JOOR	12531	WILEY	Dispatch: 20.6.17	CE: Kowsalya J
Journal Code	Manuscript No.		No. of pages: 16	PE: Mohanapriya L.

Journal of Oral Rehabilitation 2017

Review
Temporomandibular disorders and dental occlusion. A systematic review of association studies: end of an era?

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SUMMARY To answer a clinical research question: 'is there any association between features of dental occlusion and temporomandibular disorders (TMD)?' A systematic literature review was performed. Inclusion was based on: (i) the type of study, viz., clinical studies on adults assessing the association between TMD (e.g., signs, symptoms, specific diagnoses) and features of dental occlusion by means of single or multiple variable analysis, and (ii) their internal validity, viz., use of clinical assessment approaches to TMD diagnosis. The search accounted for 25 papers included in the review, 10 of which with multiple variable analysis. Quality assessment showed some possible shortcomings, mainly related with the unspecified representativeness of study populations. Seventeen (*N* = 17) articles compared TMD patients with non-TMD individuals, whilst eight papers compared the features of dental occlusion in individuals with TMD signs/symptoms and healthy subjects in non-patient populations. Findings are quite consistent towards a lack of clinically relevant association between TMD and dental occlusion. Only two (i.e., centric relation [CR]-maximum intercuspation [MI] slide and mediotrusive interferences) of the almost forty occlusion features evaluated in the various studies were associated with TMD in the majority (e.g., at least 50%) of single variable analyses in patient populations. Only mediotrusive interferences are associated with TMD in the majority of multiple variable analyses. Such association does not imply a causal relationship and may even have opposite implications than commonly believed (i.e., interferences being the result, and not the cause, of TMD). Findings support the absence of a disease-specific association. Based on that, there seems to lack ground to further hypothesise a role for dental occlusion in the pathophysiology of TMD. Clinicians are encouraged to abandon the old gnathological paradigm in TMD practice.

KEYWORDS: **dental occlusion, temporomandibular disorders, association, systematic review**

Accepted for publication 6 June 2017

Introduction

The relationship between dental occlusion and temporomandibular disorders (TMD) is still a controversial topic in dentistry. Indeed, whilst communities of oro-facial pain experts seem to have embraced a biopsychosocial model of TMD (1), within the broader context of oro-facial pain conditions (2), professionals focusing on the study and restoration of dental occlusion (i.e., orthodontists, prosthodontists, restorative dentists) are historically less prone to accept concepts that diminish the importance of occlusal dogmas (3). Thus, the occlusion-TMD field is still often source of speculations.

Temporomandibular disorders are a heterogeneous group of conditions affecting the temporomandibular joints (TMJ), the jaw muscles and/or the related structures (4). Their prevalence is not negligible at the general population level (5), and patient populations are characterised by relevant psychosocial

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doi: 10.1111/joor.12531

impairment, which is often unrelated to the physical diagnosis (6).

Dental occlusion is the core of dentistry. Decades of researches have progressively shed light to many issues concerning the management of occlusion in the clinical practice (7). A purported causal relationship between 'malocclusion' and TMDs has been advocated for years by the precepts of gnathology (8), but the occlusal paradigm for TMD has never been convincingly validated (9). Observations that conservative management of TMD symptoms is almost always enough to achieve positive outcomes (10), and that chronic pain subjects are individuals with specific personality, and not occlusal, profiles (11–13), support the concept of neutrality as far as the effects of occlusal therapies on TMDs are concerned (14–16).

Notwithstanding, this did not reduce the impact of occlusion-related issues in the field of TMD and orofacial pain, as easily perceivable with a look at popular information channels. Thus, a gap still exists between the research clinicians and the communities of dental practitioners. A possible explanation is that the association between dental occlusion, and TMDs have never been reviewed systematically. The available knowledge is mainly based on seminal papers and comprehensive reviews, which suggest clinicians to focus on other factors than dental occlusion to manage effectively TMD patients but failed to provide an end point to the gnathological era (17–19). Indeed, on the other hand, the absence of a systematic approach to literature assessment so far may justify some controversial claims that the 'occlusal question' is still unsolved (20, 21).

Based on these premises, this manuscript attempts to review the literature to answer a clinical research question: 'Is there any association between features of dental occlusion and temporomandibular disorders?'

Materials and methods

Search strategy

On 18th January 2017, a systematic search in the medical literature was performed to identify all peer-reviewed English language papers that were relevant to the review's aim. As a first step, a search query 'dental occlusion (MeSH term)' AND 'temporomandibular joint disorders (MeSH term)' were performed within the National Library of Medicine's Medline database to retrieve a list of potentially relevant papers. Limits were set to English language studies on humans, with an available abstract. Based on title and abstract (TiAb) assessment, the studies were selected for full-text retrieval and potential inclusion independently by two of the authors (D.M, L.L.), who also performed data extraction by consensus decision. Both authors contributed to the search expansion by checking for additional papers in the Scopus and Google Scholar databases, in the reference lists of potentially relevant papers, and in their own personal and institutional libraries.

The criteria for admittance in the systematic review were based on: (i) the type of study, viz., clinical studies on human adult populations assessing the association between temporomandibular disorders (e.g., signs, symptoms, specific diagnoses) and features of dental occlusion by means of single or multiple variable analysis, and (ii) their internal validity, viz., use of validated clinical or radiological assessment approaches to TMD diagnosis. Investigations with case–control design (selected populations of TMD patients versus non-TMD individuals) as well as studies assessing the TMD-dental occlusion association at the general population level (i.e., non-patient populations) were both included. Studies on self-reported TMD diagnosis and/or unclear protocols to assess occlusal features were excluded.

Systematic assessment of papers

The methodological characteristics of the selected papers were assessed based on a format that enabled a structured summary of the articles in relation to four main issues, viz., 'P' – patients/problem/population, 'I' – intervention, 'C' – comparison and 'O' – outcome (PICO), for each of which specific questions were constructed (22).

For each article, the study population ('P') was described based on the criteria for inclusion and the demographic features of the non-TMD individuals. The study design was described in the section reserved to questions on the study intervention ('I'), and information was gathered on the type and number of occlusal features under investigation. The comparison criterion ('C') was based on the description of the TMD patients. The study outcome ('O') was evaluated in relation to the measures of association between the assessed occlusal features and TMD, either with single or multiple variable analyses.

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Quality assessment

Critical appraisal of studies included in the review was performed based on the Newcastle-Ottawa Scale (NOS) for case–controls studies. NOS assesses the quality of reviewed studies by evaluating eight items concerning the Selection, Comparability and Exposure categories.

The Selection category consists of four items: case definition, representativeness of cases, selection of controls and definition of controls. In this review, case definition was considered adequate when cases (i.e., TMD patients) were identified with clinical and/or imaging assessment for TMD status; case representativeness was judged positively when they were recruited consecutively; selection of controls was endorsed for community samples; definition of controls was considered adequate when they had no history and no current presence of TMD signs and/or symptoms.

The Comparability category is made of a single item evaluating the comparability of cases and controls based on the design or analysis. The study was endorsed positively if it controls for dental occlusal variables by adopting a multiple variable design and/or it controls for additional factors (e.g., bruxism, psychosocial factors).

The exposure category consists of three items, assessing the ascertainment of exposure (i.e., dental occlusion features), the use of the same method of ascertainment for cases and controls, and the non-response rate. Ascertainment was considered adequate if the assessment of dental occlusion was based on clinical examination and/or evaluation of dental casts, for both cases and controls. The non-response rate item was endorsed positively when it was clearly specified the number of non-respondent individuals with respect to the total of invited/recruitable people.

Based on the above, a study can be awarded a maximum of one star for each item within the Selection and Exposure categories. A maximum of two stars can be given for Comparability. Thus, the highest quality studies are assigned a score of 9.

Results

Search results

The search allowed identifying 1670 citations in the Medline database, 848 of which were excluded when search limits were applied. Thus, 822 citations were screened for eligibility. As shown in Fig. 1, after excluding the citations that were clearly not pertinent for the review's aim based on their title and abstract, 46 papers were retrieved in full text and were assessed to reach consensus as to include/exclude the

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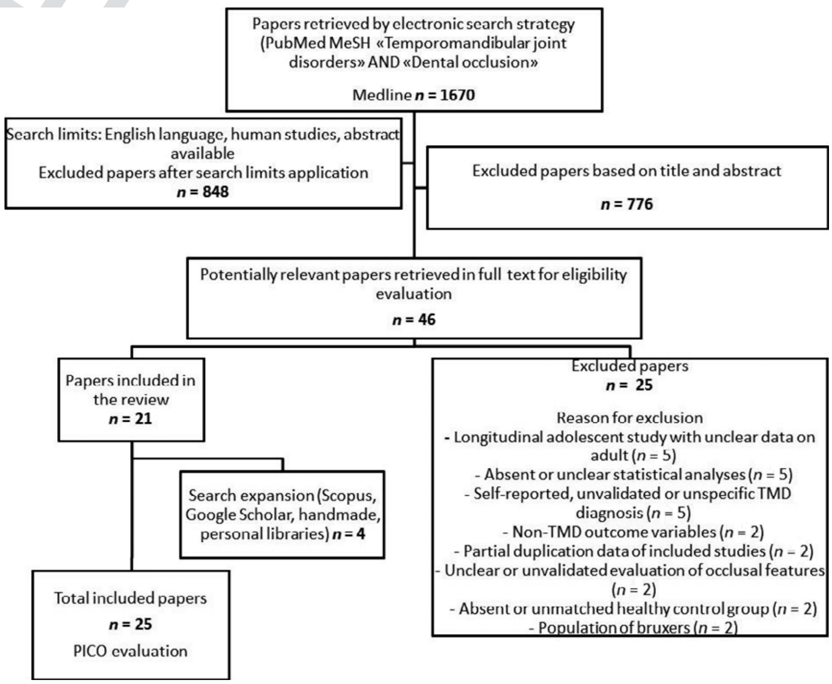

Fig. 1. Flow chart of search strategy and results.

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papers for/from systematic assessment. Consensus decision was to exclude 25 of the 46 papers. Reasons for exclusion were described in Table 1. Search expansion strategies allowed including four additional papers, thus accounting for a total of 25 papers included in the review (48–72).

Table 1. Excluded papers after full-text reading

Study first author, year	Reason for exclusion	Main finding(s) – TMD/occlusion
Egermark, 1987 (23)	Longitudinal study on adolescents, unclear data on adulthood	Unilateral contact in ICP at 20 years associated with TMJ sounds
Runge, 1989 (24)	No statistical analysis	Dental occlusion features do not seem related with TMJ click
Al-Hadi, 1993 (25)	No validated TMD criteria, unclear statistical analysis	Single variable: association between Class II-1 and TMD
Christensen, 1996 (26)	Unclear 'TMD' criteria (click sound?), no statistical analysis	Similar prevalence of mediotrusive tooth guidance in subjects with and without joint sounds
Donegan, 1996 (27)	Unclear 'TMD' criteria (click sound?), no statistical analysis	Similar prevalence of canine guidance in subjects with and without joint sounds
Liu, 1997 (28)	Sample containing children and adolescents, unclear data on adulthood	No association between morphologic occlusion and TMD
Minagi, 1997 (29)	Study on TMJ dynamics	Not pertinent
Ciancaglini, 1999(30)	Study on occlusal support, no validated TMD criteria	Multiple variable: stiffness of the jaw associated with loss of occlusal support
Pullinger, 2000 (31)	Combined sample of included 1993 and 2006 studies	Significant relative risk for disease (odds ratio >2:1) was mainly associated with infrequent, more extreme ranges of occlusion measurements.
John, 2002(32)	Self-report TMD assessment	No association with overbite and overjet
Fuji, 2003 (33)	No measure of association	Interferences more frequent in the side of pain and clickling
Sarita, 2003 (34)	Study on chewing ability and shortened dental arch	Not pertinent
Pahkala, 2004 (35)	Study on adolescents, unclear data on adulthood	Not pertinent
Mundt, 2005 (36)	Subsample of Gesch *et al.*, 2004	See main paper
Sipila, 2006 (37)	Patients with unspecified facial pain	No relationship between TMD and occlusal variables
Wang, 2007 (38)	Sample of patients with tightly locked occlusion, diagnosed with unspecific criteria	Single variable: association with unspecified TMD
Badel, 2008 (39)	Unmatched age of disc displacement (35·3 years) and control (23·4 years) groups, unclear criteria for measuring occlusal vertical dimension (OVD)	Single variable: association of TMD with reduced OVD and uneven dental contacts, no association with overjet, overbite, non-centred incisor midline
Wang, 2009 (40)	Sample of patients with missing posterior teeth (no controls without missing posterior teeth), generic TMD diagnosis	Multiple variable: number of quadrants with missing posterior teeth associated with TMD
Marklund, 2010 (41)	Longitudinal study on students (non-patients), unspecific TMD/occlusion relationship	Not pertinent
Lauriti, 2013 (42)	Study on adolescents	No association with Angle class, open bite, cross-bite
Manfredini, 2014 (43)	Study on bruxers	Multiple variable: only one significant (molar asymmetry) of 11 occlusal features
Manfredini, 2014 (44)	Study on the role of extreme occlusal features in bruxers	Not pertinent
Manfredini, 2014 (45)	Study on TMD patients, no control group	No association between TMJ click and seven occlusal variables
Baldini, 2015 (46)	Study on occlusion time	Clinically unrelevant differences between TMD and TMD-free
Michelotti, 2016 (47)	Longitudinal study, no standardised evaluation	Single variable: association between click and cross-bite independent on cross-bite correction

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Study findings

Seventeen ($N = 17$) of the included studies had a case–control design, comparing a population of TMD patients with non-TMD individuals, whilst eight papers compared the features of dental occlusion in individuals with TMD signs/symptoms and healthy subjects in non-patient populations. Structured reading of the included articles showed a high variability as far as the occlusal features under evaluation and the TMD diagnosis (i.e., muscle, joint or combined disorders) are concerned. Anterior vertical (i.e., overbite) and horizontal overlap (i.e., overjet) and slide from centric relation (CR) to maximum intercuspation (MI) were the most frequently investigated occlusal features. Multiple variable analysis was performed only in 10 papers, whilst the other investigations provide an evaluation of the association between TMD and some selected occlusal features by means of single variable analysis. Given the heterogeneity of study designs, meta-analysis of data or quality assessment could not be performed. Methodological features and main findings concerning the possible association between dental occlusion and temporomandibular disorders in patients and non-patient populations are summarised in Tables 2 and 3.

In summary, the pattern of described association is quite consistent across studies towards a lack of clinically relevant association between TMD and dental occlusion. Only two (i.e., CR-MI slide and mediotrusive interferences) of the almost forty dental occlusion features that have been evaluated in the different studies are associated with TMD in the majority (i.e., at least 50%) of single variable analyses in patient populations, and only mediotrusive interferences are associated with TMD in the majority of multiple variable analyses, with an OR of 2·45 for myofascial pain (57) and 2·14 for disc displacement (64). Other potential clinically relevant odds ratio (OR) for TMD (i.e., higher than 2) in multiple variable analysis are reported occasionally. Summary of findings per each of the most frequently investigated occlusal feature is reported in Table 4.

Quality assessment

Of the 25 papers included in the review, only two received an 8-star score. The majority of papers felt within the 4- to 6-star range. The most common shortcomings were the unspecified representativeness of the cases and unclear non-response rate. Thus, when considering the quality of the selected articles, the assessment showed the moderate level of the reviewed articles as well as their qualitative homogeneity. However, their methodological heterogeneity prevented a meta-analysis of data (Table 5).

Discussion

For years, the focus of dental professionals approaching patients with temporomandibular disorders has been solely based on the assessment and correction of purported abnormalities of dental occlusion (7). Over the past few decades, emerging evidence has grown in support of a biopsychosocial model of TMD pain (73). Notwithstanding that, it seems that the new paradigm diminishing the role of occlusal factors has not been fully accepted by some dental clinicians. There are several possible explanations for this resistance.

First, the dental profession has historically played a primary role as the caregivers for TMD patients. In addition, financial disincentives associated with the reduced importance of dental occlusion as well as patients' expectations to receive a dentally oriented treatment contribute to limit the acceptance of other concepts and practices. Finally, clinical observations of paradox effectiveness of seemingly occlusally oriented therapies (e.g., oral appliances) have persuaded many clinicians to continue using those approaches. Such difficulties can be easily appraised by browsing the Internet and giving a look at the number of congresses, events and technological devices that still focus on the search for an ideal occlusion in 'dysfunctional' patients. Speculative theories on the relationship between body posture and occlusal abnormalities, which have been refuted by all reviews on the topic (18, 74), best exemplify the situation. On the other hand, a definitive summary of the relationship between TMD and dental occlusion has not been provided so far. The heterogeneity of literature as far as the study designs and research methods is concerned may explain why most current state of the art reviews are more narrative than systematic (17).

A cause-and-effect relationship between two phenomena can be hypothesised with the accomplishment of a set of criteria for causality (e.g., strong and consistent association; temporality; theoretical and

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Table 2. Summary of findings of studies comparing the prevalence of dental features in TMD patients vs non-TMD individuals (case–control design)

Study first author, year	Population (P)	Intervention (I)	Comparison (C)	Outcomes (O)
Pullinger, 1993 (48)	N = 147 asymptomatics	11 occlusal features Anterior open bite; unilateral maxillary lingual cross-bite; RCP-ICP slide length; RCP-ICP slide; unilateral RCP contact; overbite; overjet; dental midline discrepancy; number of missing teeth; the greater of the mesio-distal intermaxillary relationship discrepancies at the first molar location; first molar intermaxillary relationship (right vs. left asymmetry)	Disc Displacement with Reduction (n = 81), Disc Displacement without Reduction (n = 48), Osteoarthrosis with Disc Displacement History (n = 75), Primary Osteoarthrosis (n = 85), and Myalgia Only (n = 124)	Significant associations (per disease) ($P < 0{\cdot}05$) Disc Displacement with Reduction: Unilateral lingual cross-bite; Overbite; Dental midline discrepancy; Missing posterior teeth; RCP-ICP slide length Disc Displacement without Reduction: Unilateral lingual cross-bite; First molar relationship Osteoarthrosis with Disc Displacement History: Anterior open bite; Unilateral lingual cross-bite; Overjet; Missing posterior teeth Primary Osteoarthrosis: Anterior open bite; Overjet; Missing posterior teeth; RCP-ICP slide length Myalgia Only: Anterior open bite; Unilateral lingual cross-bite; Overjet; RCP-ICP slide length Clinically relevant associations (per occlusal factor) (OR>2) Anterior open bite: Osteoarthrosis with disc displacement history OR = 7·39 Primary osteoarthrosis OR = 7·27 Myalgia only OR = 7·55 Unilateral lingual cross-bite: Disc displacement with reduction OR = 3·33 Disc displacement without reduction OR = 2·64
Kahn, 1998 (50)	N = 82 asymptomatics (55 with normal TMJ disc position, 27 with DD)	Two occlusal features Overbite; overjet	N = 263 symptomatics (i.e., TMJ pain) – 221 with DD, 42 with normal TMJ disc position	Single variable ($P < 0{\cdot}05$): Overjet >4 mm

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Table 2. (continued)

Study first author, year	Population (P)	Intervention (I)	Comparison (C)	Outcomes (O)
Kahn, 1999 (51)	*N* = 82 asymptomatics (55 with normal TMJ disc position, 27 with DD)	Three occlusal features Molar relationship; occlusal guidance; Non-working side contacts	*N* = 263 symptomatics (i.e., TMJ pain) – 221 with DD, 42 with normal TMJ disc position	Single variable ($P < 0{\cdot}05$): Canine guidance (Symptomatic DD); Absence of one or more non-working contacts (Symptomatic normal; symptomatic DD)
McFarlane, 2001 (52)	*N* = 196 healthy subjects aged 18–65 years	One occlusal feature Missing posterior teeth	*N* = 131 subjects with “Pain dysfunction syndrome”	Multiple variable: no association
Tallents, 2002 (54)	*N* = 82 asymptomatics (55 with normal TMJ disc position, 27 with DD)	One occlusal feature Missing posterior teeth	*N* = 263 symptomatics (i.e., TMJ pain) – 221 with DD, 42 with normal TMJ disc position	Single variable ($P < 0{\cdot}05$): missing posterior teeth (Symptomatic DD)
Landi, 2004 (57)	*N* = 49 healthy females (m.a. 34·8, range 20–61 years)	Eight occlusal features RCP-MI slide length, vertical overlap, horizontal overlap, unilateral posterior reverse articulation, anterior open occlusal relationship, incisor dental midline discrepancy, mediotrusive interferences, laterotrusive interferences	*N* = 81 females with myofascial pain (m.a. 37·2, range 20–71 years)	Single variable ($P < 0{\cdot}05$): RCP-MI > 2 mm; mediotrusive interferences; laterotrusive interferences Multiple variable ($P < 0{\cdot}05$ and OR): RCP-MI (OR = 2·57); mediotrusive interferences (OR = 2·45)
Hirsch, 2005 (58)	*N* = 573 adults (age 35–44) and 1225 seniors (age 65–74) without TMD	Two occlusal features Overbite, overjet	*N* = 82 adults (age 35–44) and 112 seniors (age 65–74) with joint noise (click or crepitus)	Single variable: no association Multiple variable: no association
Seligman, 2006 (59)	*N* = 47 asymptomatic females (m.a. 41·2 ± 15·48, range 21–74 years)	9 occlusal features RCP-ICP slide length; overbite; overjet; unilateral posterior cross-bite; anterior open bite; incisor dental midline discrepancy; number of unreplaced missing posterior teeth; first molar mesio-distal relationship; right and left first molar position asymmetry	*N* = 124 female patients with intra-capsular TMD – 51 DD, 73 OA (m.a. 35·4 ± 11·89, range 13–72 years)	Single variable ($P < 0{\cdot}05$): RCP-MI slide length; unilateral posterior cross-bite Multiple variable ($P < 0{\cdot}05$ and OR): RCP-MI (OR = 1·33); unilateral posterior cross-bite (OR = 11·67)

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Table 2. (*continued*)

Study first author, year	Population (P)	Intervention (I)	Comparison (C)	Outcomes (O)
Selaimen, 2007 (61)	N = 30 pain-free females (15–60 years)	Eight occlusal features Overbite, overjet, number of anterior teeth, number of posterior teeth, Angle class, bilateral canine guidance on lateral excursion, bilateral canine guidance of protrusion, anterior CR-CO slide	N = 72 myofascial pain females (15–60 years)	Single variable ($P < 0{\cdot}05$): Absence of canine guidance; Angle class II
Takayama, 2008 (63)	N = 970 dental patients aged >25 years	One occlusal feature Occlusal support (Eichner index)	N = 504 TMD patients aged>25 years	Single variable ($P < 0{\cdot}05$): More occlusal support in TMD than dental patients
Chiappe, 2009 (64)	N = 145 healthy subjects (65 males; m.a. 31·0 years)	12 occlusal features Cross-bite, open bite, overbite, scissor bite, overjet, incisor midline, canine Angle class, molar Angle class, slide RCP-ICP, occlusal guidance, mediotrusive interferences, laterotrusive interferences	N = 165 subjects with disc displacement alone (65 males; m.a. 32·5 years)	Single variable ($P < 0{\cdot}05$): slide RCP-ICP, mediotrusive interferences, absence of bilateral canine guidance Multiple variable ($P < 0{\cdot}05$ and OR): absence of bilateral canine guidance (OR = 2·84); mediotrusive interferences (OR = 2·14); slide RCP-ICP (OR = 1·75)
He, 2010 (65)	N = 70 students (20–30 years)	One occlusal feature CR-MI slide	N = 107 pre-treated orthodontic TMD patients (18–32 years)	Single variable ($P < 0{\cdot}05$): CR-MI slide
Manfredini, 2010 (66)	N = 166 pain-free subjects	Eight occlusal features RCP-MI slide length; vertical overlap; horizontal overlap; posterior reverse articulation; anterior open bite; mediotrusive and laterotrusive interferences	N = 110 TMJ pain subjects	Single variable ($P < 0{\cdot}05$): Overjet >4 mm Multiple variable ($P < 0{\cdot}05$ and OR): Overjet >4 mm (OR = 2·83); laterotrusive interferences (OR = 2·67)
Wang, 2012 (67)	N = 31 TMD-free subjects (19–31 years) with normal occlusion	One occlusal feature Pre-mature contact in ICP	N = 31 TMD subjects (19–31 years) with normal occlusion	Single variable ($P < 0{\cdot}05$): Pre-mature contact in ICP
Halalur, 2013 (68)	N = 50 healthy subjects (18–35 years)	Six occlusal features Type of occlusion; CR-CO Slide; Balancing Interferences; Working interferences; Protrusive Interferences; Loss of Vertical height	N = 50 subjects (18–35 years) with at least one TMD signs or symptoms	Single variable ($P < 0{\cdot}05$): group function; CR-CO slide; balancing interferences

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Table 2. (continued)

Study first author, year	Population (P)	Intervention (I)	Comparison (C)	Outcomes (O)
De Sousa, 2015 (70)	*N* = 58 TMD-free subjects aged>15 years	Five occlusal features Anterior open bite; Posterior cross-bite; Overbite ≥4 mm; Overjet ≥5 mm; more than 5 posterior teeth lost	*N* = 42 TMD subjects aged >15	Single variable: no association Multiple variable: no association
Manfredini, 2017 (72)	*N* = 58 TMD-free subjects (aged 20–40 years) without history of orthodontics	Three occlusal features Canine class; molar class; asymmetry	*N* = 96 TMD patients (aged 20–40 years) without history of orthodontics	Single variable: no association

RCP-ICP, retruded contact position-intercuspal position (Note for the readers: This was the past acronym for CR-MI [centric relation-maximum intercuspation] slide); OR, odds ratio; TMJ, temporomandibular joint; DD, disc displacement; OA, osteoarthrosis; CR-CO, centric relation-centric occlusion.

experimental validity; dose-response relationship; specificity, coherence and analogy with available knowledge) (75). Among those criteria, the presence of an association between the two conditions (i.e., the purported causal factor [dental 'malocclusion'} should be significantly more frequent in diseased ['TMD'] than healthy subjects, as well as diseased individuals should have a higher frequency of the purported causal factor than its absence) is the basic pre-requisite to get deeper into the assessment of causal hypothesis. This manuscript has systematically reviewed the literature on the topic, by including all papers that may be pertinent for the assessment of the association between dental occlusion features and TMD, on the premise that such associations are the first requirement for even considering a causal relationship between them.

Findings of this reviews support the absence of consistent, clinically relevant associations between TMD and the various features of dental occlusion. Reported associations were scarce, weak and mainly drawn from studies with a single-variable design. Multiple variable analyses described associations that reached strength for possible clinical relevance only in a few papers on patient(48, 57, 59, 64, 66) or non-patient populations (56, 60). Each of those papers identified no more than two occlusal variables in association with TMD among the full spectrum of features under investigation (i.e., ranging from 6 to 33). Conversely, each of those variables was not associated with TMD in more than a single paper. In short, patterns of association are not consistent across studies and may even be due to chance. Thus, the absence of the fundamental pre-requisite of association between the two phenomena leads to conclude that a causal role for dental occlusion in temporomandibular disorders should not be hypothesised.

Such findings may offer some interesting arguments for discussion. First, there is a scarce literature on the topic, and the quality of reviewed articles was, on average, less than optimal. Such finding contrasts with the number of papers on the different strategies to correct purported abnormalities of dental occlusion by means of orthodontics or prosthodontic treatments and calls into question the ethical principles of medicine (76, 77). Second, there is a wide methodological variability between the different investigations as for the assessed TMD signs and symptoms. The studies adopting multiple variable models, which best depict

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Table 3. Summary of findings of studies comparing the prevalence of dental features in subjects with and without TMD signs/symptoms in selected cohorts of non-patients

Study first author, year	Population (P)	Intervention (I)	Comparison (C)	Outcomes (O)
Hiltunen, 1997(49)	*N* = 301 subjects with normal or mild Helkimo dysfunction index (age 76–86 years)*	One occlusal feature Occlusal support with and without dentures (Eichner index)	*N* = 63 subjects with moderate or severe Helkimo dysfunction index (age 76–86 years)	Single variable: no association
Celic, 2002(53)	*N* = 151 non-patients without TMD (19–28 years)*	Two occlusal features Overbite; overjet	Muscle pain non-patients (*N* = 13), DDR non-patients (*n* = 21), muscle pain + DDR non-patients (*n* = 45)	Single variable ($P < 0{\cdot}05$): Overjet>4 mm (muscle pain; muscle pain + DDR); Overbite >4 mm (DDR; muscle pain + DDR)
Ciancaglini, 2003(55)	*N* = 15 subjects without TMD (19–26 years)	One occlusal feature Number of occlusal contacts	*N* = 15 Subjects with at least 2 TMD signs or symptoms	Single variable: No association
Gesch, 2004(56)	*N* = 2997 general population (20–79 years)	27 occlusal features Upper incisors crowding; lower incisors crowding; labial/lingual position of one or more canines; posterior teeth crowding; spacing; Overjet; Retroclined maxillary incisors; Edge-to-edge bite; Cross-bite anterior; Negative overjet; Distoclusion; Mesioclusion; Mixed occlusion (no specific type); Open bite anterior; Open bite posterior; Deep bite; Bucco-lingually cusp-to-cusp relation (unilateral or bilateral); Cross-bite posterior (unilateral or bilateral); Scissors-bite (unilateral or bilateral); Normal occlusion; Attrition; Non-working side interferences (unilateral or bilateral); Protrusion interferences (unilateral or bilateral); Non-working side contacts (unilateral or bilateral); Protrusion contacts (unilateral or bilateral); Non-working side contacts + wear; lateral contacts on protrusion + wear	*N* = 1292 general population with two or more TMD signs (20–79 years)	Single variable ($P < 0{\cdot}05$): Posterior crowding; Edge-to-edge bite; negative overjet; distocclusion (1 premolar width); bilateral open bite up to 3 mm; Unilateral posterior cross-bite Multiple variable ($P < 0{\cdot}05$ and OR): edge-to-edge bite (OR = 1·5); negative overjet (OR = 2·4); bilateral posterior open bite up to 3 mm (OR = 4·0); unilateral posterior cross-bite (OR = 1·2)
Schmitter, 2007(60)	*N* = 136 asymptomatic females (m.a. 31·05, range 18–65 years)	Six occlusal features Overjet, open bite, overbite, missing posterior teeth, dental attrition, RCP-ICP slide	*N* = 15 age- and sex-matched females with myofascial pain	Multiple variable ($P < 0{\cdot}05$ and OR): Non-occlusion, at least one side (OR = 4·2); open bite (OR = 3·6)

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Table 3. (continued)

Study first author, year	Population (P)	Intervention (I)	Comparison (C)	Outcomes (O)
Witter, 2007(62)	*N* = 83 general population subjects followed up for 9 years (m.a. 40 years at baseline)	One occlusal feature Short dental arch	Subjects with TMD signs symptoms within the study cohort	No differences (short vs complete dental arch)
Ferreira, 2014(69)	*N* = 164 undergraduate students without TMD (age 20·4 years)	Eight occlusal features Slide CR-MI; Mediotrusive interferences; Laterotrusive interferences; Posterior interferences; Overjet; Overbite; Cross-bite; Open bite	*N* = 37 undergraduate students with Muscle or Joint TMD	Single variable: no association
Tinastepe, 2015(71)	*N* = 9 non-patients with TMD (aged 20–45 years)*	One occlusal feature Deep bite	*N* = 51 subjects (aged 20–45 years) without TMD	Single variable: no association

DDR, disc displacement with reduction; RCP-ICP, retruded contact position-intercuspal position (Note for the readers: This was the past acronym for CR-MI [centric relation-maximum intercuspation] slide); OR, odds ratio.

*Data extracted by this review's authors.

the biological system, comprehend a very wide range of morphological and functional occlusal variables. Such a variability of contents makes meta-analysis of findings not possible and limits the generalisation of quality assessment. Despite that, it should be borne in mind that studies performing a single variable assessment of the TMD-occlusion assessment as well as those recruiting general population subjects or selected cohort of non-patients are potentially at high risk of bias. Third, some clinical observations should be made with respect to the possible interpretation of the described weak associations. Indeed, despite the fact that dental literature has predominantly been directed towards the view of dental occlusion as the cause of TMDs, the inverse relationship may even be more plausible and should have been considered to explain the occasionally described association between cross-sectionally observed phenomena. For instance, the association between unilateral cross-bite and TMJ disorders, which was described in three studies, has been recently shown to be independent on the correction of cross-bite (47). This means that in patients with TMJ disorders, the presence of cross-bite is not causative of the joint pathology, but it could be even viewed as the consequence of a certain skeletal morphology. A similar conclusion can be reached in the case of sagittal skeletal profiles that are associated with an increased risk for disc displacement (78). Such suggestion is in line with recent observations that orthodontics is neutral as far as the temporomandibular disorders are concerned (16). Similar suggestions have been proposed also for the purported relationship between anterior open bite and TMJ osteoarthrosis, with the former being the consequence, rather than the cause, of the latter (59). Moreover, the findings of a higher prevalence of CR-MI slide and functional interferences in TMD patients, as reported by a few papers (57, 66), can be explained with the pain-related adaptation of motor functioning, rather than considered the cause of pain (79–81).

In summary, it can be concluded that some significant associations between occlusal variables and TMD have been occasionally described, but they are not consistent across studies (i.e., reported in most researches). Alternative explanations for the presence of such features in TMD patients with respect to their purported causal role (e.g., consequence of peculiar skeletal anatomy or TMJ disease) tended to be ignored by the dental communities over the past few

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Table 4. Summary of findings of studies adopting multiple variable analysis: number of papers reporting the presence and absence of an association with TMD per each of the most frequently investigated occlusal feature. For positive associations, reported OR and the TMD category are put in parentheses

Occlusal features	Non-patient studies	Patient studies
Overjet	Association: $N = 0$	Association $N = 1$ (OR 2·83 for TMJ pain)
	No association: $N = 2$	No association $N = 8$
Overbite	Association: $N = 0$	Association: $N = 0$
	No association: $N = 2$	No association: $N = 10$
Open Bite	Association: $N = 2$ (anterior open bite OR 3·6 for myofascial pain; posterior open bite OR 4·0 for TMD)	Association: $N = 1$ (OR 7·27 for osteoarthrosis)
	No association: $N = 1$	No association: $N = 8$
Unilateral Cross-Bite	Association: $N = 0$	Association: $N = 3$ (OR 3·33 for DDR, OR 2·64 for DDNR, OR 11·67 for intra-capsular TMD)
	No association: $N = 1$	No association: $N = 6$
CR-MI Slide	Association: $N = 0$	Association: $N = 1$ (OR 2·57 for myofascial pain)
	No association: $N = 1$	No association: $N = 8$
Midline Discrepancy	Association: $N = 0$	Association: $N = 0$
	No association: $N = 4$	No association: $N = 8$
Posterior Missing Teeth	Association: $N = 1$ (OR 4·2 for myofascial pain)	Association: $N = 0$
	No association: $N = 1$	No association: $N = 8$
Molar Class	Association: $N = 0$	Association: $N = 0$
	No association: $N = 1$	No association: $N = 5$
Molar Asymmetry	–	Association: $N = 0$
		No association: $N = 5$
Mediotrusive Interferences	Association: $N = 0$	Association: $N = 2$ (OR 2·45 for myofascial pain; OR 2·14 for disc displacement)
	No association: $N = 1$	No association: $N = 1$
Laterotrusive Interferences	Association: $N = 0$	Association: $N = 1$ (OR 2·67 for TMJ pain)
	No association: $N = 1$	No association: $N = 2$

OR, odds ratio; TMJ, temporomandibular joint; DDR, disc displacement with reduction; DDNR, disc displacement without reduction.

decades (3, 7). In addition, epidemiologic studies of dental occlusion have demonstrated that purported malocclusions and occlusal dysharmonies should be viewed as ancillary findings that are also present with the same frequency in non-TMD patients (82). Thus, even the pre-requisite to hypothesise a causal role for dental occlusion in TMD patients, viz., the presence of a strong and consistent association between the two phenomena (i.e., occlusal feature and TMD), is lacking. On the contrary, the literature is strong and consistent to support the role of other factors, such as psychosocial and genetic issues as well as muscle-related overload, in the pathophysiology of temporomandibular disorders (1, 2, 83).

Such observations should ideally lead to an end of the so-called 'gnathological era' of aetiological thinking in the TMD field, in which normal variability in the interindividual features of dental occlusion has been considered a pathological sign. Based on this suggestion, future teaching about these topics for the dental specialties working on the correction of dental occlusion should be introduced in their academic training as well as in their clinical practices.

Conclusions

This manuscript reviewed the literature on the association between features of dental occlusion and temporomandibular disorders. Based on findings, which support the absence of a disease-specific association, there is no ground to hypothesise a major role for dental occlusion in the pathophysiology of TMDs. Dental clinicians are thus encouraged to move forward and abandon the old-fashioned gnathological paradigm.

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Table 5. Quality assessment of reviewed articles based on the Newcastle-Ottawa Scale

	Selection				Comparability	Exposure (Dental Occlusion)		
Study first author, year	Is the case definition adequate?	Representativeness of the cases	Selection of controls	Definition of controls	Comparability of cases and controls on the basis of the design or analysis	Ascertainment of exposure	Same method of ascertainment for cases and controls	Non-response rate
Pullinger, 1993 (48)	★			★	★	★	★	
Hiltunen, 1997 (49)	★	★	★	★		★	★	
Kahn, 1998 (50)	★		★	★		★	★	
Kahn, 1999 (51)	★		★	★		★	★	
McFarlane, 2001 (52)		★	★	★	★	★	★	★
Celic, 2002 (53)	★			★		★	★	
Tallents, 2002 (54)	★		★	★		★	★	
Ciancaglini, 2003 (55)	★			★		★	★	
Gesch, 2004 (56)	★	★	★	★	★	★	★	★
Landi, 2004 (57)	★			★	★	★	★	
Hirsch, 2005 (58)	★	★	★	★	★	★	★	★
Seligman, 2006 (59)	★			★	★	★	★	
Schmitter, 2007 (60)	★			★	★	★	★	
Selaimen, 2007 (61)	★			★	★	★	★	
Witter, 2007 (62)	★			★		★	★	
Takayama, 2008 (63)	★	★		★		★	★	
Chiappe, 2009 (64)	★			★	★	★	★	
He, 2010 (65)				★		★	★	
Manfredini, 2010 (66)	★			★	★★	★	★	
Wang, 2012 (67)	★			★		★	★	
Halalur, 2013 (68)	★			★	★	★	★	
Ferreira, 2014 (69)	★			★	★	★	★	
De Sousa, 2015 (70)	★	★	★	★	★	★	★	
Tinastepe, 2015 (71)	★			★		★	★	
Manfredini, 2017 (72)	★			★	★	★	★	

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Conflicts of interest

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

Funding

The authors did not receive any funding to prepare this manuscript.

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