that abnormal TMJ findings on magnetic resonance imaging were registered in TMD patients with pain of both myogenic and arthrogenous origin. In a study by Muir and Goss11 it was found that only 10% of the asymptomatic TMs examined by MRI were absolutely normal radiologically.

The decreased mandibular opening capacity in the treatment group at follow-up examination was in accordance with previous studies.25,26 This could be a consequence of immobilization of the jaws during post-surgical maxillo-mandibular fixation or to surgical trauma to the tissues. The reduction in opening capacity found in this study was relatively minor (2 mm) and probably of negligible clinical relevance.
At baseline, occlusal interferences were registered in significantly more subjects in the treatment than in the control group; at follow-up, the two groups were comparable. This result was expected and is in accordance with earlier studies.\textsuperscript{16,33} One of the strengths of the present study was the incorporation of a control group, which was examined not only at baseline but also at follow-up. A recent systematic review has disclosed that there are few such controlled studies in this field of research.\textsuperscript{4} In subjects with dentofacial deformities the main treatment objective of combined orthodontic and orthognathic surgery treatment is to normalize both morphological and functional parameters. Therefore it was of interest to compare the treatment group with a normal group. Another advantage of such a control group, besides age and gender, was the possibility to record and compare the frequencies of TMD with a control group longitudinally since TMD fluctuates over the course of time and seems to be age dependent.\textsuperscript{17} It would have been an improvement to include an untreated malocclusion group. For ethical reasons and to avoid too great a selection bias, it was decided not to compare the treatment group with untreated subjects. Therefore, the control group consisted of general dental patients that were age and gender matched to the treatment group.

Another strength of the study was that the clinical TMD examination was undertaken by specialists in stomatognathic physiology who were not involved in the orthodontic or orthognathic treatment of the patients. For the same reason TMD was assessed after the decision to perform orthognathic surgery had been made. The reliability of the methods used for clinical registration was improved by calibrating the examination techniques of the two examiners. In addition, at follow-up, the examiners were blinded as to whether the subject belonged to the treatment or control group. At baseline, blinding could not be fully achieved because of the obvious dentofacial deformities in some of the subjects. Nevertheless, in order to meet at least in part the requirement for blind- ing, the extra-oral examination preceded the intraoral examination.

Although some subjects withdrew from the study, especially in the control group, analysis showed that those who withdrew did not differ from the remainder in terms of age, gender, pain experienced in the jaws or related muscles, diagnosed TMD or self reported level of anxiety reported at baseline. According to the original sample size calculation, both treatment and control groups included sufficient participants to ensure reliability of the results despite some withdrawals.

In a review by Al-Riyami et al.,\textsuperscript{13} it was suggested that the incorporation of various dentofacial deformities in a study is a confounding factor, complicating comparison of the results of different studies. Owing to the low prevalence of specific malocclusions in the population referred for orthognathic surgery, most of the subgroups of dentofacial deformities were too small to detect any significant changes after surgery. Thus an increase in the number of subjects in the treatment group might have enhanced the results of the present study. In a larger treatment group it might have been possible to disclose more significant differences associated with specific dentofacial deformities. Despite this shortcoming, the subgroup of subjects in the treatment group with Class III jaw relationships and normal vertical angle showed significant alleviation of TMD pain after surgery.

The aim of this study was to investigate whether correction of dentofacial deformities by orthodontic treatment in conjunction with orthognathic surgery alters the frequency of TMD. The outcome in the treatment and control group may have been influenced by trauma, distress, pain conditions or alterations of the vertical facial pattern related to the muscles. These factors were not considered in this study.

Apart from aesthetics, one factor motivating patients to undergo orthodontic treatment in conjunction with orthognathic surgery is the discomfort associated with TMD.\textsuperscript{13} The present study has shown that the treatment seems to reduce TMD pain in particular. Another major motivation for treatment is to alleviate chewing problems. While pre- and post-treatment evaluation of chewing capability was beyond the scope of the present study, it is currently under investigation in a separate study.

Patients with dentofacial deformities, corrected by orthodontic treatment in conjunction with orthognathic surgery, seem to have a positive treatment outcome in respect of TMD pain. After treatment frequency of TMD is low and comparable to that in a control group.

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**Competing interests**

None declared.

**Ethical approval**

The study was approved by the Ethics Committee of Lund University, Sweden (Ref. No. LU-241-01), which follows the guidelines of the declaration of Helsinki.

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Masticatory function in patients with dentofacial deformities before and after orthognathic treatment – a prospective, longitudinal and controlled study.

Cecilia Abrahamsson, Thor Henrikson, Lars Bondemark, Ewa Carin Ekberg

SUMMARY
The aim of this study was to investigate the self estimated masticatory ability and masticatory performance in patients with dentofacial deformities before and after orthognathic treatment; in comparison to an age- and gender-matched control group. The masticatory ability and masticatory performance were evaluated in 121 consecutive patients (treatment group), referred for orthognathic treatment. Masticatory ability was assessed on a visual analogic scale (VAS) while the masticatory performance was evaluated by a masticatory test using round silicon tablets. Signs and symptoms of temporomandibular disorders (TMD) were registered by a questionnaire and a clinical examination. The control group comprised 56 age- and gender-matched subjects who were examined at baseline.

At the baseline examination, the treatment group had a significantly lower masticatory ability and performance index compared with the control group. After treatment the masticatory ability significantly improved in the treatment group and reached the same level as in the control group. The masticatory performance index increased significantly but was still lower than in the control group. Both the masticatory ability and masticatory performance were affected by the number of occlusal contacts during maximal biting pressure and by the self estimated overall symptoms of TMD. The findings suggest that patients with dentofacial deformities, corrected by orthognathic treatment, have a significant positive treatment outcome in respect of masticatory ability and masticatory performance. Furthermore, the occlusion and symptoms of TMD have an impact on both masticatory ability and masticatory performance.

INTRODUCTION
Mastication is the first step, and one of the main functions in the digestion process, in which food is broken down into smaller particles to facilitate the enzymatic activity. Continuously the mastication is adapting to food, occlusion and oral health. Mastication can be assessed by subjective and objective measurements. Self estimated masticatory ability has been defined as an individual’s own assessment of mastication. Masticatory ability has been shown to be lower in individuals having signs and symptoms of TMD (Henrikson et al., 1998; Kurita et al., 2001). Masticatory performance, defined as a
person’s capacity to break down a standardized test food, has been shown to be related to maximum bite force, body size, salivary flow rates and to the number of interocclusal contacts during maximum intercuspidation (Henrikson et al., 1998; Fontijn-Tekamp et al., 2000; Harada et al., 2000; Kobayashi et al., 2001; Okiyama et al., 2003; Engelen et al., 2005). A reduced masticatory performance has been reported for patients with malocclusions (Henrikson et al., 1998; English et al., 2002) and especially skeletal open bite has been correlated to impaired bite force (Proffit et al., 1983). Individuals with an impaired masticatory performance often compensate it by a higher number of chewing cycles resulting in longer duration of masseter muscle activity before swallowing and by swallowing coarser particles than individuals with good masticatory performance (Engelen et al., 2005).

Brennan et al. (2008) concluded that the masticatory ability was correlated to the number of teeth in contact and positively associated with oral-health related quality of life assessed by the Oral Health Impact Profile 14-item version (OHIP-14). Still there is a discussion to what extent nutrition and general health might be affected by an impaired masticatory ability and performance (Pera et al., 2002; Brennan et al., 2008).

Impaired masticatory ability is, apart from TMD and aesthetics, one of the main indications for orthognathic surgery in patients with dentofacial deformities (Rivera et al., 2000; Modig et al., 2006; Abrahamsson et al., 2009) Previous controlled studies in patients with dentofacial deformities (Zarrinkelk et al., 1995; Kobayashi et al., 2001; van den Braber et al., 2004) indicate impaired masticatory ability and performance both before and after treatment compared with controls. The studies above disclose somewhat different results considering if treatment will be beneficial for the patients regarding masticatory ability and performance. There are few studies on this topic, and in general with small sample sizes, and also, using different methodologies. Therefore, a great need exist to evaluate longitudinally and in a controlled manner the masticatory ability and masticatory performance in patients who have undergone treatment of dentofacial deformities.
The aim of this study was to investigate the self estimated masticatory ability and masticatory performance in patients with dentofacial deformities before and after orthognathic treatment, in comparison with an age- and gender-matched control group. A further aim was to investigate factors with possible impact on masticatory ability and masticatory performance.

The hypothesis was firstly, that patients with dentofacial deformities have, compared to controls, impaired masticatory ability and masticatory performance. Secondly, the masticatory ability and masticatory performance will be improved by orthognathic treatment.

MATERIAL AND METHODS
Subjects
The treatment group comprised 121 consecutive patients (51 males and 70 females) with dentofacial deformities, referred to the Department of Oral Maxillofacial Surgery, Malmö University Hospital, Sweden for orthodontic treatment in conjunction with orthognathic surgery (forward described as orthognathic treatment). The mean age was 22.5 ± 7.4 years. All patients were recruited during two periods, between 1992-1995 and 2000-2002. Under the Swedish National Health Service, patients with such severe deformities are entitled to subsidized treatment. The exclusion criteria were craniofacial syndromes, systemic arthritic and muscular diseases, and a dentition of fewer than 24 teeth. Twenty-three patients withdrew from the study after the baseline examination (Figure 1). Thus, 98 patients (81%) met the inclusion criteria and the final sample comprised 38 males and 60 females, mean age 22.4 ± 7.5 years.
The control group, age- and gender-matched with the subjects undergoing treatment, comprised 56 subjects, 23 males and 33 females, mean age 23.4 ± 7.4 years. The controls were recruited from general dental patients at the Faculty of Odontology, Malmö University, Sweden, and the Public Dental Health Clinic in Oxie, County Skane, Sweden. The inclusion criteria were normal occlusion, or minor malocclusions for which neither orthodontic treatment nor orthognathic surgery was indicated. The same exclusion criteria applied to the control group as to the treatment group.

Methods
All patients in the treatment group underwent pre- and postsurgical orthodontic treatment with fixed orthodontic appliances in both arches. Ten specialists carried out the orthodontic treatment and the treatment duration varied between 18 and 24 months.

The orthognathic surgery was undertaken by four oral maxillofacial surgeons at the Department of Oral Maxillofacial Surgery, Malmö. The methods for surgery and postsurgical fixation have been described in detail in Abrahamsson et al. (2012).
In the treatment group, the masticatory ability, masticatory performance and signs and symptoms of TMD were assessed by means of a questionnaire, a test of masticatory performance and a clinical examination before and 18 months post-treatment. The interval between the two examinations was approximately three years. The questionnaire, the test of masticatory performance and the clinical examination were performed after treatment planning. The control group was examined at one occasion and in equal manner as the treatment group.

**Questionnaire**

The following variables were addressed in the baseline and follow-up questionnaires: ability to masticate different kind of food; meat (yes/no), carrots (yes/no), toffee (yes/no), French loaf (yes/no) or coldcuts of ham, cheese and cucumber (yes/no). The subjects estimated their ability to masticate food on a visual analog scale (VAS) 0-100 mm with the end points “good” = 0 mm and “bad” =100 mm. The individuals also estimated the severity of overall symptoms of TMD on the following scale: 0 – little or none, 1- slight, 2 –moderate, 3 -severe, 4 -very severe.

**Masticatory performance test**

For assessment of masticatory performance (Edlund and Lamm, 1980), the individuals were instructed to chew round tablets of silicon impression material (Optosil®, Bayer, Germany) with a standardized weight. The test implies chewing for 20 strokes of 5 separate tablets. The chewed sample was expectorated in a plastic cup. The mouth was rinsed with water until all particles were removed from the mouth. The water was also collected in the cup and then filtered. The chewed material from each of the tablets was fractionated in a system of sieves with coarse, medium and fine meshes. Essentially, the more efficient the mastication was, the greater the quantity of material that passed through the finest sieve. The quantity of material was estimated by weight.

A masticatory performance value, by proportion of weight, was calculated for each test portion, and the mean of the best four values out of five was used as the masticatory performance index (MPI)
(Edlund and Lamm, 1980). The index ranges from 0 to 100 - the highest number corresponds to the highest performance value. Data of the MPI test was lost from 1 patient at baseline and another 6 patients at follow-up in the treatment group.

Clinical examination
The clinical examinations were conducted at the Department of Stomatognathic Physiology at the Faculty of Odontology, Malmö University, by two calibrated specialists in stomatognathic physiology (Abrahamsson et al., 2012). The extra oral examination preceded the intraoral examination. The methods for the clinical examination and the registration of signs and symptoms of TMD have been described in detail previously (Abrahamsson et al., 2012). TMD pain was diagnosed according to Research Diagnostic Criteria for TMD (RDC/TMD) (Dworkin and LeResche, 1992).

The number of tooth contacts was recorded in habitual intercuspal position during maximal isometric biting force. The indication of contacts was registered in the maxilla by means of a thin double folded plastic-foil (GHM occlusion foil® 8 μm, Hanel –Ghm Dental, Germany). The markings by the foil were registered as follows: single dot = one contact; line = two contacts; region of several small markings = three contacts. The evaluation of the method error for measuring the number of occlusal contacts has been described earlier and was found to be low (Henrikson et al., 1998).

The skeletal and morphological occlusion was registered by methods described previously (Abrahamsson et al., 2012). The diagnoses in the treatment group were separated into sagittal and vertical discrepancies, according to a combination of morphological and cephalometric values (Table 1).
Table 1. Distribution of sagittal and vertical discrepancies in the treatment group (n=98).

<table>
<thead>
<tr>
<th>Skeletal discrepancies</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sagittal discrepancies;</td>
<td></td>
</tr>
<tr>
<td>Class I</td>
<td>13</td>
</tr>
<tr>
<td>Class II</td>
<td>28</td>
</tr>
<tr>
<td>Class III</td>
<td>57</td>
</tr>
<tr>
<td>Total</td>
<td>98</td>
</tr>
<tr>
<td>Vertical discrepancies;</td>
<td></td>
</tr>
<tr>
<td>Open bite</td>
<td>41</td>
</tr>
<tr>
<td>Deep bite</td>
<td>9</td>
</tr>
<tr>
<td>Normal vertical relation</td>
<td>48</td>
</tr>
<tr>
<td>Total</td>
<td>98</td>
</tr>
</tbody>
</table>

Statistical Methods
Significance (alpha) was set at 0.05. The test was 2-tailed, i.e. an effect in either direction was analysed. With the proposed sample size of 35 in each subgroup, the study had a power of 89.8% to yield a statistically significant result. This computation assumed that the difference in proportions was 0.30 (specifically, 0.05 vs 0.35) in prevalence of TMD pain. This effect was selected as the smallest effect that would be important to detect, in the sense that any smaller effect would not be of clinical or substantive significance.

Differences between groups.
Pearson’s chi square test with Yate’s correction for continuity was used when 2 x 2 cross tabulations were applicable. When the expected cell value in a 2 x 2 table was less than 5, Fisher’s exact test was used. The two-sample t-statistic was used to compare means in numerical variables. To calculate ordinal data Mann Whitney test was used. The tested masticatory performance index was considered a numerical variable while the masticatory ability on a VAS
was considered ordinal data. When comparing means between subgroups of sagittal and vertical discrepancies, analysis of variances (ANOVA) was used.

Differences within groups before and after treatment. McNemar exact test was used to compare ordinal data and the paired t-test for the numerical data.

For multivariate analysis a linear regression analysis, with the enter method to adjust for age and group belonging, was used.

RESULTS
Analysis of those who withdrew from the treatment group (n = 23, 19 %), shown in Figure 1, did not differ from the final study group with respect to age, gender, self-estimated masticatory ability or masticatory performance. Thus, the patients who completed the study were considered to be representative of the initial study sample.

Self estimated masticatory ability
A large individual variation of the masticatory ability was found within the groups (Figure 2). At baseline, the patients (Mean = 52.2 ± 29.5, Median = 50.0) rated their masticatory ability lower than the control group (Mean = 85.7 ±17.4, Median = 92.0 P < .001), Figure 2. They also found it more difficult to chew meat (P < .001), raw carrots (P = .019), toffee (P = .002), French loaf (P < .001) and coldcuts of ham, cheese, cucumber (P < .001). At follow-up the masticatory ability had significantly improved in the treatment group (Mean = 83.9 ± 19.2, Median = 92.0 P < .001) and reached similar level as in the control group implying no significant difference between the groups.
Before treatment the treatment group estimated their masticatory ability, on a VAS, to be poorer than what the control group did ($P < .001$). After treatment there was no significant difference in the reported masticatory ability between the two groups. Fifty percent of the individuals have values within the box. The bar across the box represents the median. The whiskers show the largest and smallest value that is not an outlier. o = outliers, values more than 1.5 box lengths from the box; star = extreme, values more than 3 box lengths from the box.

Factors influencing the self estimated masticatory ability
Occlusal contacts during maximal biting pressure, severity of overall symptoms of TMD and study group belonging explained 45 percent of the total variation of the masticatory ability in a linear regression analysis adjusted for age (Table 2). The masticatory ability was in the regression analysis negatively affected by fewer occlusal contacts during maximal biting pressure, a higher severity of the overall symptoms of TMD and belonging to the treatment group (Table 2).
Table 2. Multiple linear regression analysis (enter method) of the relation between self estimated masticatory ability and explanatory variables, adjusted for age.

<table>
<thead>
<tr>
<th>Explanatory variables</th>
<th>B</th>
<th>SE B</th>
<th>P</th>
<th>Lower MPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study group</td>
<td>21.3</td>
<td>4.5</td>
<td>&lt; .001</td>
<td>Treatment group</td>
</tr>
<tr>
<td>Gender</td>
<td>7.4</td>
<td>3.9</td>
<td>NS</td>
<td>With lower number of occlusal contacts</td>
</tr>
<tr>
<td>Number of occlusal contacts during maximal biting pressure</td>
<td>1.1</td>
<td>0.3</td>
<td>&lt; .001</td>
<td>With more severe symptoms</td>
</tr>
<tr>
<td>Severity of overall symptoms of TMD (verbally)</td>
<td>- 8.0</td>
<td>1.9</td>
<td>&lt; .001</td>
<td></td>
</tr>
</tbody>
</table>

B = Regression coefficient; SE B = Standard error of B. Total factor of explanation (R2) = 45%.

**Masticatory performance**

There was a large individual variation of the masticatory performance index (MPI), within the groups (Figure 3). At baseline, the treatment group had a lower MPI than the control group (Mean = 10.4 ± 10.4, Median = 7.1 versus Mean = 37.3 ± 16.8, Median = 37.1 respectively, P < .001, 95 % CI 21.3 – 30.9). For the treatment group the MPI increased at follow-up (Mean = 21.0 ± 19.2, Median = 12.9, P < .001) but was still lower than the control group (P < .001, 95 % CI 10.2-22.4).
Figure 3. Individuals in the treatment group had a lower MPI compared with the control group (P < .001). Fifty percent of the individuals have values within the box. The bar across the box represents the median. The whiskers show the largest and smallest value that is not an outlier. o = outliers, values more than 1.5 box lengths from the box.

After stratifying the material into sagittal and vertical deformities it was found that the MPI improved after treatment in patients with a Class III malocclusion, from $11.7 \pm 10.5$ to $25.3 \pm 19.6$ (P < .001, 95 % CI 8.2-19.0), and in patients with an open bite, from $7.0 \pm 6.8$ to $18.1 \pm 18.7$ (P < .001, 95 % CI 5.5 – 16.8). No significant alteration was found in patients with deep bite or Class II malocclusion.

Factors influencing MPI
Variables like; gender; number of occlusal contacts during maximal biting pressure; self reported severity of overall symptoms of TMD and TMD pain diagnoses were all found to significantly have an influence on the MPI at baseline (Table 3). No association was found between age and MPI.
Table 3. Statistically significant differences of the mean Masticatory Performance Index (MPI) by levels of Occlusal factors and TMD in the whole study group (Both Treatment and Control group) n = 153.

<table>
<thead>
<tr>
<th>Influencing binary parameters</th>
<th>n</th>
<th>MPI</th>
<th>SD</th>
<th>p</th>
<th>95% confidence interval of the difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>93</td>
<td>17.0</td>
<td>16.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>60</td>
<td>25.3</td>
<td>19.6</td>
<td>.008</td>
<td>2.2–14.4</td>
</tr>
</tbody>
</table>

Number of occlusal contacts during maximal biting pressure

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>MPI</th>
<th>SD</th>
<th>p</th>
<th>95% confidence interval of the difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10</td>
<td>37</td>
<td>7</td>
<td>9.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 10</td>
<td>116</td>
<td>24</td>
<td>18.7</td>
<td>&lt;.001</td>
<td>12.6–21.9</td>
</tr>
</tbody>
</table>

One diagnosis of TMD pain

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>MPI</th>
<th>SD</th>
<th>p</th>
<th>95% confidence interval of the difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>115</td>
<td>23.8</td>
<td>18.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>38</td>
<td>9.6</td>
<td>12.2</td>
<td>&lt;.001</td>
<td>9.6–18.7</td>
</tr>
</tbody>
</table>

Severity of overall symptoms of TMD

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>MPI</th>
<th>SD</th>
<th>p</th>
<th>95% confidence interval of the difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insignificant-light</td>
<td>106</td>
<td>24.5</td>
<td>19.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate-very severe</td>
<td>47</td>
<td>10.6</td>
<td>11.8</td>
<td>&lt;.001</td>
<td>8.9–18.9</td>
</tr>
</tbody>
</table>

A linear regression analysis, adjusted for age and group belonging, explained 37% of the total variation of MPI (Table 4). Number of occlusal contacts during maximal biting pressure was the factor that had the highest influence on MPI and indicated that MPI increased with a higher number of contacts during maximum biting pressure. Open bite was the only kind of dentofacial deformity having a significant influence on MPI, i.e. open bite had negative effect on MPI.
Table 4. Multiple linear regression analysis (enter method) of the relation between tested masticatory performance (MPI) and explanatory variables, adjusted for age and group belonging (treatment group or control group).

<table>
<thead>
<tr>
<th>Explanatory variables</th>
<th>B</th>
<th>SE B</th>
<th>P</th>
<th>Lower MPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>-6.5</td>
<td>1.9</td>
<td>.001</td>
<td>Women</td>
</tr>
<tr>
<td>Number of occlusal contacts during maximal biting pressure</td>
<td>0.6</td>
<td>0.1</td>
<td>&lt; .001</td>
<td>With lower number of occlusal contacts</td>
</tr>
<tr>
<td>Open bite</td>
<td>-4.3</td>
<td>2.0</td>
<td>.031</td>
<td>With open bite</td>
</tr>
<tr>
<td>Severity of overall symptoms of TMD (verbally)</td>
<td>-2.5</td>
<td>1.1</td>
<td>.028</td>
<td>With more severe symptoms</td>
</tr>
<tr>
<td>Pain in the masticatory muscles/TMJs</td>
<td>4.7</td>
<td>2.6</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

B = Regression coefficient; SE B = Standard error of B. Total factor of explanation (R2) = 37%.

Occlusal contacts

Before treatment, there were no significant differences in number of teeth between the treatment (Mean = 28 ± 1.9) and the control group (Mean = 29 ± 2.0). The treatment group had significantly fewer intercuspal contacts during maximum biting pressure than the control group (Mean = 13 ± 6.4 versus 18 ± 5.5, P < .001, 95 % confidence interval (95 % CI) 3.5 – 7.5). At follow-up the number of occlusal contacts increased in the treatment group (Mean= 16 ± 6.1, P < .001, 95 % CI 2.1-5.2) and did not significantly differ from the control group. When sub groups of sagittal and vertical discrepancies were assessed before treatment, the 41 patients with open bite had significantly fewer intercuspal contacts during maximum biting pressure compared with the 9 patients with deep bite (Mean = 10 ± 5.0 versus 19 ± 9.5, P < .001) and those 48 patients with normal vertical relation (Mean = 14 ± 5.8, P = .014). No significant differences between sagittal discrepancies were found before treatment. After treatment there were no differences between neither of the sub groups.
DISCUSSION
The main findings in the present study were that patients with dentofacial deformities had impaired masticatory ability and performance in comparison with the control group before treatment. Furthermore, the masticatory ability and masticatory performance improved after orthognathic treatment why the hypotheses could not be rejected. The number of occlusal contacts during maximal biting pressure and the severity of overall symptoms of TMD were found to have an influence on both masticatory ability and masticatory performance.

In the present study both the masticatory ability and masticatory performance significantly improved after treatment. The masticatory ability was at the follow-up estimated equal in the patient and control group. However, the masticatory performance index did not reach the same level as in the control group, which may be explained by the limited follow-up period. It has been discussed that a follow-up period of 5 years after treatment, to be compared with 18 months in the present study, would be more appropriate and beneficial for the masticatory performance. Explained by that the musculature may need time to readapt after surgery before regaining full strength (van den Braber et al., 2006; Magalhaes et al., 2010). Van den Braber et al. (2006) showed an improvement in masticatory performance in retrognathic individuals 5 years after treatment, which was not found in previous studies, with shorter follow-up, performed by the same research group (van den Braber et al., 2004; van den Braber et al., 2005). Neither did Zarrinkelk et al. (1995) find any difference in masticatory performance 2 to 3 years after orthognathic treatment of individuals with dentofacial deformities. Anyhow, an interesting finding in the present study was that the individuals with a Class II bite did not show an improvement, which was in line with van Braber et al. (2006).

The difference in masticatory performance between the treatment group and the control group before treatment is in accordance with other studies using similar testing methods (Henrikson et al., 1998; English et al., 2002). English et al. (2002) found that individuals with malocclusions had impaired masticatory performance compared
with individuals with normal occlusion. They also found that individuals with a Class III malocclusion had the lowest masticatory performance compared with other malocclusion groups, however, vertical discrepancies were not considered. Their result was in contrast to the present study, in which an open bite was the only discrepancy that was found to have an impact on the MPI.

The linear regression analysis only explained 45% of the total variation of the masticatory ability and 37% of the total variation of MPI. Salivary flow rates, body builds and muscle strength are variables not assessed in the present study but are probably influential factors when evaluating mastication. It has been discussed that maximum bite force is related to body size (Proffit et al., 1983) and it has been shown that females have less muscular bite force than males (Helkimo et al., 1977; Tate et al., 1994). This could be a possible explanation to the result in this study where women were shown to have a lower masticatory performance compared with men.

Moreover, the positive treatment outcome implying increased amount of occlusal contacts may be one explanation of improvement in masticatory performance. The number of occlusal contacts has been suggested to be of major importance for the masticatory performance (Zarrinkelk et al., 1995; Kobayashi et al., 2001). This is in line with the present study since it was found that before treatment the number of occlusal contacts during maximal biting pressure was the greatest explanatory factor of the variance of the MPI. It is further confirmed by the fact that the open bite, the malocclusion with the lowest number of occlusal contacts, was another explanatory factor in the regression model.

A shortcoming of this study was the limited part in the questionnaire assessing masticatory ability. After this study was initiated, in 1992, a Jaw Function Limitation Scale (JFLS) has been developed (Ohrbach et al., 2008). The JFLS has been shown to exhibit good reliability and validity assessing limitations in mastication, jaw mobility and verbal and emotional expression (Ohrbach et al., 2008). The questionnaire in this study focused solely on mastication and it would have
been interesting to extend it according to the JFLS to come to an understanding if patients with dentofacial deformities are limited in their daily life when talking, swallowing, in facial expressions etc.

A silicon material (Optosil®, Bayer, Germany) was chosen for testing masticatory performance (Edlund and Lamm, 1980). Silicon material and the sieving method has been used in other studies (Henrikson et al., 1998; English et al., 2002; van den Braber et al., 2005, Henrikson et al., 2009) but in the study by van den Braber et al (2005) the Optosil tablets were modified by heat to gain a softer consistency. It is known that the newer type of Optosil has higher tear strength than the one used in the study by Edlund and Lamm (1980). The main requirement of an ideal test material for studying masticatory efficiency with fractional sieving is that the material is pulverized by chewing in such a manner that the degree of pulverization can be clearly established and that the material is unaffected by water and saliva. If this requirement is met, both the fractionating and the laboratory procedure can be simplified. Optosil ® (Bayer, Germany) fulfilled the above mentioned criteria (Edlund and Lamm, 1980) and another advantage of using artificial food is that it can be standardized and easily reproduced in both form and consistency. Moreover, it has been reported that the use of artificial food gives a lower test-retest consistency variation compared with for example peanuts (Olthoff et al., 1984).

An interesting finding in the present study was that the self-estimated masticatory ability was significantly affected by group belonging but not by gender. In contrast to masticatory performance that was significantly affected by gender but not by group belonging. Could it be that patients, with dentofacial deformities, men and women equally, are more prone to report impaired masticatory ability since they feel it is a more acceptable reason for having orthognathic treatment compared with for example esthetics? And therefore the gender gap, found in masticatory performance disappears. Moreover, with these results in mind it would be of interest to assess the impact of oral health related quality of life on masticatory ability in patients with dentofacial deformities. However, this was not in the scope of the present study.
Conclusions

• Masticatory ability and performance increased after orthognathic treatment.
• The number of occlusal contacts and severity of overall symptoms of TMD influenced both the masticatory ability and performance.
• Open bite had a negative effect on masticatory performance.

Acknowledgement

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CECILIA ABRAHAMSSON

Masticatory Function and Temporomandibular Disorders in Patients with Dentofacial Deformities

Studies before and after orthodontic and orthognathic treatment

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