

Review Article

The role of orthodontics in temporomandibular disorders

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SUMMARY Temporomandibular Disorder (TMD) is the main cause of pain of non-dental origin in the oro-facial region including head, face and related structures. The aetiology and the pathophysiology of TMD is poorly understood. It is generally accepted that the aetiology is multifactorial, involving a large number of direct and indirect causal factors. Among such factors, occlusion is frequently cited as one of the major aetiological factors causing TMD. It is well known from epidemiologic studies that TMD-related signs and symptoms, particularly temporomandibular joint (TMJ) sounds, are frequently found in children and adolescents and show increased prevalence among subjects between 15 and 45 years old. Aesthetic awareness, the development of new aesthetic orthodontic techniques and the possibility of improving prosthetic rehabilitation has increased the number of adults seeking orthodontic treatment. The shift in patient age also has increased the likelihood of patients presenting

with signs and symptoms of TMD. Because orthodontic treatment lasts around 2 years, orthodontic patients may complain about TMD during or after treatment and orthodontists may be blamed for causing TMD by unsatisfied patients. This hypothesis of causality has led to legal problems for dentists and orthodontists. For these reasons, the interest in the relationship between occlusal factors, orthodontic treatment and TMD has grown and many studies have been conducted. Indeed, claims that orthodontic treatment may cause or cure TMD should be supported by good evidence. Hence, the aim of this article is to critically review evidence for a possible association between malocclusion, orthodontic treatment and TMD.

KEYWORDS: occlusion, orthodontics, temporomandibular disorders

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Introduction

Temporomandibular disorder (TMD) is usually defined as a collective term that embraces a number of clinical problems that involve the masticatory muscles, the temporomandibular joint (TMJ) and the associated structures and forms the most prevalent clinical entity afflicting the masticatory apparatus. In this respect, it is considered a musculo-skeletal disorder. However, TMD is also the main cause of pain of non-dental origin in the oro-facial region including head, face and related structures (1).

The aetiology and the pathophysiology of TMD is poorly understood. It is generally accepted that the aetiology of TMD is multifactorial, involving a large

number of direct and indirect causal factors. Among these, occlusion is frequently cited as one of the major aetiological factors causing TMD (1). Numerous aetiological and therapeutic theories are based on this presumed association and have justified the use of several therapeutic approaches such as occlusal appliance therapy (2), anterior repositioning appliances (3), occlusal adjustment (4), restorative procedures (5), orthodontic (6) and orthognathic treatment (7). Conversely, many types of dental interventions, including routine orthodontic treatment, have been reported as causes of TMD (8).

Prior to the late 1980s, a very limited number of well-designed clinical studies focusing on this subject were available. Reynders (9), in a review published in 1990,

found that of the 91 articles published between 1966 and 1988 on the relationship between orthodontic treatment and TMD, only six were sample studies involving large groups of individuals. The remaining articles were case reports ($n = 30$) and viewpoint articles ($n = 55$), usually giving an expert's opinion with almost no data. The attention of the orthodontic community regarding TMD was heightened in the late 1980s after litigation involving orthodontic treatment as the cause of TMD in orthodontic patients (10). Evidence to suggest that orthodontics had not caused the problem was lacking. The case went against the orthodontist, resulting in almost a million dollars being paid out in compensation.

It is well known from epidemiologic studies that TMD-related signs and symptoms, particularly temporomandibular joint (TMJ) sounds, are frequently found in children and adolescents and show increased prevalence among subjects between 15 and 25 years old (11). Nowadays the orthodontic patient population includes both children and adults. Aesthetic awareness, the development of new aesthetic orthodontic techniques (i.e. lingual appliances or transparent removable appliances) and the possibility of improving prosthetic rehabilitation have increased the number of adults seeking orthodontic treatment. The shift in patient age also has increased the likelihood of patients presenting with signs and symptoms of TMD (12). Because orthodontic treatment lasts around 2 years, orthodontic patients may complain about TMD during or after treatment and orthodontists may be blamed for causing TMD by unsatisfied patients. This hypothesis of causality has led to legal problems for dentists and orthodontists. For this reason, the interest in the relationship between occlusal factors, orthodontic treatment and TMD has grown and many studies have been conducted. Indeed, claims that orthodontic treatment may cause or cure TMD should be supported by good evidence. The quality of the published studies has improved throughout the last decade, since 1995, when a seminal article on evidence-based medicine was published (13). According to evidence-based dentistry, dental practitioners should use current best evidence when making decisions about the care of each patient through a literature review, considering studies that are at the highest level of scientific weight. Nevertheless, a literature search on malocclusion and TMD shows that nowadays metaanalysis is lacking, only few

systematic reviews have been published and most articles are case reports or case/control studies.

Currently, the possible relationship between orthodontic therapy and TMD signs and symptoms is still a matter of debate among orthodontists, dental community and dental patients. Hence, the aim of this article is to critically review evidence for a possible association between malocclusion, orthodontic treatment and TMD.

Does malocclusion cause TMD?

Historically, the first report of a relationship between occlusion and temporomandibular joint function was suggested by Costen (14), an otorhinolaryngology surgeon, who hypothesized that changes in dental condition (e.g. loss of vertical dimension and deep bite) led to anatomical changes in the temporomandibular joint, creating ear symptoms. He stated that '*The actual source of this group of complaints was confirmed by the marked improvement which followed correction of the over-bite, renewal of molar support to take pressure off the condyle, and establishment of proper articulation of the condyle within the fossa*'. Although this hypothesis was based on the analysis of only 11 cases, the dental profession started treating patients diagnosed with the so-called 'Costen Syndrome' with bite-raising appliances.

Thereafter, occlusal interferences have been considered as risk factors for TMD. Ramfjord (15), through an electromyographic (EMG) study on 34 patients, stated that '*The most common occlusal factor in bruxism is a discrepancy between centric relation and centric occlusion; invariably such discrepancy is accompanied by asynchronous contraction or sustained strain in the temporal and masseter muscles during swallowing*'. Therefore, he suggested occlusal equilibration to provide muscular balance and to eliminate the bruxism. The proposed causal chain of events suggested that interference acts as a trigger for bruxism, which in turn may result in overload of the masticatory muscle, tenderness, pain and TMJ clicking (16, 17). Hence, the dental profession embarked on massive occlusal equilibration looking for an ideal occlusion (18, 19). However, EMG studies aiming to test this hypothesis by applying experimental interferences gave inconsistent findings (20–27). Reviews on this issue have pointed out that the relationship between occlusal interferences and masticatory function is still far from being clearly understood (for a review see (28, 29). Michelotti *et al.* (30) investigated

the effects of an acute occlusal interference on habitual muscle activity assessed in the natural environment, and on signs and symptoms of TMDs. In the study carried out in a double-blind crossover design, each subject served as his/her own control and was monitored during 6 weeks, in four different conditions: interference-free condition before the application of any interference, active interference condition, dummy interference condition and interference-free condition after the removal of the interferences. A strip of gold foil was placed on the lower first molar on the occlusal contact, disturbing the intercuspal position. To create the dummy interference, the strip was placed on the vestibular surface without interfering with the intercuspal position. The activity of the masseter muscle ipsilateral to the interference side was recorded by means of a portable EMG recorder for eight consecutive hours in the natural environment. This study gave evidence that the response of the masticatory system to active occlusal interference was a reduction in daytime habitual activity of the masseter muscle. None of the subjects reported signs and/or symptoms of TMD. The reduction may reflect an avoidance behaviour that the subjects acquired during their common diurnal activities. The increasing trend of the EMG activity levels found after the third recording day of the active occlusal interference condition indicates rapid adaptation to the disturbed occlusal condition and is consistent with the gradual decrease in the perception of occlusal discomfort. The sample investigated in this study included healthy subjects without self-report of parafunctional activities. It is possible that the reaction to occlusal disturbance is different in patients with TMD. Indeed, the results obtained by Le Bell *et al.* (31, 32) in former patients with TMD support this view. The same study design previously described (30) was used, thereafter, to investigate the effects of an acute occlusal interference on habitual muscle activity assessed in the natural environment in a group of subjects with myofascial pain. Preliminary results showed increase in daytime habitual activity of the masseter muscle and increase in masticatory muscle pain (Michelotti A, Palla S, Festa P, Farella M, unpublished data). Consistently, a study conducted on rats showed hyperalgesia at the masticatory muscles after the application of experimental occlusal interferences by directly bonding crowns of different heights (33). The authors also found that removal of the crown after 6 days did not reduce the hyperalgesia observed for at least 1 month after the

induced occlusal interference and that the N-methyl-D-aspartate antagonist reduced the induced hyperalgesia suggesting central sensitization mechanisms.

It could be hypothesized that subjects who are occlusally hypervigilant are disturbed by the interference and increase the activity of the masticatory muscles which in turn may lead to pain and dysfunction. Occlusal hypervigilance may be explained by the Generalized Hypervigilance Hypothesis according to which hypervigilance is a 'perceptual habit' that involves subjective amplification of a variety of aversive sensations, not just painful ones (34). According with this hypothesis, if attention is habitually focused on sensations of a particular type, their amplification increases and became autonomous (35, 36). An explanatory model for this hypothesis is shown in Fig. 1.

Orthodontists were introduced to the field of TMD following the theorising of Thompson (37) who believed that malocclusion caused the posterior and superior displacement of the condyle. Hence, there was the need to bring downward and forward the condyle by freeing up the trapped mandible. Since then, various malocclusions have been associated with TMD signs or symptoms. In 1988, Greene and Laskin (38) published a list of 10 myths in this field that, surprisingly after 20 years, are still a matter of debate among orthodontists:

- 1** People with certain types of untreated malocclusion (for example, Class II Division 2, deep overbite, cross-bite) are more likely to develop TM disorders.
- 2** People with excessive incisal guidance, or people totally lacking incisal guidance (open bite), are more likely to develop TM disorders.
- 3** People with gross maxillo-mandibular disharmonies are more likely to develop TM disorders.
- 4** Pre-treatment radiographs of both TMJs should be taken before starting orthodontic treatment. The position of each condyle in its fossa should be assessed, and orthodontic treatment should be directed at producing a good relationship at the end. ('Good' position usually was defined as being a concentric placement of the condyle in the fossa).
- 5** Orthodontic treatment, when properly done, reduces the likelihood of subsequently developing TM disorders.
- 6** Finishing orthodontic cases according to specific functional occlusion guidelines (e.g. gnathologic principles) reduces the likelihood of subsequently developing TM disorders.

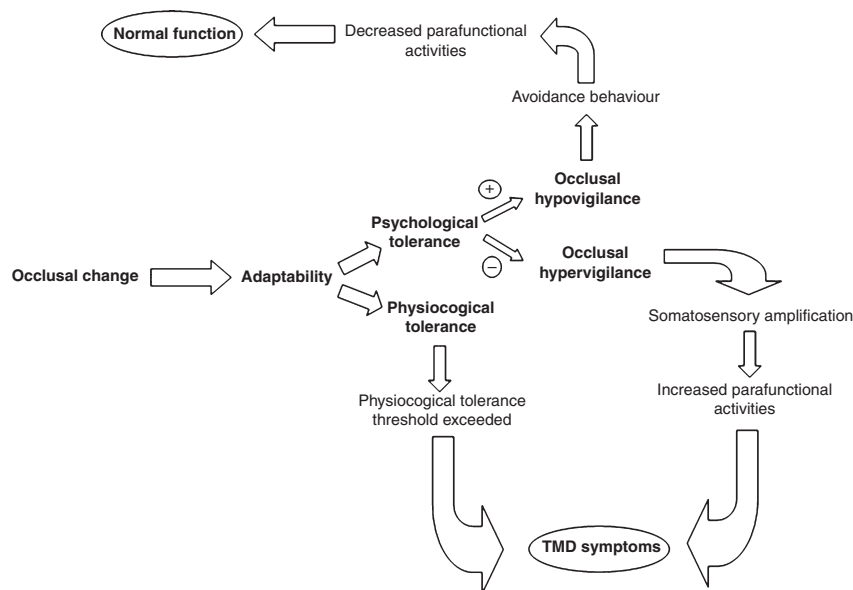


Fig. 1. Different reaction to occlusal changes according to the 'hypervigilance' hypothesis.

7 The use of certain traditional orthodontic procedures and/or appliances may increase the likelihood of subsequently developing TM disorders.

8 Adult patients who have some type of occlusal 'disharmony' along with the presence of TMD symptoms will probably require some form of occlusal correction to get well and stay well.

9 Retrusion of the mandible because of natural causes or after treatment procedures is a major factor in the aetiology of TM disorders.

10 When the mandible is distalized, the articular disc may slip off the front of the condyle.

None of these statements is evident according to current mainstream scientific opinion. The majority of studies carried out using an appropriate study design and relevant outcome measures were unable to show that orthodontic therapy has a preventive or curative effect on the occurrence of TMD. Therefore, even though various malocclusions have been associated with TMD signs or symptoms, the studies published have not been carried out with a rigorous design and are open to criticism. Indeed, several studies investigating the relationship between occlusal factors and TMDs have been carried out with small sample sizes or have used dental students/staff as controls in case-control design; this might lead to selection bias, particularly if potential confounding variables are not taken into account in the analysis. A population-based study of risk factors for TMD has the advantage that cases and

controls are not selected according to patient referral. Controls come from the same population as the cases, which reduces the possibility of selection bias and confounding.

Population-based studies were done on 3033 subjects to investigate the association between overbite (vertical occlusal discrepancy) or overjet (sagittal occlusal discrepancy) and self-report of TMD symptoms (39), and the relationship between clicking and crepitus of the TMJ, overjet and overbite (40). Both studies failed to demonstrate a relationship between overbite or overjet and TMD signs and symptoms.

Among different malocclusions, posterior crossbite (transversal occlusal discrepancy) is thought to have a stronger impact on the correct functioning of the masticatory system. Several problems have been ascribed to the unilateral posterior crossbite. Firstly, it has been suggested that the altered morphological relationship between the upper and lower dentition may result in right-to-left-side differences in the condyle-fossa relationship, and in the height of the condyle and the mandibular ramus resulting in an asymmetric mandibular growth (41–46). However, early treatment to normalize the occlusion created appropriate conditions to obtain a normal growing pattern both in animal studies and in human studies (44–46). Secondly, jaw function alteration including asymmetric pattern of jaw muscles EMG activity (47), lower bite forces (48), reduced thickness of the ipsilateral masseter (49) and a

reverse sequence chewing pattern (50, 51) have been reported. Also, these functional alteration normalized after early correction of the crossbite (52–54). Thirdly, it has been hypothesized that the crossbite is a compensatory curvature in the visceral cranium for the transmission of the asymmetry of the body to the skull. According to this hypothesis, dental occlusion may influence whole body posture, and disorders of the functioning, such as chewing and swallowing, of masticatory muscles can be transmitted to distal musculature along the so-called 'muscle chains' (55). Again, early treatment of children with unilateral crossbites is suggested to reduce the adaptive demands on the masticatory system and to create appropriate conditions for normal occlusal development, facial symmetry and stable head posture. Thilander *et al.* (56) recommended the treatment of posterior crossbite at a young age to prevent asymmetrical facial growth. Also, early treatment of posterior crossbites is advocated to prevent them from being passed on to the adult dentition (57). In contrast, crossbite orthodontic correction could hardly give benefits in adults where skeletal adaptation has already occurred (58). Finally, according to the proposed causal chain of events, posterior crossbite may result in alterations of the disc–condyle relationship, which in turn are responsible for disc displacement and TMJ clicking (59–62). Pullinger *et al.* (60) examined five patient groups (i.e. disc displacement with reduction, disc displacement without reduction, TMJ osteoarthritis with disc displacement history, primary osteoarthritis and myalgia only) in comparison with asymptomatic controls and reported that the chance of an individual with unilateral posterior crossbite having TMJ disc displacement with reduction was 3.3:1. The association between TMJ disc displacement and unilateral posterior crossbite has been analysed in a population-based cross-sectional study (63). In a sample of 1291 young adolescents recruited from three schools, regression analysis failed to find a significant association between unilateral posterior crossbite and disc displacement with reduction. The authors concluded that posterior unilateral crossbite does not appear to be a risk factor for TMJ clicking, at least in young adolescents and that there is an initial optimal TMJ functional adaptation to unilateral posterior crossbite, at least until young adolescence. Although there appears to be some rationale for early correction of unilateral posterior crossbites in children, no prospective clinical trial of this type of treatment efficacy

has been conducted to date. Based on these observations, although there is a rationale for early correction of unilateral posterior crossbites in children to improve neuromuscular function of the stomatognathic system, clinicians should be cautious in recommending early orthodontic treatment aiming only to prevent joint clicking. Consistently, Arat *et al.* (64) investigated condyle-disc positions on sagittal and coronal closed-mouth magnetic resonance imaging (MRI) in unilateral and bilateral posterior crossbite patients before and 18 weeks after rapid maxillary expansion (RME). The authors concluded that RME is neither a risk factor nor a prevention for TMD. Furthermore, it has been found that RME in children with unilateral posterior crossbite did not change articular disc position and configuration (65).

The evidence for causality linking malocclusion and TMD should respect several criteria as suggested by Hill (66) in 1965. First of all, the causes (i.e. malocclusions) should precede the effects (i.e. TMDs), whereas in the literature, we find studies that show the opposite [i.e. muscle pain causes changes in the occlusion (67)]. Then, the association must be strong and the more severe the malocclusion, the more severe should be the disease. By contrast, previous reports suggest that the risk of TMD may be doubled by just a few severe occlusal factors (60). Furthermore, in the case of evidence of causality, results from the scientific literature should be consistent across time. This does not hold for TMD: on examining the publications from 1995 to 2009, an increasing number of studies refute or reduce the importance of the role of occlusal factors in the aetiology of TMD. Finally, the major role of occlusion also appears unlikely when taking into account the higher prevalence of TMD in females during their child-bearing years, whereas malocclusion is equally distributed among genders and ages. The predominance of women seeking treatment much more often than men points to a possible connection between oestrogen hormones and dysfunction (68, 69). In such a case, the concept of biological plausibility is not satisfied because the cause–effect relationship is not consistent with our knowledge of the mechanisms of the disease. It can be concluded that occlusion is currently declining in importance and is now considered as a cofactor. Other aetiological factors, such as trauma, parafunctional behaviour, psychosocial disorders, gender, genetics and centrally mediated mechanisms, are considered more important.

**Does orthodontic treatment cause TMD?
Do any orthodontic procedures (i.e. extraction, functional appliances, class II/III elastics, chin-cup, headgear, fixed or removable appliances) lead to a greater incidence of TMD?**

The need to investigate on the relationship between orthodontics and TMD came from the occurrence of legal cases in which patients blamed orthodontists for causing TMD symptoms during or after orthodontic treatment (10). From the late 1980s, the orthodontic community was alerted and gave funds to investigate the relationship between orthodontic treatment and TMD. In 1995, a review of this topic by McNamara, Seligman and Okeson (70) listed eight conclusions that refute this possible association.

- 1 Signs and symptoms of TMD occur in healthy individuals
- 2 Signs and symptoms of TMD increase with age, particularly during adolescence. Thus, TMD that originates during orthodontic treatment may not be related to the treatment.
- 3 Orthodontic treatment performed during adolescence generally does not increase or decrease the chances of developing TMD later in life.
- 4 The extraction of teeth as part of an orthodontic treatment plan does not increase the risk of developing TMD.
- 5 There is no elevated risk for TMD associated with any particular type of orthodontic mechanics.
- 6 Although a stable occlusion is a reasonable orthodontic treatment goal, not achieving a specific gnathologically ideal occlusion does not result in TMD signs and symptoms.
- 7 No method of TM disorder prevention has been demonstrated.
- 8 When more severe TMD signs and symptoms are present, simple treatments can alleviate them in most patients.

Although these statements were published 15 years ago, most orthodontists and dental community still believe that internal derangement may be the consequence of the retraction of the mandible during some forms of orthodontic treatment (71). In particular, it has been suggested that premolar extractions in the upper arch can cause a posterior displacement of the condyle which in turn could be associated with increased risk of joint dysfunction (72). This concern, as well as the

medico-legal implications, has had a considerable impact on the decline of the extraction rate for orthodontic purpose (73). Indeed, condylar retro-position has been found in patients with disc displacement (74). However, correlation between disc displacement and the posterior position of the condyle is controversial because of the large inter-individual variation in condylar position. For instance, it has been shown that asymptomatic subjects may have anterior, normal or posterior position of the condyle within the fossa (75). Actually, the 'ideal' position of the condyle still remains one of the controversial issues in orthodontics and in prosthodontics (76). Also, mounting casts on the articulator, using axiography to find the kinematic centre (77) to plan the orthodontic treatment and maintaining the condyle in the centric relation position, is not supported by scientific evidence (78). Furthermore, there is no evidence in the literature to prove that the positional differences are to be considered 'pathological'. It is probable that they are merely related to the unreliable measurements obtained by using a bi-dimensional diagnostic tool instead of a three-dimensional one such as individualized magnetic resonance or computer tomography scan (79). Finally, even if a retro-positioned condyle is slightly more frequently found in patients than in asymptomatic subjects, it is not possible to say whether this is the cause or consequence of anterior disc displacement for remodelling changes in the joint geometry.

The hypothesis that different orthodontic techniques (e.g. functional appliances, class II/III elastics, chin-cup, headgear, fixed or removable appliances) and treatment plans can be involved as aetiological factors for TMD has also been tested in recent decades. Dibbets and van der Weele (80) compared groups of children who were treated with different orthodontic treatment procedures, functional appliances, Begg light wire, chin cups, four-first premolars extracted, all other types of extraction and no extraction. Patients were monitored for a 20-year period after the start of orthodontic treatment. Although signs and symptoms of TMD increased with age, after 20 years neither orthodontic treatment nor extraction showed a causal relationship with the signs and symptoms of TMD. Therefore, the authors concluded that neither orthodontic treatment nor extraction had a causal relationship with the signs and symptoms of TMD.

Henrikson and Nilner (81) compared 11–15-year-old treated and untreated female subjects with class II

division 1 malocclusions with females with normal occlusions. All the patients were treated with a fixed appliance together with either headgear or class II elastics and/or extractions. Signs and symptoms of TMD were monitored for 2 years. They reported individual fluctuations of TMD symptoms in all three groups. In the orthodontic group, the prevalence of TMD symptoms decreased over the 2 years. The Class II and Normal groups showed minor changes during the 2-year period. TMJ clicking increased in all three groups over the 2 years. Hence, orthodontic treatment did not increase the risk for or worsen pre-treatment signs of TMD. On the contrary, subjects with Class II malocclusions and signs of TMD of muscular origin seemed to benefit functionally from orthodontic treatment in a 2-year perspective.

Rey *et al.* (82) compared a sample of Class III patients treated with orthodontics and mandibular cervical headgear, Class I patients treated orthodontically without extractions and subjects who had not been previously treated for the presence or absence of TMD: Class III patients treated with mandibular cervical headgear and fixed appliances for 2–3 years had no greater prevalence of TMD signs and symptoms than Class I patients treated with fixed appliances only or untreated controls. Therefore, treatment-induced modifications in the TMJ must be interpreted as remodelling changes.

Another matter of debate among orthodontists is the influence of orthognathic surgery (OS) on TMD. Some reports suggest that surgery may alleviate signs and symptoms of TMD (83, 84); others indicate that surgery might initiate or aggravate temporomandibular dysfunction (85, 86). A literature review covering the period from 1966 to 2006 aimed to answer the question whether orthognathic surgery does affect the prevalence of signs and symptoms of TMDs. Among 467 articles, three met the inclusion criteria. The scientific evidence was insufficient to evaluate the effects that OS had on TMD (87). The lack of consistent findings across studies may be ascribed to different methods used to assess stomatognathic function and dysfunction, the lack of separate evaluation of muscular and articular problems, the inclusion of different skeletal malocclusions in the samples investigated, the use of different surgical techniques and the limited follow-up time. Orthognathic surgery represents an interesting model to study pain and function of the masticatory system. The surgical approach provokes tissue damage and inflammatory reactions. Investigat-

ing in a longitudinal study the effects of an orthognathic procedure in a group of patients with class III malocclusion on muscular and articular signs and symptoms of TMD, Farella *et al.* (88) reported that bimaxillary osteotomy did not initiate or aggravate signs and symptoms of TMD and that the occurrence of signs and symptoms of TMD after OS fluctuated with an unpredictable pattern.

According to current knowledge, the role of orthodontic treatment in the aetiology of TMD is not confirmed. The conclusions listed by McNamara *et al.* (70) are still valid. Consistently, a meta-analysis on orthodontics and TMD (89) reported that no study indicated that traditional orthodontic treatment, including Begg appliance, Herbst appliance, Class II elastics and extraction, bionator and headgear, facial mask and chin cup, increased the prevalence of TMD. The same conclusions can be drawn from the reviews published by Luther (8, 90) who stated that neither static nor dynamic occlusal factors (including orthodontics) can be said to 'cause' TMD, and from the systematic review published by Mohlin (91) who found that TMD could not be correlated to any specific type of malocclusion, and there was no support for the belief that orthodontic treatment may cause TMD. Finally, a 20 year cohort longitudinal study investigating the relationship between orthodontic treatment and TMD concluded that orthodontic treatment neither causes nor prevents TMD and that participants with a history of orthodontic treatment did not have higher risk of new or persistent TMD (92).

We carried out a PubMed search using 'Orthodontics AND tmd' as keywords yielded 404 studies, of which 58 were indexed as review articles, two were discarded because not in English, 34 were not related to the topic or were not reviews, five did not have the abstract available. The remaining 17 reviews are summarized in Table 1 (line 1–17). Furthermore, a PubMed search using 'Orthodontics AND occlusion AND tmd' as keywords yielded 132 studies, of which 26 were indexed as review articles, three were discarded because not in English, six did not have the abstract available. Among the remaining 17 reviews, five were not reported in the previous research and have been added to Table 1 (line 18–22). Finally, a PubMed search using 'Orthodontics AND occlusion AND tmd AND meta-analysis' as keywords yielded three studies. Among these, two were not reported in the previous research and have been added to Table 1 (line 23–24).

Table 1. Studies published between 1989 and November 2009 that examined the relationship between orthodontic treatment and TMD

1	Abrahamsson C <i>et al</i> (87)	Angle Orthod	2007	TMD and orthognathic surgery	No scientific evidence
2	Mohlin B <i>et al</i> (91)	Angle Orthod	2007	TMD in relation to malocclusion and orthodontic treatment	No correlation between TMD, malocclusion and orthodontics
3	Luther F (8)	Br Dent J	2007	TMD and occlusion	No correlation between TMD and static or dynamic occlusal factors
4	Gesch D (122)	Quintessence Int	2004	Association of malocclusion and functional occlusion with TMD	No morphologic or functional occlusal factor was found as cause of TMD
5	Koh H and Robinson PG (123)	J Oral Rehabil	2004	Occlusal adjustment and TMD	There is no evidence that OA treats or prevents TMD
6	Forssell H and Kalso E (124)	J Orofac Pain	2004	Occlusal treatment for temporomandibular disorders	No evidence supporting the use occlusal adjustment
7	Koh H and Robinson PG (125)	Cochrane Database	2003	Occlusal adjustment and TMD	Absence of evidence that occlusal adjustment treats or prevents TMD
8	Hagag G <i>et al</i> (126)	J Med Dent Sci	2000	Occlusion, prosthodontic treatment and temporomandibular disorders	Weak correlation between occlusal interference and TMD. Unstable occlusion in the intercuspal position may cause TMD
9	De Boever JA <i>et al</i> (127)	J Oral Rehabil	2000	Occlusal therapy for TMD	Generalized prophylactic occlusal adjustment is not justified.
10	Forssell H <i>et al</i> (128)	Pain	1999	Occlusal treatments in temporomandibular disorders	Evidence for the use of occlusal adjustment is lacking
11	McNamara JA Jr and Türp JC (129)	J Orofac Orthop	1997	Orthodontic treatment and temporomandibular disorders	Orthodontic treatment does not increase or decrease the chances of developing TMD; The orthodontic extraction of teeth does not increase the risk of TMD; no convincing evidence that orthodontic treatment cure TMD
12	McNamara JA Jr (130)	Oral Surg Oral	1997	Orthodontic treatment and temporomandibular disorders	Not achieving a specific gnathologic ideal occlusion does not result in signs and symptoms of TMD; there is little evidence that orthodontic treatment prevents TMD
13	Clark GT <i>et al</i> (131)	Oral Surg Oral	1997	Occlusal therapy for temporomandibular disorders	No comparative studies testing the efficacy of occlusal adjustment in preventing TMD.
14	Dibbets JM and Carlson DS (132)	Semin Orthod	1995	Implications of temporomandibular disorders for facial growth	Little is known about the influence of TM pathology, disc interferences or myofascial disorders on facial growth.
15	McLaughlin RP and Bennett JC (71)	Angle Orthod	1995	Extraction and TMD	No higher incidence of TMDs in patients treated with the extraction of premolars
16	McNamara JA Jr <i>et al</i> (70)	J Orofac Pain	1995	Occlusion, orthodontic treatment and temporomandibular disorders	The relationship of TMD to occlusion and orthodontic treatment is minor.

Table 1. (Continued)

17	Bales JM and Epstein JB (133)	J Can Dent Assoc	1994	Malocclusion and orthodontics in temporomandibular disorders	Little evidence to support occlusal factors in TMD. Anterior open bite may represent predisposing factors. Orthodontic therapy may not affect the risk of developing TMD and has little role in treatment
18	Türp JC <i>et al</i> (134)	J Oral Rehabil	2008	Dental occlusion	Naturally occurring features such as centric, balancing, working or protrusive occlusal interferences, various occlusal guidance patterns, missing teeth and oral/dental parafunctions are not meaningfully associated with TMD signs and symptoms
19	Kirveskari P (135)	Oral Surg Oral	1997	Occlusal adjustment in the management of temporomandibular disorders	Controlled clinical trials suggest an effect for occlusal adjustment on chronic headaches and on chronic neck and shoulder pain in comparison with conventional treatments
20	Greene CS (136)	Semin Orthod	1995	Aetiology of temporomandibular disorders.	There are no special occlusal or orthodontic factors to be considered, and therefore occlusion-changing procedures are not generally required for successful treatment
21	Haber J (137)	Curr Opin Dent	1991	Dental treatment of temporomandibular disorders	Current information supports the use of reversible treatments for these disorders
22	Baker RW Sr <i>et al</i> (138)	N Y State Dent J.	1991	Occlusion as it relates to TMJ	There is no research that shows that restorative dentistry or orthodontics are aetiological factors in TMJ dysfunction
23	Kim MR <i>et al</i> (89)	Am J Orthod Dentofacial Orthop	2002	Orthodontics and temporomandibular disorder: a meta-analysis	Because of heterogeneity, a definitive conclusion cannot be drawn. This comprehensive meta-analysis does not indicate that traditional orthodontic treatment increased the prevalence of TMD
24	Tsukiyama Y <i>et al</i> (139)	J Prosthet Dent	2001	Occlusal adjustment as a treatment for temporomandibular disorders	The experimental evidence reviewed was neither convincing nor powerful enough to support the performance of occlusal therapy as a general method for treating a non-acute temporomandibular disorder, bruxism or headache

Even though most of the studies consistently do not support the correlation between orthodontic treatment and temporomandibular disorders, it must be stressed that definitive conclusions cannot be drawn because of the unknown cause of TMD, heterogeneity in the methodology and in the study design and lack of a widely accepted classification scheme. Recently, a search has begun for a genetic influence on TMD

aetiology (93). The potential for the existence of gene environment interactions that can influence TMD risk, using orthodontic treatment as an example of an environmental influence, has been investigated in a prospective cohort study. Interestingly, among people with a variant of the gene encoding catechol-O-methyltransferase, an enzyme associated with pain responsiveness, risk of developing TMD was significantly

greater for subjects who reported a history of orthodontic treatment (94). This finding opens a new scenario on the risk for developing TMD that need to be further investigated in the future.

How should orthodontic treatment be managed if the patient presents signs and symptoms of TMD before or during treatment?

Before starting orthodontic treatment, it is advisable to perform always a screening examination for the presence of TMD. For medico-legal reasons, any findings, including TMJ sounds, deviation during mandibular movements or pain, should be recorded and updated at 6-month intervals, and informed consent should be signed by the patient (95, 96). Guidelines for the examination were recently published by the American Academy of Orofacial Pain (1). If the patient presents signs or symptoms of TMD before starting orthodontic treatment, the first step is to make the diagnosis. When the patient's chief complaint is pain, it is important to make a differential diagnosis to determine whether the pain is because of TMD, i.e. musculoskeletal condition, or to another disease. The second step is to resolve the pain by following a conservative treatment protocol (97)

including pharmacotherapy, counselling, behavioural therapy, home exercises, physical therapy and/or occlusal appliances. As a rule, orthodontic treatment should not be initiated as long as a patient suffers from facial pain. Indeed, experimentally induced pain in masticatory muscles has been shown to induce significant displacement of the gothic arch apex in the anterior and transverse direction, and changes in the orientation and magnitude of lateral movements. These effects were reversible and disappeared when the subjects became pain-free again (67). Then comes the third step: once the pain has been resolved and the condition is stable over a reasonable amount of time, initiation of orthodontic therapy may be considered. The treatment plan should always be tailored according to the problem list of the patient, to evidence-based dentistry principles and to common sense considering the characteristics of the single patient and taking into account why the patient is seeking treatment. Patients with generalized musculoskeletal pain, such as fibromyalgia, or patients with a systemic inflammatory disease, such as rheumatoid arthritis, should be managed by an interdisciplinary team (Fig. 2).

TMD signs and symptoms are fluctuating and unpredictable and can emerge during orthodontic treatment. The orthodontist should inform the patient

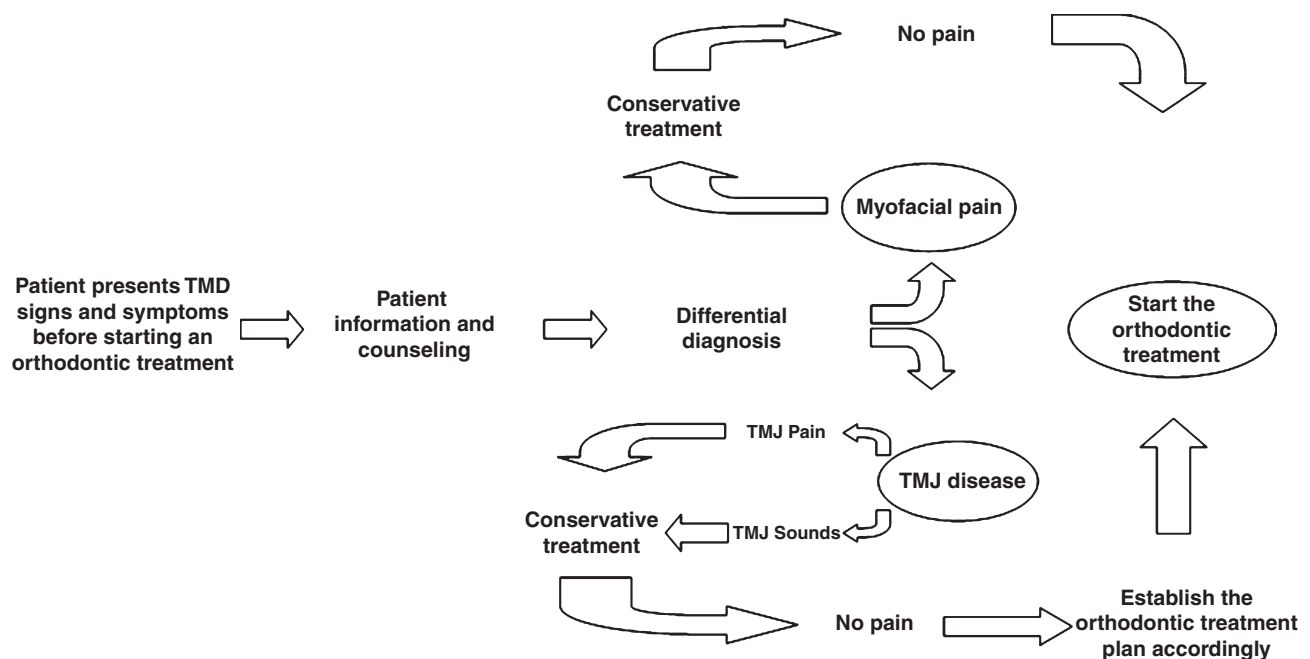


Fig. 2. TMD signs occurring before starting an orthodontic treatment.

that because they are highly prevalent in the general population and the aetiology is multifactorial, it is not possible to establish a correlation with the orthodontic therapy. If the patient presents signs or symptoms of TMD during active orthodontic treatment, the first step is always to make the diagnosis. The second step is to stop active orthodontic treatment temporarily to avoid exacerbating factors. Activating orthodontic appliances applies forces to teeth that can cause transient discomfort or pain. Indeed, orthodontic pain induced by means of separators resulted in a transient reduction in the pressure pain thresholds of the masseter and temporalis muscles (98). These reductions can probably be ascribed to neuroplastic changes involving the brainstem second order neurons, which receive extensive convergent inputs from trigeminal afferents (99, 100). The third step is to resolve the pain by following the same conservative treatment protocol as suggested above (i.e. pharmacotherapy, counselling, behavioural therapy, home exercises, physical therapy). If required, an occlusal appliance can also be used to evaluate the interference-free position of the mandible. Afterwards, when the patient is pain-free, orthodontic treatment can be continued as previously planned or, if necessary, modified according to the patient's condition (Fig. 3).

Does TMD (i.e. development disorders, arthritis, condylar resorption, osteoma) cause malocclusion? Hence, how should orthodontic treatment be planned?

TMDs, as classified by the American Association of Orofacial Pain, embrace several TMJ disorders, including developmental (i.e. hypo/hyperplasia), acquired (i.e. neoplasms) and inflammatory (i.e. rheumatoid arthritis) disorders. These disorders can cause skeletal as well as dental changes and frequently lead to marked facial asymmetry. Sometimes, they occur in the age group of patients generally seen by the orthodontist who is the first clinician that can make the diagnosis. It is therefore essential, when it is present, that orthodontists recognize the condition before beginning orthodontic treatment so that patients will not consider it a consequence of their therapy. Therefore, their recognition is of great importance in planning and managing orthodontic treatment.

Unilateral condylar hyperplasia

Condylar hyperplasia (CH) (101) is a pathological overgrowth condition in the condylar process, which leads to variable abnormal mandibular and/or facial

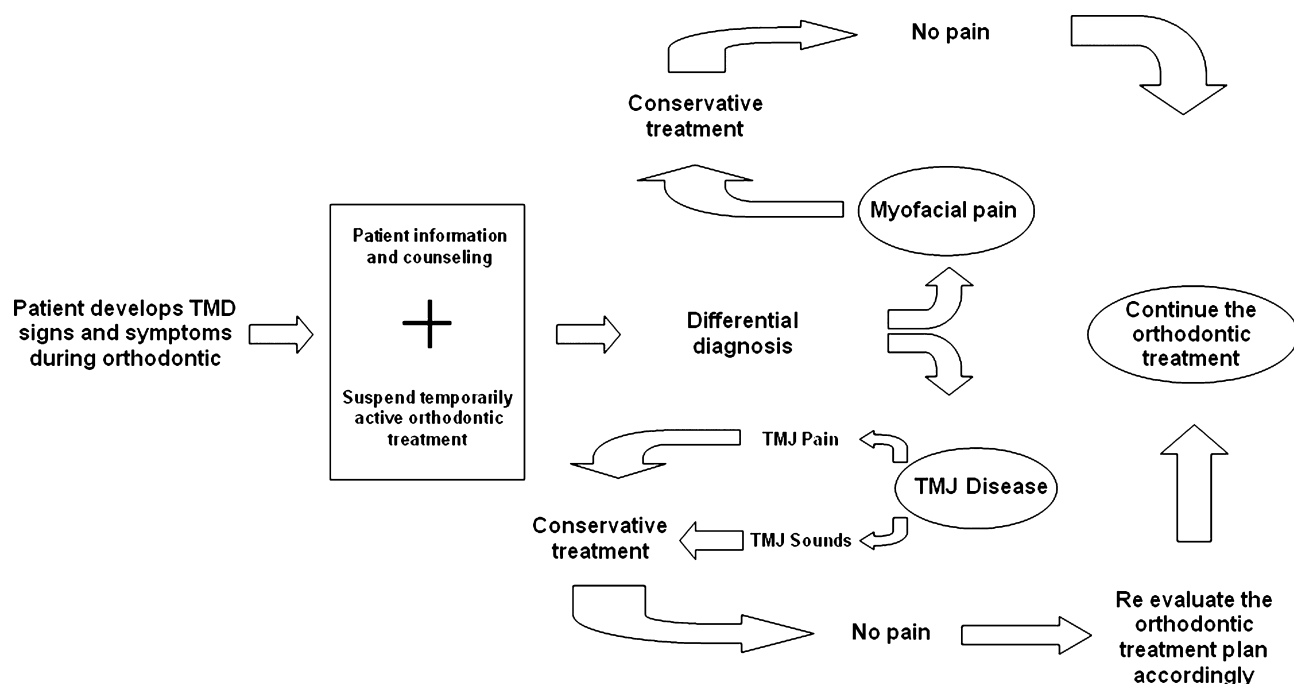


Fig. 3. TMD signs occurring during orthodontic treatment.

asymmetry. This disorder of unknown origin is characterized by persistent or accelerated unilateral condylar growth. CH usually develops during puberty and rarely begins after the age of 20. Identification of the sex hormone receptors in and around the TMJ and the pubertal onset of CH strongly suggest a hormonal influence in the aetiology (102).

The slowly progressive unilateral enlargement of the mandible causes facial asymmetry and shifting of the midpoint of the chin to the unaffected side, and most of the time a cross-bite malocclusion. Concomitant with the increased downward and forward growth of the mandible, which carries the teeth with it, there is compensatory eruption of the maxillary teeth and downward growth of the maxillary alveolar process, as well as upward growth of the mandibular alveolar process in an attempt to maintain the occlusion. A panoramic imaging is considered a reliable basic tool to evaluate mandibular asymmetries (103). Radiographically, the TMJ appears normal or there may be symmetrical enlargement of the condyle and elongation of the mandibular neck (Fig 4). New 3D imaging methods, such as cone beam computed tomography, are now available.

Single photon emission computed tomography or bone scintigraphy with ^{99m}Tc methylene diphosphonate is necessary to reveal possible asymmetric growth activity in the mandibular condyles. If the difference in the uptake of the radiotracer between the condyles exceeds 10%, which is considered to be the cut-off value (104), there is the indication for high condylectomy (HC), or condylar shaving, on the affected side to stop excessive growth. During this procedure, 2–3 mm of the condylar head, that is the growing condylar cartilage as well as the uppermost part of the subchondral bone, is removed. Patients with CH usually present jaw function within normal limits without TMD signs or symptoms. Immediately after HC, Maximal Mouth Opening is usually reduced because of surgical side effects, but

recovers almost completely at patient follow-up. In experimental animals, remodelling of the excised condylar head and formation of new articulating cartilage when a proper mandibular function is maintained has been noted (105). Therefore, TMJ functioning can recover well despite the major trauma caused by the HC to the articulating surface of the condyle. Orthodontic treatment is necessary to obtain teeth alignment. At the end of growth, usually additional OS is also needed to correct maxillo-mandibular relationship and compensatory tilting of the maxillary plane.

Chondroma or osteochondroma

Chondroma or osteochondroma of the condyle occurs singly or as part of an autosomal dominant syndrome known as osteochondromatosis. As it can produce signs and symptoms similar to unilateral condylar hyperplasia, a differential diagnosis has to be made. The pathogenesis of osteochondroma is still under debate. In the most accepted view, it is a metaplastic change in the periosteum and/or the osteochondral layer in the mandibular condyle, leading to production of cartilage that subsequently ossifies.

The mean age of discovery of osteochondromas of the mandibular condyle is reported to be the fourth decade of life. Generally, it grows rapidly, causing quick changes in facial symmetry. Moreover, because of the rapid growth, dental compensation may not occur and an open bite develops (86). Another distinguishing characteristic is the fact that with a chondroma or osteochondroma, the condyle is asymmetrically enlarged with unusual morphological characteristics (Fig. 5).

Rheumatoid arthritis

Juvenile idiopathic arthritis (JIA) is a term that indicates a childhood disease characterized primarily

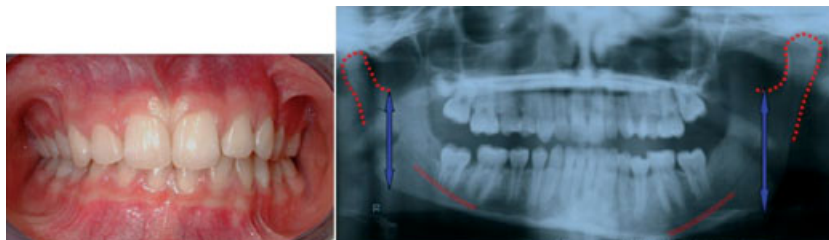


Fig. 4. Condylar Hyperplasia left TMJ.



Fig. 5. Osteochondroma right TMJ.

by arthritis persisting for at least 6 weeks, starting before the sixteenth birthday. (106) All joints can be involved in JIA, including the TMJ. From 50% to 78% of patients with rheumatoid arthritis will show some involvement of the TMJ. One or both TMJs can be involved in JIA, and the TMJ may even be the initial joint to be involved (107, 108). Involvement of the TMJ often occurs without clinically detectable signs and symptoms, therefore delaying diagnosis. Patients with involvement of the TMJ usually complain of a deep, dull, aching pain in the preauricular region that is exacerbated by function, swelling of the preauricular tissues during the acute phases, and progressive limitation of jaw movement. Severe damage to the periarticular and articular structures occurs in a late stage. As the most important growth centre of the mandible is located on the articular surface of the mandibular condylar head, destructive changes during the growth period affect mandibular development with subsequent

alteration in dental occlusion. In these cases, the patient may develop a progressive class II malocclusion and an anterior open bite caused by loss of ramal height (109, 110) (Fig. 6).

Panoramic imaging is a good diagnostic tool for evaluating erosive alterations. Nowadays, MRI is considered to be the gold standard to diagnose TMJ involvement (111, 112). The radiographic findings with juvenile rheumatoid arthritis include erosion of the articular surface of the condyle, flattening and erosion of the articular eminence and loss of the joint space. When rheumatoid arthritis is suspected on the basis of the clinical and radiographic findings, laboratory tests (rheumatoid factor, erythrocyte sedimentation, antinuclear antibodies) can be used to confirm the diagnosis.

Controlling JIA with systemic drugs is always the first step in the treatment protocol. In growing patients, treatment includes the application of a functional orthopaedic orthodontic appliance to favour the regen-

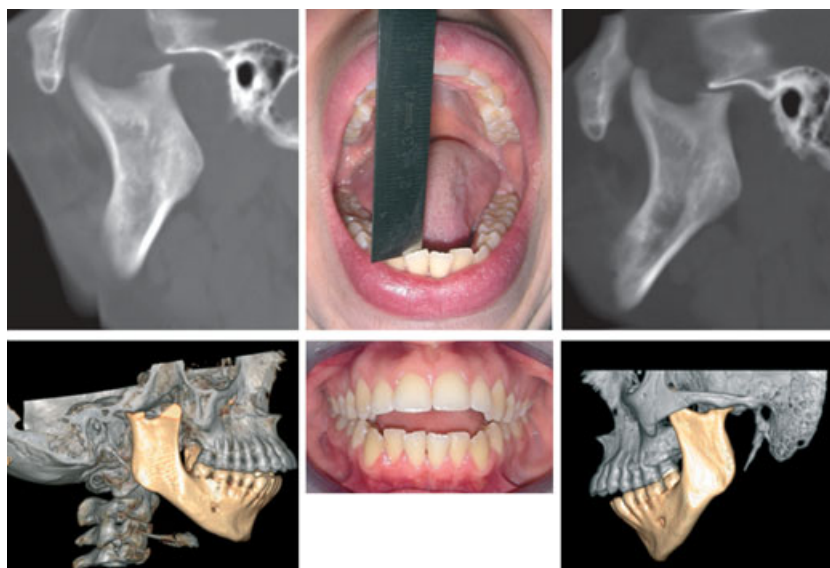


Fig. 6. Rheumatoid arthritis right and left TMJs.

erative capacity of the condyle and to improve condylar alterations (113–115). Interestingly, in a 5-year follow-up study of paediatric patients with JIA, a decrease in the frequency of TMJ involvement was observed (109, 113, 116). When the resultant malocclusion is severe, a combination of orthodontics and OS is required to attain both an acceptable occlusion and an improvement in facial aesthetics. Distraction osteogenesis (117) can increase bone volume by gradual traction of a fracture callus formed between osteotomized bony segments. Application of this technique is recommended for the treatment of a severe dentofacial deformity with significant hard and soft tissue deficiency.

Conclusion

TMD is a multifactorial pathology, and it is difficult to demonstrate a direct correlation between one of the causes, such as occlusion, and TMD. The variables are so many and so mixed that, nowadays, we do not have adequate diagnostic instruments to establish a clear correlation or to know if how and when a malocclusion can unbalance the stomatognathic system. Even though currently occlusion is considered a potential cofactor with a much lower weight when compared to the beliefs underpinning the Costen Syndrome, we have to consider that absence of evidence does not mean evidence of absence. Based on this concept, orofacial pain and TMD require a comprehensive team approach. It is important to rule out other causes of facial pain before investigating the teeth as the potential aetiological factor. According to evidence-based dentistry, dental practitioners should use current best evidence when making decisions about the treatment of each patient, integrating individual clinical expertise with the best available clinical evidence.

When the treatment protocol includes a dental intervention, this must be done to address patient discomfort and obtain an occlusion that is stable. It is important to bear in mind that dysfunctional patients have a lower adaptive capability to occlusal changes because they seem to be more vigilant on their occlusion and are easily disturbed by occlusal instability. Therefore, occlusal and/or orthodontic treatment has to be performed according to the rules that allow an 'ideal and stable' result to be achieved.

Several therapeutic protocols have been suggested for TMD management. As a consequence of the multifactorial aetiology, multidisciplinary non-invasive therapy

is generally suggested, with reversible treatments for TMD problems. Therefore, treatments should address not only the physical diagnosis, but also the psychological distress and the psychosocial dysfunction found in patients affected with chronic pain conditions (118). Indeed, case severity and chronicity represent critical factors in the decision-making process. When severe pain is present, occlusal treatments (such as orthodontics and prosthodontics) have to be postponed until symptoms are improved. There is a current consensus on treatment strategies being reversible. This therapeutic approach is supported by evidence showing that no treatment modality has been proven better than others. Long-term follow-up of patients with TMD shows that 75–85% of the patients with chronic pain are cured or improve significantly irrespective of the treatment modality used (119).

With regard to TMJ dysfunction, the treatment goals should of course be to reduce pain and to improve function. The reversible therapies commonly used for the management of TMJ dysfunction include physiotherapy (to improve movements and function), pharmacotherapy (anti-inflammatory, antidepressants etc.), occlusal therapy (occlusal appliances) and psychological therapy (cognitive behavioural therapy). These modalities can be offered together or as a single management strategy (120, 121). Intraoral appliances, such as occlusal stabilization splints, have been for many decades the main treatment for jaw dysfunction and continue to be a common treatment modality. Several hypotheses have been suggested to explain their action, but scientific validation is still lacking. Therefore, it is difficult to establish the efficacy of splints in the management of TMDs. Occlusal therapy should be considered only to address TMD patient discomfort with occlusion.

It must be stressed that for the vast majority of patients with TMD, the prognosis is favourable. Therefore, it is important to develop a tailored treatment protocol aiming to manage pain and function. Unsuccessfully treated patients with TMD are frequently highly disabled by the pain and should be included in a comprehensive pain management protocol.

References

1. de Leeuw R (ed) Orofacial pain; guidelines for assessment, diagnosis, and management, 4th edn. Chicago: Quintessence Pub. Co.; 2008, 129–204.

2. Ekberg E, Vallon D, Nilner M. The efficacy of appliance therapy in patients with temporomandibular disorders of mainly myogenous origin. A randomized, controlled, short-term trial. *J Orofac Pain*. 2003;17:133–139.
3. Kurita H, Ohtsuta A, Kurashina K, Kopp S. A study of factors for successful splint capture of anteriorly disc displaced Temporomandibular joint disc with disc repositioning appliance. *J Oral Rehab*. 2001;28:651–657.
4. De Boever JA, Carlsson GE, Klineberg IJ. Need for occlusal therapy and prosthodontic treatment in the management of temporomandibular disorders. Part I. Occlusal interferences and occlusal adjustment. *J Oral Rehab*. 2000;27:367–379.
5. De Boever JA, Carlsson GE, Klineberg IJ. Need for occlusal therapy and prosthodontic treatment in the management of temporomandibular disorders. Part II. Tooth loss and prosthodontic treatment. *J Oral Rehab*. 2000;27:647–659.
6. Sadowsky C, Theisen TA, Sakols EI. Orthodontic treatment and temporomandibular joint sounds –a longitudinal study. *Am J Orthod Dentofacial Orthop*. 1991;99:441–447.
7. Egermark I, Blomqvist JE, Cromvik U, Isaksson S. Temporomandibular dysfunction in patients treated with orthodontics in combination with orthognathic surgery. *Eur J Orthod*. 2000;22:537–544.
8. Luther F. TMD and occlusion part I. Damned if we do? Occlusion: the interface of dentistry and orthodontics. *Br Dent J*. 2007;13:202–209.
9. Reynders RM. Orthodontics and temporomandibular disorders: a review of the literature (1966–1988). *Am J Orthod Dentofacial Orthop*. 1990;97:463–471.
10. Pollack B. Cases of note. Michigan jury awards \$850,000 on ortho case: a tempest in a teapot. *Am J Orthod Dentofacial Orthop*. 1988;94:358–360.
11. Magnusson T, Carlsson GE, Egermark I. Changes in clinical signs of craniomandibular disorders from the age of 15 to 25 years. *J Orofac Pain*. 1994;8:207–215.
12. LeResche L. Epidemiology of Temporomandibular disorders: implication for investigation of etiologic factors. *Crit Rev Oral Biol Med*. 1997;8:291–305.
13. Sackett DL, Rosenberg WM. The need for evidence-based medicine. *J R Soc Med*. 1995;88:620–624. Review.
14. Costen JB. A syndrome of ear and sinus symptoms dependent upon disturbed function of the temporomandibular joint. *Ann Otol Rhinol Laryngol*. 1934;43:1–15.
15. Ramfjord SP. Bruxism, a clinical and electromyographic study. *J Am Dent Assoc*. 1961;62:21–44.
16. Ash MM, Ramfjord SP. Occlusion. 4th edn. Philadelphia: Saunders; 1995.
17. Dawson PE. Evaluation, diagnosis and treatment of occlusal problems. 2nd edn. Louis: Mosby; 1998:434–456.
18. Kirveskari P, Alanen P, Jämsä T. Association between craniomandibular disorders and occlusal interferences in children. *J Prosthet Dent*. 1992;67:692–696.
19. Kirveskari P, Jämsä T. Health risk from occlusal interferences in females. *Eur J Orthod*. 2009;31:490–495.
20. Belser UC, Hannam AG. The influence of altered working-side occlusal guidance on masticatory muscles and related jaw movement. *J Prosthet Dent*. 1985;53:406–413.
21. Ikeda T, Nakano M, Bando E, Suzuki A. The effect of light premature occlusal contact on tooth pain threshold in humans. *J Oral Rehabil*. 1998;25:589–595.
22. Kobayashi Y. Influences of occlusal interference on human body. *J Int Coll Dent*. 1982;13:56–64.
23. McGlynn FD, Bichajian C, Tira DE, Lundeen HC, Mahan PE, Nicholas BV. The effect of experimental stress and experimental occlusal interference on masseteric EMG activity. *J Craniomandib Disord*. 1989;3:87–92.
24. Ingervall B, Carlsson GE. Masticatory muscle activity before and after elimination of balancing side occlusal interference. *J Oral Rehabil*. 1982;9:183–192.
25. Sheikholeslam A, Riise C. Influence of experimental interfering occlusal contacts on the activity of the anterior temporal and masseter muscles during submaximal and maximal bite in the intercuspal position. *J Oral Rehabil*. 1983;10:207–214.
26. Riise C, Sheikholeslam A. Influence of experimental interfering occlusal contacts on the activity of the anterior temporal and masseter muscles during mastication. *J Oral Rehabil*. 1984;11:325–333.
27. Christensen LV, Rassouli NM. Experimental occlusal interferences. Part I. A review. *J Oral Rehabil*. 1995;22:515–520.
28. Christensen LV, Rassouli NM. Experimental occlusal interferences. Part II. Masseteric EMG responses to an intercuspal interference. *J Oral Rehabil*. 1995;22:521–531.
29. Clark GT, Tsukiyama Y, Baba K, Watanabe T. Sixty-eight years of experimental occlusal interference studies. What have we learned? *J Prosthet Dent*. 1999;82:704–713.
30. Michelotti A, Farella M, Gallo LM, Veltri A, Palla S, Martina R. Effect of occlusal interferences on habitual activity of human masseter. *J Dent Res*. 2005;84:644–648.
31. Le Bell Y, Jämsä T, Korri S, Niemi PM, Alanen P. Effect of artificial occlusal interferences depends on previous experience of temporomandibular disorders. *Acta Odontol Scand*. 2002;60:219–222.
32. Le Bell Y, Niemi PM, Jämsä T, Kylmälä M, Alanen P. Subjective reactions to intervention with artificial interferences in subjects with and without a history of temporomandibular disorders. *Acta Odontol Scand*. 2006;64:59–63.
33. Cao Y, Xie QF, Li K, Light AR, Fu KY. Experimental occlusal interference induces long-term masticatory muscle hyperalgesia in rats. *Pain*. 2009;144:287–293.
34. McDermid AJ, Rollman GB, McCain GA. Generalized hypervigilance in fibromyalgia: evidence of perceptual amplification. *Pain*. 1996;66:133–144.
35. Hollins M, Harper D, Gallagher S, Owings EW, Lim PF, Miller V *et al*. Perceived intensity and unpleasantness of cutaneous and auditory stimuli: an evaluation of the generalized hypervigilance hypothesis. *Pain*. 2009;141:215–221.
36. Raphael KG, Marbach JJ, Gallagher RM. Somatosensory Amplification and Affective Inhibition Are Elevated in Myofascial Face Pain. *Pain Med*. 2000;1:247–253.
37. Thompson JR. Temporomandibular disorders: diagnosis and treatment. In: Sarnat BG, ed. *The temporomandibular joint*. 2nd edn. Springfield, IL: Charles C Thomas; 1964:146–184.

38. Greene CS, Laskin DM. Long-term status of TM clicking in patients with myofascial pain and dysfunction. *J Am Dent Assoc.* 1988;117:461–465.
39. John MT, Hirsch C, Drangsholt MT, Mancl LA, Setz JM. Overbite and overjet are not related to self-report of Temporomandibular Disorder Symptoms. *J Dent Res.* 2002;81:164–169.
40. Hirsch C, John MT, Drangsholt MT, Mancl LA. Relationship between overbite/overjet and clicking or crepitus of the temporomandibular joint. *J Orofac Pain.* 2005;19:218–225.
41. O'Byrne BL, Sadowsky C, Schneider B, BeGole EA. Evaluation of mandibular asymmetry in adults with unilateral posterior crossbite. *Am J Orthod Dentofacial Orthop.* 1995;107:394–400.
42. Hesse KL, Artun J, Joondeph DR, Kennedy DB. Changes in condylar position and occlusion associated with maxillary expansion for correction of functional unilateral posterior crossbite. *Am J Orthod Dentofacial Orthop.* 1997;111:410–418.
43. Nerder PH, Bakke M, Solow B. The functional shift of the mandible in unilateral posterior crossbite and the adaptation of the temporomandibular joints: a pilot study. *Eur J Orthod.* 1999;21:155–166.
44. Pinto AS, Buschang PH, Throckmorton GS, Chen P. Morphological and positional asymmetries of young children with functional unilateral posterior crossbite. *Am J Orthod Dentofacial Orthop.* 2001;120:513–520.
45. Sato C, Muramoto T, Soma K. Functional lateral deviation of the mandible and its positional recovery on the rat condylar cartilage during the growth period. *Angle Orthod.* 2006;76:591–597.
46. Lippold C, Hoppe G, Moiseenko T, Ehmer U, Danesh G. Analysis of condylar differences in functional unilateral posterior crossbite during early treatment – a randomized clinical study. *J Orofac Orthop.* 2008;69:283–296.
47. Troelstrup B, Møller E. Electromyography of the temporalis and masseter muscles in children with unilateral cross-bite. *Scand J Dent Res.* 1970;78:425–430.
48. Sonnesen L, Bakke M, Solow B. Bite force in pre-orthodontic children with unilateral crossbite. *Eur J Orthod.* 2001;23:741–749.
49. Kiliaridis S, Mahboubi PH, Raadsheer MC, Katsaros C. Ultrasonographic thickness of the masseter muscle in growing individuals with unilateral crossbite. *Angle Orthod.* 2007;77:607–611.
50. Piacino MG, Talpone F, Dalmaso P, Debernardi C, Lewin A, Bracco P. Reverse-sequencing chewing patterns before and after treatment of children with a unilateral posterior crossbite. *Eur J Orthod.* 2006;28:480–484.
51. Piacino MG, Farina D, Talpone F, Merlo A, Bracco P. Muscular activation during reverse and non-reverse chewing cycles in unilateral posterior crossbite. *Eur J Oral Sci.* 2009;117:122–128.
52. Sonnesen L, Bakke M. Bite force in children with unilateral crossbite before and after orthodontic treatment. A prospective longitudinal study. *Eur J Orthod.* 2007;29:310–313.
53. Kecik D, Kocadereli I, Saatci I. Evaluation of the treatment changes of functional posterior crossbite in the mixed dentition. *Am J Orthod Dentofacial Orthop.* 2007;131:202–215.
54. Dong Y, Wang XM, Wang MQ, Widmalm SE. Asymmetric muscle function in patients with developmental mandibular asymmetry. *J Oral Rehabil.* 2008;35:27–36.
55. Valentino B, Melito F. Functional relationship between the muscles of mastication and the muscles of the leg. An electromyographic study. *Surg Radiol Anat.* 1991;13:33–37.
56. Thilander B, Wahlund S, Lennartsson B. The effect of early interceptive treatment in children with posterior crossbite. *Eur J Orthod.* 1984;6:25–34.
57. Harrison JE, Ashby D. Orthodontic treatment for posterior crossbites. *Cochrane Database Syst Rev.* 2001;1:1–25.
58. Rilo B, da Silva JL, Mora MJ, Cadarso-Suárez C, Santana U. (2008) Midline shift and lateral guidance angle in adults with unilateral posterior crossbite. *Am J Orthod Dentofacial Orthop.* 2008;133:804–808.
59. Wilkinson TM. The lack of correlation between occlusal factors and TMD. In: McNeil C, ed. *Current controversies in temporomandibular disorders.* California: Quintessence Publishing; 1991:90–94.
60. Pullinger AG, Seligman DA, Gornbein JA. A multiple logistic regression analysis of the risk and relative odds of temporomandibular disorders as a function of common occlusal features. *J Dent Res.* 1993;72:968–979.
61. Egermark I, Magnusson T, Carlsson GE. A 20-year follow-up of signs and symptoms of temporomandibular disorders and malocclusions in participants with and without orthodontic treatment in childhood. *Angle Orthod.* 2003;73:109–115.
62. Buranastidporn B, Hisano M, Soma K. Effect of biomechanical disturbance of the temporomandibular joint on the prevalence of internal derangement in mandibular asymmetry. *Eur J Orthod.* 2006;28:199–205.
63. Farella M, Michelotti A, Iodice G, Milani S, Martina R. Unilateral posterior crossbite is not associated with TMJ clicking in young adolescents. *J Dent Res.* 2007;86:137–141.
64. Arat FE, Arat ZM, Tompson B, Tanju S. Muscular and condylar response to rapid maxillary expansion. Part 3: magnetic resonance assessment of condyle-disc relationship. *Am J Orthod Dentofacial Orthop.* 2008;133:830–836.
65. Masi M, Lederman HM, Yamashita HK, de ArrudaAldar LA. Temporomandibular joint evaluation with magnetic resonance imaging in children with functional unilateral posterior crossbite treated with rapid maxillary expansion. *Am J Orthod Dentofacial Orthop.* 2009;136:206–217.
66. Hill AB. The environment and disease: association or causation? *Proc R Soc Med.* 1965;58:295–300.
67. Obrez A, Stohler CS. Jaw muscle pain and its effects on gothic arch tracing. *J Prosthet Dent.* 1996;75:393–398.
68. LeResche L, Mancl L, Sherman JJ, Gandara B, Dworkin SF. Changes in temporomandibular pain and other symptoms across the menstrual cycle. *Pain.* 2003;106:253–261.
69. LeResche L, Sherman JJ, Huggins K, Saunders K, Mancl LA, Lentz G *et al.* Musculoskeletal orofacial pain and other signs

- and symptoms of temporomandibular disorders during pregnancy: a prospective study. *J Orofac Pain*. 2005;19:193–201.
70. McNamara JA Jr, Seligman DA, Okeson JP. Occlusion, orthodontic treatment, and temporomandibular disorders: a review. *J Orofac Pain*. 1995;9:73–90.
 71. McLaughlin RP, Bennett JC. The extraction – nonextraction dilemma as it relates to TMD. *Angle Orthod*. 1995;63:175–186.
 72. Spahl TJ, Witzig JW. The clinical management of basic maxillofacial orthopedic appliances I. Mechanics, Littleton (MA): PSG Publishing; 1987.
 73. O' Connor BM. Contemporary trends in orthodontic practice: a national survey. *Am J Orthod Dentofacial Orthop*. 1993;103:163–170.
 74. Gateno J, Anderson PB, Xia JJ, Horng JC, Teichgraber JF, Liebschner MAK. A comparative assessment of mandibular condylar position in patients with anterior disc displacement of the Temporomandibular joint. *J Oral Maxillofac Surg*. 2004;62:39–43.
 75. Bonilla-Aragon H, Tallents RH, Katzberg RW, Kirkanides S, Moss ME. Condyle position as a predictor of temporomandibular joint internal derangement. *J Prosthet Dent*. 1999;82:205–208.
 76. Keshvad A, Winstanley RB. An appraisal of the literature on centric relation. Part III. *J Oral Rehab*. 2001;28:55–63.
 77. Gallo LM, Gössi DB, Colombo V, Palla S. Relationship between kinematic center and TMJ anatomy and function. *J Dent Res*. 2008;87:726–730.
 78. Rinchuse DJ, Kandasamy S. Myths of orthodontic gnathology. *Am J Orthod Dentofacial Orthop*. 2009;136:322–330.
 79. Chen YJ, Gallo LM, Meler D, Palla S. Individualized oblique-axial magnetic resonance imaging for improved visualization of mediolateral TMJ disc displacement. *J Orofac Pain*. 2000;14:128–139.
 80. Dibbets JM, van der Weele LT. Long-term effects of orthodontic treatment, including extraction, on signs and symptoms attributed to CMD. *Eur J Orthod*. 1992;14:16–20.
 81. Henrikson T, Nilner M. Temporomandibular disorders and the need for stomatognathic treatment in orthodontically treated and untreated girls. *Eur J Orthod*. 2000;22:283–292.
 82. Rey D, Oberti G, Baccetti T. Evaluation of temporomandibular disorders in Class III patients treated with mandibular cervical headgear and fixed appliances. *Am J Orthod Dentofacial Orthop*. 2008;133:379–381.
 83. Pahkala R, Heino J. Effects of sagittal split ramus osteotomy on temporomandibular disorders in seventy-two patients. *Acta Odontol Scand*. 2004;62:238–244.
 84. Westermark A, Shayeghi F, Thor A. Temporomandibular dysfunction in 1,516 patients before and after orthognathic surgery. *Int J Adult Orthodon Orthognath Surg*. 2001;16:145–151.
 85. Kerstens HC, Tuinzing DB, van der Kwast WA. Temporomandibular joint symptoms in orthognathic surgery. *J Craniomaxillofac Surg*. 1989;17:215–218.
 86. Wolford LM, Reiche-Fischel O, Mehra P. Changes in temporomandibular joint dysfunction after orthognathic surgery. *J Oral Maxillofac Surg*. 2003;61:655–660.
 87. Abrahamsson C, Ekberg EK, Henrikson T, Bondemark L. Alterations of temporomandibular disorders before and after orthognathic surgery. *Angle Orthod*. 2007;77:729–734. Review.
 88. Farella M, Michelotti A, Bocchino T, Cimino R, Laino A, Steenks MH. Effects of orthognathic surgery for class III malocclusion on signs and symptoms of temporomandibular disorders and on pressure pain thresholds of the jaw muscles. *Int J Oral Maxillofac Surg*. 2007;36:583–587.
 89. Kim MR, Graber TM, Viana MA. Orthodontics and temporomandibular disorder: a meta-analysis. *Am J Orthod Dentofacial Orthop*. 2002;121:438–446.
 90. Luther F. TMD and occlusion part II. Damned if we don't? Functional occlusal problems: TMD epidemiology in a wider context. *Br Dent J*. 2007;13:210–216.
 91. Mohlin B, Axelsson S, Paulin G, Pietilä T, Bondemark L, Brattström V *et al*. TMD in relation to malocclusion and orthodontic treatment. *Angle Orthod*. 2007;77:542–548.
 92. Macfarlane T, Kenealy P, Kingdon A, Mohlin B, Pilley R, Richmond S *et al*. Twenty-year cohort study of health gain from orthodontic treatment: temporomandibular disorders. *Am J Orthod Dentofacial Orthop*. 2009;135:692.
 93. Diatchenko L, Slade GD, Nackley AG, Bhalang K, Sigurdsson A, Belfer I *et al*. Genetic basis for individual variations in pain perception and the development of a chronic pain condition. *Hum Mol Genet*. 2005;14:135–143.
 94. Slade G, Diatchenko L, Ohrbach R, Maixner W. Orthodontic Treatment, Genetic Factors and Risk of Temporomandibular Disorder. *Semin Orthod*. 2008;14:146–156.
 95. Machen DE. Legal aspects of orthodontic practice: risk management concepts. Excellent diagnostic informed consent practice and record keeping make a difference. *Am J Orthod Dentofacial Orthop*. 1990;98:381–382.
 96. Machen DE. Legal aspects of orthodontic practice: risk management concepts. Disposing of your orthodontic practice: be careful. *Am J Orthod Dentofacial Orthop*. 1991;99:486–487.
 97. Michelotti A, De Wijer A, Steenks MH, Farella M. Home-exercise regimes for the management of non-specific temporomandibular disorders. *J Oral Rehabil*. 2005;32:779–785.
 98. Michelotti A, Farella M, Martina R. Sensory and motor changes of the human jaw muscles during induced orthodontic pain. *Eur J Orthod*. 1999;21:397–404.
 99. Sessle BJ. Acute and chronic craniofacial pain: brainstem mechanisms of nociceptive transmission and neuroplasticity, and their clinical correlates. *Crit Rev Oral Biol Med*. 2000;11:57–91.
 100. Mørch CD, Hu JW, Arendt-Nielsen L, Sessle BJ. Convergence of cutaneous, musculoskeletal, dural and visceral afferents onto nociceptive neurons in the first cervical dorsal horn. *Eur J Neurosci*. 2007;26:142–154.
 101. Obwegeser HL, Makek MS. Hemimandibular hyperplasia–hemimandibular elongation. *J Maxillofac Surg*. 1986;14:183–208.
 102. Nitzan DW, Katsnelson A, Bermanis I, Brin I, Casap N. The clinical characteristics of condylar hyperplasia: experience with 61 patients. *J Oral Maxillofac Surg*. 2008;66:312–318.

103. Kjellberg H, Ekestubbe A, Kiliaridis S, Thilander B. Condylar height on panoramic radiographs. A methodologic study with a clinical application. *Acta Odontol Scand.* 1994;52:43–50.
104. Deleurant Y, Zimmermann A, Peltomäki T. Hemimandibular elongation: treatment and long-term follow-up. *Orthod Craniofac Res.* 2008;11:172–179.
105. Sarnat BG, Muchnic H. Facial skeletal changes after mandibular condylectomy in growing and adult monkeys. *Am J Orthod.* 1971;60:33–45.
106. Twilt M, Schulten AJ, Verschure F, Wisse L, Prahl-Andersen B, van Suijlekom-Smit LW. Long-term follow-up of temporomandibular joint involvement in juvenile idiopathic arthritis. *Arthritis Rheum.* 2008;59:546–552.
107. Martini G, Baciliero U, Tregnaghi A, Montesco MC, Zulian F. Isolated temporomandibular synovitis as unique presentation of juvenile idiopathic arthritis. *J Rheumatol.* 2001;28:1689–1692.
108. Billiau AD, Hu Y, Verdonck A, Carels C, Wouters C. Temporomandibular joint arthritis in juvenile idiopathic arthritis: prevalence, clinical and radiological signs, and relation to dentofacial morphology. *J Rheumatol.* 2007;34:1925–1933.
109. Twilt M, Schulten AJM, Nicolaas P, Dülger A, van Suijlekom-Smit LVA. Facioskeletal changes in children with juvenile idiopathic arthritis. *Ann Rheum Dis.* 2006;65:823–825.
110. Kjellberg H, Fasth A, Kiliaridis S, Wenneberg B, Thilander B. Craniofacial structure in children with juvenile chronic arthritis (JCA) compared with healthy children with ideal or postnormal occlusion. *Am J Orthod Dentofacial Orthop.* 1995;107:67–78.
111. Miller E, Uleryk E, Doria AS. Evidence-based outcomes of studies addressing diagnostic accuracy of MRI of Juvenile Idiopathic Arthritis. *Am J Roentgenol.* 2009;192:1209–1218.
112. Muller L, Kellenberger CJ, Cannizzaro E, Ettlin D, Schraner T, Botl IB *et al.* Early diagnosis of Temporomandibular joint involvement in Juvenile rheumatoid arthritis: a pilot study comparing clinical examination and ultrasound to magnetic resonance imaging. *Reumatology.* 2009;48:680–685.
113. Pedersen TK, Grønhoj J, Melsen B, Herlin T. Condylar condition and mandibular growth during early functional treatment of children with juvenile chronic arthritis. *Eur J Orthod.* 1995;17:385–394.
114. Kjellberg H, Kiliaridis S, Thilander B. Dentofacial growth in orthodontically treated and untreated children with juvenile chronic arthritis (JCA). A comparison with Angle Class II division 1 subjects. *Eur J Orthod.* 1995;17:357–373.
115. Farronato G, Carletti V, Maspero C, Farronato D, Giannini L, Bellintani C. Craniofacial growth in children affected by juvenile idiopathic arthritis involving the temporomandibular joint: functional therapy management. *J Clin Pediatr Dent.* 2009;33:351–357.
116. Twilt M, van der Giesen E, Mober SMLM, ten Cate R, van Suijlekom-Smit LWA. Abrupt condylar destruction of the mandibula in juvenile idiopathic arthritis. *Ann Rheum Dis.* 2003;62:366–367.
117. McCarthy JC, Schreiber J, Karp N, Thorne CH, Grayson BH. Lengthening of the human mandible by gradual distraction. *Plast Reconstr Surg.* 1992;89:1–8.
118. Ohrbach R. Disability assessment in temporomandibular disorders and masticatory system rehabilitation. *J Oral Rehabil.* 2010;37:452–480.
119. Okeson JP. (ed) Management of temporomandibular disorders and occlusion. 6th edn. San Louis: Elsevier Mosby; 2008:334–375.
120. Cairns BE. Pathophysiology of TMD pain – basic mechanisms and their implications for pharmacotherapy. *J Oral Rehabil.* 2010;37:391–410.
121. List T, Axelsson S. Management of TMD: evidence from systematic reviews and meta-analyses. *J Oral Rehabil.* 2010;37:430–451.
122. Gesch D, Bernhardt O, Kirbschus A. Association of malocclusion and functional occlusion with temporomandibular disorders (TMD) in adults: a systematic review of population-based studies. *Quintessence Int.* 2004;35:211–221.
123. Koh H, Robinson PG. Occlusal adjustment for treating and preventing temporomandibular joint disorders. *J Oral Rehabil.* 2004;31:287–292.
124. Forssell H, Kalso E. Application of principles of evidence-based medicine to occlusal treatment for temporomandibular disorders: are there lessons to be learned? *J Orofac Pain.* 2004;18:9–22; discussion 23–32.
125. Koh H, Robinson PG. Occlusal adjustment for treating and preventing temporomandibular joint disorders. *Cochrane Database Syst Rev.* 2003;1:1–23.
126. Hagag G, Yoshida K, Miura H. Occlusion, prosthodontic treatment, and temporomandibular disorders: a review. *J Med Dent Sci.* 2000;47:61–66.
127. De Boever JA, Carlsson GE, Klineberg IJ. Need for occlusal therapy and prosthodontic treatment in the management of temporomandibular disorders. Part I. Occlusal interferences and occlusal adjustment. *J Oral Rehabil.* 2000;27:367–379.
128. Forssell H, Kalso E, Koskela P, Vehmanen R, Puukka P, Alanen P. Occlusal treatments in temporomandibular disorders: a qualitative systematic review of randomized controlled trials. *Pain.* 1999;83:549–560.
129. McNamara JA Jr, Türp JC. Orthodontic treatment and temporomandibular disorders: is there a relationship? Part 1: clinical studies. *J Orofac Orthop.* 1997;58:74–89.
130. McNamara JA Jr. Orthodontic treatment and temporomandibular disorders. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 1997;83:107–117.
131. Clark GT, Tsukiyama Y, Baba K, Simmons M. The validity and utility of disease detection methods and of occlusal therapy for temporomandibular disorders. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 1997;83:101–106.
132. Dibbets JM, Carlson DS. Implications of temporomandibular disorders for facial growth and orthodontic treatment. *Semin Orthod.* 1995;1:258–272.
133. Bales JM, Epstein JB. The role of malocclusion and orthodontics in temporomandibular disorders. *J Can Dent Assoc.* 1994;60:899–905.

134. Türp JC, Greene CS, Strub JR. Dental occlusion: a critical reflection on past, present and future concepts. *J Oral Rehabil.* 2008;35:446–453.
 135. Kirveskari P. The role of occlusal adjustment in the management of temporomandibular disorders. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 1997;83:87–90.
 136. Greene CS. Etiology of temporomandibular disorders. *Semin Orthod.* 1995;1:222–228.
 137. Haber J. Dental treatment of temporomandibular disorders and masticatory muscle pain. *Curr Opin Dent.* 1991;1:507–509.
 138. Baker RW Sr, Catania JA, Baker RW Jr. Occlusion as it relates to TMJ. A study of the literature. *N Y State Dent J.* 1991;57:36–39.
 139. Tsukiyama Y, Baba K, Clark GT. An evidence-based assessment of occlusal adjustment as a treatment for temporomandibular disorders. *J Prosthet Dent.* 2001;86:57–66.
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