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Centric relation–intercuspal position discrepancy and its relationship with temporomandibular disorders. A systematic review

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ABSTRACT

Objective: The objective of this study is to assess the relationship between centric relation–intercuspal position discrepancy (CR–ICP discrepancy) and temporomandibular disorders (TMDs), by systematically reviewing the literature.

Materials and methods: A systematic research was performed between 1960 and 2016 based on electronic databases: PubMed, Cochrane Library, Medline, Embase, Scopus, EBSCOhost, BIREME, Lilacs and Scielo, including all languages. Analytical observational clinical studies were identified. Two independent authors selected the articles. PICO format was used to analyze the studies. The Newcastle–Ottawa Scale (NOS) was used to verify the quality of the evidence.

Results: Four hundred and sixty-seven potentially eligible articles were identified. Twenty studies were analyzed, being grouped according to intervention in studies in orthodontic patients ($n = 3$) and studies in subjects without intervention ($n = 17$). Quality of evidence was low, with an average score of 3.36 according to Newcastle–Ottawa Scale. In most studies, the presence of CR–ICP discrepancy is associated with the presence of muscle (pain) and joint disorders (noise, disc displacement, pain, crepitus, osteoarthritis and osteoarthrosis). However, the lack of consistency of the results reported reduces the validity of the studies making it impossible to draw any definite conclusions.

Conclusions: Because of the heterogeneity of the design and methodology and the low quality of the articles reviewed, it is not possible to establish an association between CR–ICP discrepancy and TMD. The consequence of CR–ICP discrepancy on the presence of TMD requires further research, well-defined and validated diagnostic criteria and rigorous scientific methodologies. Longitudinal studies are needed to identify CR–ICP discrepancy as a possible risk factor for the presence of TMD.

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Introduction

The relationship among occlusion, condylar position and temporomandibular disorders (TMDs) has been part of an extensive discussion in dentistry [1]. There is a belief that the discrepancy between the centric relation (CR) and the intercuspal position (ICP) could predispose to the presence of TMDs [2].

In the past, some studies suggested that malocclusion and occlusal interferences were considered as the main factors for predisposition, initiation and perpetuation of TMDs [3–6]. In the 1990s, studies suggested that some occlusal and skeletal characteristics as anterior open bite, unilateral posterior crossbite, overjet greater than 6–7 mm, absence of five or more posterior teeth and CR to maximum intercuspalation (MI) discrepancy greater than 2 mm could be considered occlusal risk factors for TMDs [7–9]. Currently, the evidence has shown no differences between subjects with or without malocclusion and presence of TMDs [10–12].

The concept of CR is controversial in dentistry and its definition has changed over the years. The academy of Prosthodontists defines CR as ‘The maxillomandibular relationship in which the condyles articulate with the thinnest avascular portion of their respective disks with the condyle in the anterior–superior position against the slopes of the articular eminence. This position is independent of teeth contact’ [13]. Dawson described CR as the most comfortable and stable position of the jaw, in which the joints can be subjected to load without causing discomfort [14]. Currently, there are about 26 definitions of CR. However, its definition needs to be oriented clinically to reduce confusion and controversy, so that an adequate definition could improve communication at all levels of dentistry [2,15]. Evidence shows that there is not one ideal position of the condyle in the fossa but a range of normal positions [8,16–19]. Celenza says that there could be several CR positions acceptable [20]. Serrano supports this statement by indicating that CR is not

only a position, but a range of positions [21]. The MI position or ICP is defined as ‘The complete intercuspatation of the opposing teeth independent of condylar position’ [13]. It is also known as centric occlusion (CO): position determined by the teeth, when the patient closes in a position of complete tooth intercuspidation [8,22–26].

CR-ICP discrepancy or centric slide is defined as ‘the movement of the mandible while in CR, from the initial occlusal contact into maximum intercuspatation’ [13]. The neuromusculature places the jaw on the site with the highest number of occlusal contacts without taking into account the final position of the condyle [23,26,27]. Despite this, it is considered that the role of condylar displacement may be a risk factor in the presence of TMD [28]. The controversy would be given by the ideal relationship condyle–fossa when the teeth are in MI [23,27,29], as premature contacts would change the arc of mandibular closure, displacing the condyles to achieve the maxillo-mandibular relationship MI to avoid premature contact [30], which may result in condyle displacement, potentially causing alteration on TMJ structure due to friction, increased intra-articular pressure and muscle tension [31]. Some authors have shown that the presence of occlusal interferences causes an imbalance between the inferior lateral pterygoid muscles and elevator muscles, which triggers muscle hyperactivity leading to the development of TMDs [29,32–34]. Nevertheless, it is not clear how occlusal changes could affect the function of temporomandibular joint (TMJ) [24,35], but the lack of scientific evidence does not support the fact that the condylar position is related to the presence of TMD [36,37].

Orthodontists with gnathologic guidance recommend the use of articulators with study models mounted in CR, in order to establish a match in the treatment of CR-ICP [29]. Thus, they believe in a tolerance of the CR-ICP discrepancy of 1.5 mm in the horizontal (H) and vertical plane (V) and 0.5 mm in the transverse plane (T). Utt et al. [27] found an average of 2.0 mm (H and V) and 0.5 mm (T); and Crawford [30] 1.0 mm (H and V) and 0.5 mm (H).

While some studies would relate occlusal factors with the presence of TMD [38–40], the evidence is not conclusive, showing a high heterogeneity in the design, methodology and diagnostic methods. The aim of the study was to conduct a systematic review to determine if CR-ICP discrepancy is associated with TMDs.

Material and methods

To establish the relationship between CR-ICP discrepancy and presence of TMDs, an electronic search was conducted on 8 May 2016. The databases used were PubMed, Cochrane Library, EBSCOhost, Scopus, Embase, Medline, Bireme, Lilacs and Scielo.

Type of studies

Observational studies, analytical case–control or cohort.

Language of the studies

The search was conducted without limitation of language.

Type of participants

The studies selected for this systematic review included subjects older than 11 years from both genders.

Type of results

Primary outcomes: to determine the relationship between CR-ICP discrepancy and TMDs. *Secondary outcomes:* to determine type of temporomandibular pathology related to CR-ICP discrepancy. To determine the amount of centric discrepancy and TMD.

Data collection

For TMD

Data were collected from studies that showed diagnosis of TMD not limited to any method, with a clear reference to the concept and diagnosis of TMD: research diagnostic for TMDs (RDC/TMD), diagnostic criteria for TMDs (DC/TMD), evaluation according to AAOP guide, Helkimo index, imaging studies (cone beam computed tomography (CBCT) and magnetic resonance imaging (MRI) and other methods), surveys’ studies and/or clinical examination based on signs and symptoms with reference to TMD and others.

For CR-ICP discrepancy

Data collected from studies that determined the presence of CR-ICP discrepancy without limitation of methods: condylar position indicator (CPI), use of articulators with studies mounted models, T-scan, clinical methods, other digital methods and others.

For the identification and selection of the number of potentially eligible studies for this systematic review (N), a specific and individualized search strategy for each database was developed. A semantic field was determined for the term ‘CR-ICP discrepancy or centric slide’ and another semantic field related to the term ‘Temporomandibular Disorders’ (Supplementary material 1).

Database used

1. PubMed database. Filters used: Publication dates: from 1966-01-01 to 2016/05/09.
2. The Cochrane Library. Filters: Publication years: All years; Database: Trials.
3. Embase:Publication dates: to-2016
4. Medline:Publication dates: to-2016
5. BIREME:Publication dates: to-2016
6. Lilacs:Publication dates: to-2016
7. Scielo:Publication dates: to-2016
8. Scopus:Publication dates: 1960 to 2016/Source Type: Journals
9. EBSCOhost:Without limiting publication date

Study selection and data collection

In a first screening, the title and abstract of all potentially eligible articles were listed and evaluated by two

Table 1. Studies retrieved in full text and excluded from the review.

First author (year)	Reason for exclusion
Costea (2016) [42]	Effect of CO-CR discrepancy in orthodontic treatment planning
Ciavarella (2012) [43]	CPI and T-scan analysis in the condylar position and occlusal contacts and forces
Gusmão (2011) [44]	Variation of centric discrepancy by the use of intraoral devices in subjects with TMD
Winocur (2007)[45]	Post orthodontic change of the masticatory muscles
Clark (1998) [46]	No related CR-ICP discrepancy and TMD
Huber (1990) [47]	No related CR-ICP discrepancy and TMD. It evaluates differences between men and women with CR-ICP discrepancy and TMD

CR: centric relation; CO: centric occlusion; CPI: condylar position indicator; ICP: intercuspation position; MI: maximum intercuspation; TMD: temporomandibular disorders.

researchers independently (J. A. and T. J.). The titles of the selected articles were transferred to an Excel table. In a second stage, the full text of articles that potentially met eligibility criteria based on the first screening were assessed independently by the same two researchers (J. A. and T. J.) according to inclusion criteria (case-control or cohort studies, assessing CR-ICP discrepancy, establishing a relationship between the presence of CR-ICP discrepancy and TMD). When no agreement was found, the inclusion of the article within the sample was discussed with a third researcher (P. H.) acted as an arbiter. Articles that met inclusion criteria were included in the review for the final analysis. The reasons why some studies were excluded were recorded in an adjacent column and presented in the results (Table 1). The quality of assessment according to NOS scale [41] was performed by two independent reviewers (V. S. and P. E.).

Extracting data from the studies

The PICO criteria (Population, Intervention, Control groups and Outcome) was used to make the tables of analyzed articles. *Population* (sample size, distribution by gender, age range and standard deviation); *intervention*: without intervention (main variables to compare, related to the topic, statistical analysis, type of method used for the diagnosis of TMD and method for determining discrepancy between CR-ICP); *comparison criteria or control*: (presence of any control group) and *outcomes* (including the answer to the hypothesis, the presence or causal relationship between discrepancy CR-ICP and TMD).

Presentation of results and quality of evidence

The tables were developed with the summary of the main results of the studies analyzed. The quality of evidence was determined by the Newcastle Ottawa-Scale (NOS) [41], which measures the quality of the evidence for case-control and cohort studies, assigning a score ranging from 0 to 9 points. For case-control studies, there were three categories. (1) Selection (4 points), (2) comparability (2 points) and (3) exposure (3 points). To determine the quality of cohort studies, there were also three categories with a level of evidence ranging from 0 to 9 points. The categories were (1) selection (4 points), (2) comparability (2 points) and (3) outcome (3 points). The highest quality achieved is obtained by the items that reached a maximum score of 9.

Results

Four hundred and sixty-seven potentially eligible articles were identified in the first approach in the nine databases used (Supplementary material 1); however, 111 of these articles were excluded because they were duplicates. After reviewing the title and abstract of the remaining 356 studies, 330 articles were excluded due to their non-relevance. Of the 26 articles left, six were eliminated in the reading of the full text for not meeting the inclusion criteria for this systematic review (Table 1). Finally, 20 studies were analyzed. Figure 1 summarizes the results described.

Included studies

Twenty articles were analyzed in this systematic review. According to its design, all were case-control studies. The analysis tables were prepared according to the PICO criteria (Tables 2 and 3). The articles analyzed were summarized according to intervention in (a) CR-ICP discrepancy and TMD in orthodontics patients ($n=3$) and (b) CR-ICP discrepancy and TMD in patients without intervention ($n=17$).

Characteristics of participants

Regarding the gender, three studies included only women in their sample [49,52,60]. The age range in orthodontic patients' studies was 11–29 years and, in the studies of patients without intervention, it was 13–65 years.

Quality assessment

None of the reviewed articles obtained the highest score based on Newcastle-Ottawa Scale. The range of scores was between 2 and 6 with an average of 3.36 points and a median of 3.13 (Tables 4 and 5).

Muscular disorders and CR-ICP discrepancy

One study established the relationship between muscle disorder (defined as myogenic disorder according to Visser et al.) and CR-ICP discrepancy in the transversal plane. The diagnosis of TMD was based on signs and symptoms and used a clinical method to determine CR-ICP discrepancy, obtaining 3.0 points according the NOS scale [61] (Tables 4 and 6).

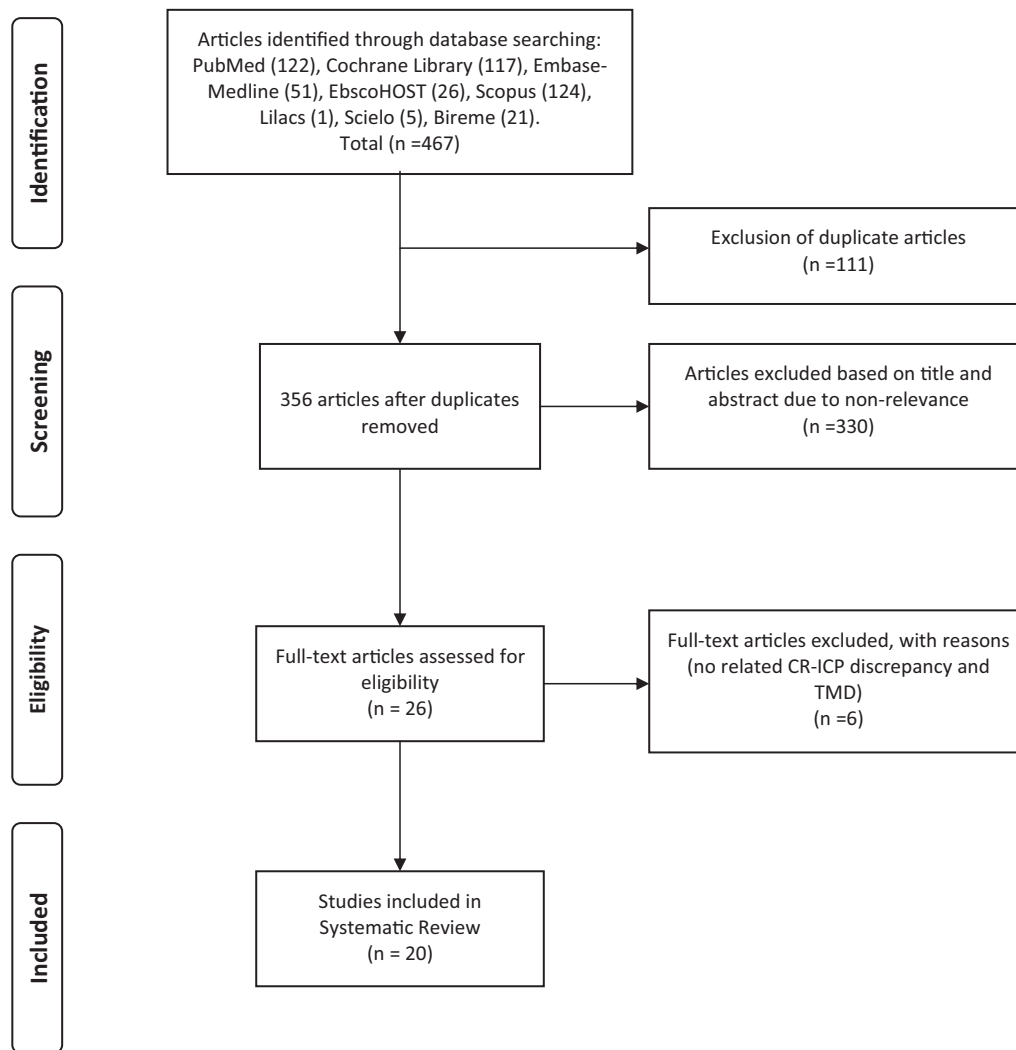


Figure 1. Search method, identification, selection and inclusion of articles.

Joint disorders and CR-ICP discrepancy

Five articles determined a significant association between CR-ICP discrepancy and joint disorder. Three studies concluded that antero-posterior, medial-lateral and asymmetric slides were associated with joint pathology [48,50,62]. The other two articles did not report details of CR-ICP discrepancy [52,53]. The range of scores of articles varied from 2 to 4 points, with a median of 3.0 points. One study used the RDC/TMD, but without establishing a clear diagnosis [53]; two studies used imaging methods for diagnosing disc displacement [52] (MRI) and osteoarthritis [48] (CBCT); Sigaroudi et al. did not specify the method for diagnosing a click in TMJ [50] and Pullinger et al. based their results on the study of signs and symptoms for diagnosing joint click [62]. The methods used to determine CR-ICP discrepancy in these studies were T-scan III [53], clinical [52] mounting articulator [50,62] and three-dimensional TRIMET device [48].

Muscular and joint disorders and CR-ICP discrepancy

Half of the analyzed studies suggested a positive relationship between the presence of CR-ICP discrepancy and muscle and

joint disorders collectively. The score range of studies was between 2 and 6 points with a median of 3.0 according to NOS scale. Diseases found were muscle pain, disc displacement, arthralgia, joint noise, crepitus, osteoarthritis and osteoarthrosis. Only two articles specified the plane in which the discrepancy occurs (antero-posterior, vertical and horizontal) related to the presence of TMD [58,64]. According to the diagnostic method, two studies used the RDC/TMD, two studies the Helkimo index, two studies were based on the presence of signs and symptoms and one article did not specify any method. The methods used to determine CR-ICP discrepancy were clinical [51,53], mounting articulator [30,58,59], T-scan II [31] and Mandibular Kinesiograph [64]. The findings are summarized in Table 6.

Discussion

This systematic review aimed to determine the relationship between CR-ICP discrepancy and presence of TMDs. To that end, 20 analytical observational studies were selected and analyzed.

The analysis of articles comprised studies of patients with and without orthodontic treatment. Two studies in

Table 2. Summary of articles relating the discrepancy between CR-ICP with TMD in subjects with orthodontic treatment (n = 3).

First author (year)	Population	Intervention	Comparison (control group)	Outcome	Conclusions
Yamada (2003) [48]	40 Subjects. 10M, 30F.	TMD diagnostic: CT for TMJ pathology, pain questionnaire, difficulty opening. Clinical examination at the beginning of orthodontic treatment. Centric slide: TRIMET device, tridimensional analysis. IP to RCP analysis. Mann-Whitney U-test analysis and Kruskal-Wallis	BBC group (bilateral bone change) n = 15; 4M; 11F; m.a. 20.1 years. UBC group (unilateral bone change): n = 10; 2M; 8F. m.a: 22.6 years. NBC group (no bone change) n = 15; 30 joints 4M, 11F; m.a. 21.2 years	There were significant differences in three dimensional length, anterior-posterior and latero-medial with respect to the condylar slides IP-RCP between osteophyte, erosion, flattening and NBC group. There were significant differences in three dimensional, antero-posterior, supero-inferior latero-medial incisal and condylar slides IP-RCP due to the uni/bilateral bone change	IP-RCP slides might be related to the types of TMJ pathosis
Artun (1992) [49]	63 patients. All women. a.r: 11-25 years	TMD diagnostic: clinical examination. Joint noises to palpation. TMJ sensitivity exam. Condylar position: radiographic examination, TMJ tomography. CR-ICP discrepancy: clinical examination. sagittal and lateral slides between CR and CO Student's t test, Chi-square	Group with extraction (n = 29; 11-25 year. m.a: 16.9 years, SD = 3.0) Group without extraction (n = 34; 13.1-24.9 years; m.a: 16. 6 years, SD 2.6)	Mean sagittal slides CR-CO were 0.66 mm (SD 0.61) treated with extraction and 0.78 mm (SD 0.55) without extraction. The difference was not significant (p < .05)	It could not be determined that a posterior condylar position is a consequence or cause of disc slide On the side of the CR-CO lateral slide a tendency to posterior condylar position was found
Sigaroudi (1983) [50]	31 subjects. a.r: 22-29 years. M:15;F:6	TMD diagnostic: clinical examination (Click in the TMJ) CR-ICP discrepancy: examination of the presence from centric relation to centric occlusion and its severity (greater or less than 1 mm)	Control group (n = 10; M: 8; F: 2)	Sliding from centric relation to centric occlusion in 70% control group and 90% test group Lateral deviation from centric relation to centric occlusion in 50% control group and 90% test group Pterygoid lateral pain 62% test group. Temporal muscle pain 62% test group	The most important etiological factors for the click in TMJ are bruxism, teeth clenching and sliding from centric relation to centric occlusion greater than 1 mm and lateral deviation

a.r: age range; BBC: bilateral condylar change; CR: centric relation; CO: centric occlusal; CT: computed tomography; F: female; ICP: intercuspal position; M: male; m.a.: mean age; mm: millimetre; RCP: retruded contact position; SD: standard deviation; TMD: temporomandibular disorders; TMJ: temporomandibular joint; UBC: unilateral condylar bone change.

Table 3. Summary of relating the discrepancy between CR-ICP with TMD in subjects without intervention (non-orthodontics patients) ($n = 17$).

First author (year)	Population	Intervention	Comparison (control group)	Outcome	Conclusions
Lila-Krasniqi (2015) [28]	54 subjects. 19M; 35F. a.r = 20–65 years.	TMD diagnostic: anamnesis-responded to a Fonseca questionnaire CR-ICP discrepancy; clinical measurements analyzed with electronic system T-scan III Kolmogorov–Smirnov test, Lilliefors test and Shapiro–Willks test	G1: subjects with fixed dentures ($n = 17$; 8M; 9F. a.r. = 22–65 years old) G2: subjects with TMD ($n = 14$; 5M, 9F; a.r. = 23–58 years old) GC: control group: healthy subjects ($n = 23$; 6M; 17F; a.r. = 20–35 years old) Coincidence between CR-MI Slide between CR-MI	After measurement in the three groups it was not significant differences $p > .05$	There are no statistically significant differences between CR and MI in the group of individuals without any symptom or sign of TMD
Chisnoiu (2015) [51]	234 subjects. ma = 23 ± 4.24 years F:124; M:89	TMD diagnostic: according to RDC/TMD (trained examiners) with additional procedures CR-ICP discrepancy; observing coincidences between CR and MI Chi-square test. Student's t-test	Control group: small CR-MI discrepancies, less than 1.0 mm ($n = 27$; 25.9 years SD 7.2) Study group: large CR-MI discrepancy, greater than 2 mm ($n = 20$; 24.7 years, SD 6.5)	Subjects with centric slides show joint clicks ($p = .05$). The interferences between CR and MI may have a consequence, contractions of the trapezius muscle ($p < .001$), lateral pterygoid muscle ($p < .001$), SCM ($p = .003$) or milohyoid ($p = .001$) All patients with large CR-MI discrepancy had TMJ disk displacement	Occlusal abnormalities may play a role in temporo-mandibular joint disorder development. They can induce contraction and pain in the oro-facial muscles, but also temporo-mandibular joint pain
Lim (2014) [52]	47 subjects. F: 47	TMD diagnostic: signs and symptoms. MRI High-resolution to evaluate the TMJ CR-ICP discrepancy; clinical method, patients in the supine position, and the jaw was passively manipulated until the first tooth contact. Acrylic gnathological stabilizing splints used in patients with CR-MI discrepancy	Without control group	Analysis between TMD and RCP-ICP slide, showed value of r of 0.217, $p = .01$. The influence RCP-ICP slide at the beginning of TMD (OR: 3.10. 95% CI: 1.22–7.94, $p = .018$) RCP-MI slide ≥ 2 mm; ORs = 1.89 (1.27–2.79), $p = .001$	Patients with large CR-MI discrepancy had TMJ disk displacement
Haralur (2014) [53]	250 patients. a.r 15–35 years	TMD diagnostic: clinical history, RDC/TMD CR-ICP discrepancy; clinical method (joint paper, caliper) Pearson test and logical regression	Without control group	Centric slide more than 2 mm found to have a strong influence on the aetiology of TMD ($p = .008$)	This study indicates that RCP-PCI slide has a strong association with TMD
Manfredini (2014) [54]	442 TMD patients. 725 female; a.r. 32.2 ± 5.7 years. a.r:25–44 years	TMD diagnostic: according to the RDC/TMD by the same expert trained operator CR-ICP discrepancy; calculated in the three spatial axes after manual mandibular distraction Chi-square test was used	TMJ clicking group ($n = 253$; 70% female; mean age of 31.8 ± 6.7 years) No-TMJ clicking group ($n = 189$; 74% female; mean age of 33.9 ± 4.5 years)	Centric slide more than 2 mm found to have a strong influence on the aetiology of TMD ($p = .008$)	RCP-MI slide ≥ 2 mm was the only predictor for TMJ clicking The value of the OR for the presence of click in the TMJ was not reached to be clinically significant
Haralur (2013) [55]	100 subjects. (a.r = 18–35)	TMD diagnostic: clinical interview and examination by single clinician CR-ICP discrepancy; evaluated both by conventional and digital methods (T-scan III) Chi-square statistical analysis y t-student.	Group I: ($n = 50$) patients with normal TMJ Group II: ($n = 50$) patients had a minimum of one positive sign or symptom of TMD	Centric slide more than 2 mm found to have a strong association with TMD	Centric slides more than 2 mm found to have a strong association with TMD
Zonnenberg (2013) [56]	110 subjects	TMD diagnostic: RDC/TMD CR-ICP discrepancy; occlusal analysis on articulator-mounted casts and clinical evaluation Occlusal parameters measurements before and after TMD treatment, subjects with Tanner splint	GC: healthy ($n = 27$) MYO: myofascial pain ($n = 26$) OA: osteoarthritis ($n = 28$) ID: disc displacement without reduction ($n = 29$)	Splint treatment did not influence the magnitude of the slide in the MYO and OA groups. Splint treatment increased the magnitude of the slide in the ID group. However, the increase in magnitude was not statistically significant ($p = .053$)	No relationship was demonstrated between centric slide and temporomandibular disorders in this study Centric slides were equally distributed between healthy control subjects and patients with selected TMD diagnoses
Costa (2012) [57]	100 patients M:24; F:76 a.r. 10–60 years	TMD diagnostic: questionnaire proposed by Fonseca et al. CR-ICP discrepancy; intraoral clinical examination for evaluation of occlusal characteristics. For slide centric, the position of CR was obtained with the technique of manipulating the tip of the chin. Chi-square test analysis	G1: control group with no TMD symptoms ($n = 50$) G2: patients had TMD ($n = 50$)	Discrepancy between the positions of CR and MI, deviations greater than 2 mm were found in 32% of patients with TMD. Discrepancies from 0 to 2 mm are considered normal and in this study they were found in 82% of asymptomatic patients and in 68% of TMD	A statistically significant association was found between TMJ and occlusal factors. The extent to which these changes can actually be considered predisposing, triggering or perpetuating factors of this disease can not be exactly defined

(continued)

Table 3. Continued

First author (year)	Population	Intervention	Comparison (control group)	Outcome	Conclusions
Padala (2012) [58]	40 subjects (a.r = 15–35 years)	<i>TMD diagnostic:</i> clinical examination and modified Helkimo index <i>CR-ICP discrepancy:</i> mounted casts in AD2 articulator with MDC for CPR Chi-square and t-student test.	TMD group (n = 20) (a.a = 24.5). Control group: without TMD (n = 20) (a.a = 23.4).	patients showing that this discrepancy was common both in the control group and in patients with TMD (p > .05)	Condylar displacements in horizontal and vertical directions were greater in the symptomatic group (with TMD) than in the asymptomatic group (control)
Wang (2012) [31]	31 subjects M: 16; F:15 a.r: 19–31 years	<i>TMD diagnostic:</i> clinical examination. Evaluation for TMJ sounds and pain, muscular pain and functionality of the mandible <i>CR-ICP discrepancy:</i> T-scan II. Performed by same operator Chi-square analysis	<i>TMD group:</i> presence of signs and symptoms of TMD <i>Control group:</i> without signs and symptoms of TMD	Premature contacts appeared in both groups but were more dominant in the TMD group. There was statistical significance between the groups (p<.019)	A significant association between occlusal stability and TMD was found. The possible aetiopathogenic role of occlusion in TMD should be further investigated
He (2010) [59]	177 subjects M: 61; F: 116	<i>TMD diagnostic:</i> signs and symptoms and RDC/TMD confirmation <i>CR-ICP discrepancy:</i> mounted diagnostic casts with CPI for condylar measurements Chi-square and Pearson's correlation test were used	<i>Experimental group</i> (n = 107; a.a: 24 years, SD:4.5) <i>Control group:</i> no TMD (n = 70; a.a: 24.4, SD: 4.1)	Significant differences in CR-MI discrepancies were found between groups (p<.001) Correlation between CR-MI discrepancies and TMD was significant	There is correlation between centric slide and signs and symptoms of TMD. Severity of CR-MI discrepancy has positive correlation with the severity of TMD
Selaimen (2007) [60]	102 subjects Only female a.r: 15–60 years	<i>TMD diagnostic:</i> based on the standardized digital caliper (Mitutoyo Digimatic Caliper, Tokyo, Japan) Chi-square, Fisher exact test and Mann-Whitney U-test	<i>Control group:</i> no-pain (n = 30) <i>TMD group:</i> primary diagnosis of myofascial pain, with or without limited opening, and arthralgia (n = 72)	CR-CO slide was not significant between groups Only 11.3% of TMD patients had a CR-CO slide greater than 2 mm versus none in the control group	CR-CO slide did not yield significant results between TMD and no-pain groups
Crawford (1999) [30]	60 subjects (M: 27; F: 33)	<i>TMD diagnostic:</i> questionnaire based on the Helkimo index and clinical examination <i>CR-ICP discrepancy:</i> mounted casts (Panadent articulator), condylar position measured with CPI Student's t-test	<i>Restored ideal group:</i> full-mouth reconstruction using gnathologic principles (n = 30) (a.a = 50.8) <i>Control group:</i> untreated (n = 30) (a.a = 38.4)	CPI values and anamnestic and clinical scores were smaller in the restored ideal group when compared with the untreated control (p<.001)	There is a relationship between condylar axis position determined by occlusion and signs and symptoms of TMD
Visser (1994) [61]	121 subjects M: 52; F: 69 a.r: 13–63 years	<i>TMD diagnostic:</i> clinical examination <i>CR-ICP discrepancy:</i> lateral slide between RCP-ICP: clinically determined Chi-square and Kruskal-Wallis tests were performed	<i>Control group:</i> without CMD (n = 60, m.a: 21 years) <i>CMD group:</i> (n = 61, m.a.: 29 years)	Prevalence of lateral slide was greater in the CMD group when compared to the control group (p<.01); the CMD group also showed larger RCP-ICP lateral slides (p<.05)	CMD group showed a greater RCP-ICP discrepancy than the control group
Pullinger (1988) [62]	222 subjects M = 120; F = 102 (a.a: 23.9; a.r.: 19–40 years)	<i>TMD diagnostic:</i> signs and symptoms by questionnaire and clinical examination <i>CR-ICP discrepancy:</i> clinical examination and dental casts evaluation Chi-square test for statistical analysis	No control group	Among subjects with unilateral RCP contact, those with no clinically obvious RCP-ICP slide (p<.005) and those with asymmetric slides (p<.05) had more TMJ clicking than subjects with symmetric slides	Certain occlusomorphologic conditions may require less adaptation in the TMs. Results indicates that an ICP anterior to the RCP in association with bilateral occlusal stability may be protective
Bush (1985) [63]	298 subjects M = 242; F = 56 (a.r = 22–37; a.a = 24).	<i>TMD diagnostic:</i> muscular or joint tenderness to palpation <i>CR-ICP discrepancy:</i> intraoral and mounted casts (Whip-Mix) Three different examiners Statistical analysis using t-test.	Groups according to: Angle's classification and presence/absence of tenderness Class I (n = 262) Class II (n = 21) Class III (n = 15)	Class I subjects without tenderness showed greater vertical (p = .05) and horizontal (p = .02) displacements (RCP-IP) than subjects with tenderness	The findings contradict the notion that the presence of a minor slide contributed to some marked clinical symptoms such as tenderness
Maruyama (1982) [64]	30 subjects M = 20; F = 10 (a.r = 24–35)	<i>CR-ICP discrepancy:</i> relationships between CR-CO recorded with a mandibular kinesiograph Statistical analysis by Student's t-test	<i>Control group</i> Study group: subjects with TMD (n = 30)	Deviations in antero-posterior, left and linear directions showed significant differences between groups (p<.01)	Centric slide can be one of the causes of TMD; however, it is not the only cause

a.a.: age average; a.r.: age range; CMD: craniomandibular disorders; CPI: condylar position indicator; CPR: condyle position recording; CR-CO: centric relation-centric occlusion; CR-MI discrepancy: centric relation-maximum intercuspation discrepancy; F: female; ICP: intercuspal position; M: male; m.a.: mean age; mm: millimetre; MRI: magnetic resonance imaging; MSD: measured condyle deviation; OR: odds ratio; RCP-ICP slide: retruded contact position-intercuspal position slide; RDC/TMD: Research Diagnostic Criteria for Temporomandibular Disorders; SCM: sternocleidomastoid muscle; SD: standard deviation; TMD: temporomandibular disorders; TMJ: temporomandibular joint.

Table 4. Summary of articles studying the relationship between CR-ICP discrepancy and TMDs, CR-ICP discrepancy type, temporomandibular disorder diagnostic and quality of evidence according to Newcastle-Ottawa Scale (NOS).

Relationship between TMD and CR-ICP discrepancy					
Author	Year	Orthodontic patient? (yes/no)	CR-ICP discrepancy type	Pathology (TMD)	NOS score
He [59]	2010	No	No report	Muscular/joint (DD, arthralgia, osteoarthritis and osteoarthrosis)	6
Wang [31]	2012	No	No report	Joint (crepitus, pain, click); muscular (pain)	5
Lim [52]	2014	No	No report	Disc displacement	4
Haralur [55]	2013	No	No report	Unclear diagnosis	4
Padala [58]	2012	No	Horizontal and vertical displacement.	Joint (noises, pain, lock); Muscular (unclear diagnosis)	4
Yamada [48]	2003	Yes	Antero-posterior/lateromedial	Osteoarthritis	4
Haralur [53]	2014	No	No report	Joint disorders (pain, clicking), muscle pain	3
Crawford [30]	1999	No	No report	Muscular pain/joint (pain, lock, noises)/jaw pain	3
Visser [61]	1994	No	Lateral slide	Muscular (myogenic disorder)	3
Chisnoiu [51]	2015	No	No report	Muscular (pain) and joint (click and pain)	2
Pullinger [62]	1988	No	Asymmetric slides	Joint (click)	2
Sigaroudi [50]	1983	Yes	Lateral slide	Joint (click)	2
Maruyama [64]	1982	No	Antero-posterior/left and linear directions	Muscular (pain)/joint (pain, click)/altered jaw movement	2
Without relationship between TMD and CR-ICP discrepancy					
		Orthodontic patient? (yes/no)	CR-ICP discrepancy type	Pathology (TMD)	NOS score
Manfredini [54]	2014	No	Anteroposterior (three spacial axes)	–	6
Selaimen [60]	2007	No	No report	–	5
Zonnenberg [56]	2013	No	Horizontal and vertical displacement	–	4
Lila Krasniqi [28]	2015	No	Lateral slide	–	3
Costa [57]	2012	No	No report	–	3
Artun [49]	1992	Yes	Lateral and sagittal slide	–	3
Bush [63]	1985	No	Lateral, horizontal and vertical displacement	–	3

CR-ICP discrepancy: centric relation-intercuspal position discrepancy; DD: disc displacement; NOS: Newcastle-Ottawa Scale; TMD: temporomandibular disorders.

Table 5. Quality of evidence according to NOS scale in studies with and without intervention.

Intervention	Quality of evidence (NOS scale)	
	Score range	Median score
Orthodontics patients		
With TMD (<i>n</i> = 2)	2–4	3.0
Without TMD (<i>n</i> = 1)	3	3.0
Non-orthodontics patients		
With TMD (<i>n</i> = 11)	2–6	3.0
Without TMD (<i>n</i> = 6)	3–6	3.5
Average total score		3.13

NOS: Newcastle-Ottawa Scale; TMD: temporomandibular disorders.

Table 6. Summary of studies according to methodology for the diagnosis of TMD and CR-ICP discrepancy determination.

TMD diagnostics	Method for determining CR-ICP discrepancy			
	Articulator mounting, (<i>n</i> =)	T-scan, (<i>n</i> =)	Clinics, (<i>n</i> =)	Others, (<i>n</i> =)
RDC/TMD	2	1	3	1
Helkimo index	2	0	0	0
Signs and symptoms	2	1	3	0
Questionnaire	0	1	1	0
Imagenologic (MRI, CBCT)	0	0	1	1
Others	0	0	0	1
Total	6	3	8	3

CBCT: Cone beam Computed Tomography; CR-ICP discrepancy: centric relation-intercuspal position discrepancy; MRI: magnetic resonance imaging; RDC/TMD: Research Diagnostic Criteria for Temporomandibular Disorders.

orthodontics patients found a positive relationship and one study did not. In studies without intervention, 11 articles related a positive association between CR-ICP discrepancy and presence of TMD and six articles did not.

From a methodological point of view, the scientific quality of most part of the studies analyzed was low, with a range of scores according to NOS scale between 2 and 6 points with a median of 3.13 points (range scale score between 0 and 9 points). The weakness of the studies was mainly characterized by the presence of bias in the conformation of study groups, blinding, calibration of examiners and problems in the selection of cases and controls. The poor quality of evidence and designs influenced the possibility to determine whether or not there is a relationship between the variables.

When using NOS instrument to determine the quality of evidence in case-control and cohort studies [41], recurring methodological flaws in item selection were observed, particularly in the representativeness of cases, selection of controls and their definition, which resulted in substantially lower scores in studies. Another weakness was the presence of diagnostic instruments with low sensitivity for the diagnosis of TMD, as well as for determining CR-ICP discrepancy and its magnitude, which added to a high heterogeneity of the methods used in this item, complicating the comparison between studies.

According to the design of the articles, 20 case-control studies were analyzed (*n* = 20), making it difficult to establish a cause and effect relationship between CR-ICP discrepancy and TMD. That is, the design of most of the studies conducted did not allow to establish which condition occurs first, CR-ICP discrepancy or TMD. To establish a cause-effect relationship, cohort or longitudinal studies with large and representative samples are needed, but not yet available.

The lack of scientific evidence regarding the use of the articulator [65], as well as the methods that determine the position of the condyles in the mandibular fossa, are factors to be considered in the sensitivity of the instruments used to determine CR-ICP discrepancy. Regarding the methods for determining the CR record, studies based on magnetic resonance imaging (MRI) indicate that the condyles would not be located where clinicians think [66]. There would be no anterior condylar position in CR when different methods for bite registration were compared, reflecting a lack of precision in the registration process to determine the position of the condyle in the fossa [1]. This was supported by Henriques et al., who concluded that there is no significant difference in the mandibular condyle–fossa relationship between CR and ICP in asymptomatic subjects [40]. The conceptual differences related to the position in CR, variation in reproducibility, contradictory findings in the literature, the small discrepancy between CR-ICP positions, lack of scientific evidence supporting that the condylar position could be related to TMD and the limitations of the articulator to reproduce the anatomy and function of the TMJ has prompted several authors to oppose to the use of CR [36,37,67].

CR-ICP discrepancy and TMDs

Thirteen studies determined a positive relationship between CR-ICP discrepancy and TMD, according to orthodontic subjects ($n=2$) and subjects without intervention ($n=11$). Regarding the diagnostic of temporomandibular pathology, almost half of the articles included in this systematic review found a positive association between CR-ICP discrepancy and joint and muscular disorders ($n=7$), five studies with joint disorders and one article with muscle disorder.

According to the American Academy of Orofacial Pain (AAOP), TMD are defined as 'a group of disorders involving the masticatory muscles, the temporomandibular joint (TMJ), and associated structures' [68], with different aetiologies and associated risk factors. Although there are diagnostic methods to determine different diagnoses of TMD as the RDC/TMD [69] and DC/TMD [70] which has increased the reproducibility of the results and their comparison with other studies, almost half of the included articles in this review, regarding the diagnosis of TMD, were based on the presence of signs and symptoms and questionnaires, which implies a low sensitivity in the diagnosis method, making difficult the comparison between studies and reproducibility of results.

Regarding muscle disorders and CR-ICP discrepancy in orthodontics patients, some studies show that after the removal of brackets, there would be an increase in muscle strength and decrease in muscle sensitivity, generated by an increase in muscle mass, occlusal stability [71,72] and adaptations of the neuromusculature [45]. The centric slide provides information regarding the adaptation of the masticatory muscles, where the slide would be determined by the masticatory muscles. In this regard, orthodontic correction involves horizontal changes in teeth and jaw. A weak muscle function in orthodontic patients or post-orthodontic patients could cause increased susceptibility to pain and tenderness [69].

However, given the level of evidence, diagnostics methods and the number of studies found, it is not possible to support this assertion.

While questions have been raised in recent decades about the concept and importance of occlusal characteristics as aetiologic factor in the presence of TMDs [17,73,74], current evidence shows that the jaw muscle pain would have an effect on the position of occlusal contacts. Mobilio et al. concluded that by inducing muscle pain using a hypertonic saline 5%, different occlusal contacts would appear, disappearing after resolution of pain, so that their amount would not change, while their position itself would, generating posterior occlusal contacts [75]. The explanation may be that the jaw and consequently the occlusal contacts change for the presence of pain. This would be grounded within the context of the adaptation model of pain [76], where the presence of pain changes motor function for adaptation–protection [77].

The majority of the studies show that most patients present a discrepancy between CR and ICP [78,79]. Evidence linking the amount of CR-ICP discrepancy and TMD shows that a discrepancy minor than 1.0 mm in the horizontal or vertical plane is considered normal and would not be considered as a risk factor for TMD [30]. Most of the analyzed studies that positively associated the presence of CR-ICP discrepancy and TMD did not clearly determine the amount in millimetres (mm) necessary for the presence of TMD. The studies that determined the amount in mm ($n=7$) varied in a range of values greater than 1.0, 1.5 and 2.0 mm of discrepancy, which means a lack of agreement among the authors who maintain this relationship [50,52,53,55,58,59,61]. Similar findings were observed in relation to the report in the plane where CR-ICP discrepancy occurs; only six articles specified that if the CR-ICP discrepancy occurs in the horizontal, vertical, transversal plane or if it presents asymmetrically, it would cause TMD [48,50,58,61,62,64].

Limitations

While the search for the articles was conducted in nine electronic databases without limitation of language and year of publication, the amount of evidence available is limited and contradictory. In addition, most studies found only considered one risk factor for the presence of TMD (CR-ICP discrepancy and TMD) and did not evaluate other factors involved, such as bruxism [80,81], facial morphology [82] and posterior crossbite [83]. Another limitation of the articles analyzed in this systematic review was the heterogeneity of evidence in relation to the design and diagnostic methods for TMD and to determine CR-ICP discrepancy and its magnitude.

Regarding studies in subjects with orthodontic treatment, there was a great variability in both the treatment modalities, the determination of CR-ICP discrepancy and diagnosis of TMD. One study did not report the details of the orthodontic treatment [48], another evaluated the relationship between CR-ICP discrepancy and TMD in groups with and without extractions [49], and the last study included subjects with and without orthodontic treatment [50].

Agreements and disagreements with other reviews

Two of the reviews related the occlusal factors to TMDs. The studies agreed that occlusion would not play a major role in the aetiology of TMDs. Türp et al. review [84] of observational and experimental studies determined that when artificial interference is introduced, occlusal discomfort and masticatory problems would be generated. This would be explained by a decrease in the adaptive capacity. In addition, acute occlusal interventions differ from long-standing occlusal interferences that may have been present for years. De Boever et al. [6] analyzed the benefit of eliminating centric slide, concluding that a prophylactic occlusal adjustment is not justified for the prevention and treatment of TMDs. Therefore, they suggested to continue the research on the relationship between the occlusion and TMD using evidence-based study methods.

Discrepancies regarding this study are related to the design of the reviews found regarding the search strategies, inclusion and exclusion criteria, analysis of the included studies, determination of the quality of evidence according to the design of the selected studies (experimental and observational studies), and finally neither the diagnostic criteria of TMD nor the methods to determine the discrepancy between CR-ICP were evaluated.

In this systematic review, all the studies that investigated the relationship between CR-ICP discrepancy and TMDs were analyzed. This remains a controversial topic. According to some articles included in this study, the CR-ICP discrepancy would be one of the occlusal factors associated with the presence of TMDs. Conversely, other studies indicate that there is no significant association between CR-ICP discrepancy and TMDs. Therefore, caution should be taken when deciding to eliminate this discrepancy to prevent or to treat TMD.

It would be recommended to develop cohort studies to determine the cause and effect relationship and to use validated diagnostic instruments with adequate sensitivity to determine a correct diagnosis of the different subgroups of TMD.

Based on the findings, it was not possible to consistently determine the association between CR-ICP discrepancy and TMDs. Due to the high heterogeneity in study designs, the low quality of the evidence and variability of diagnostic methodology for TMD and CR-ICP discrepancy, a meta-analysis was not feasible.

Conclusions

Establishing the causal relationship between CR-ICP discrepancy and TMD is one of the most controversial topics in the dental literature, and although there is evidence, it is limited and of low quality.

In relation to the findings in this systematic review, we can conclude that

- The available evidence does not support a relationship between CR-ICP discrepancy and TMDs.
- The amount of evidence is limited and the quality is low, so it is not possible to establish consistent conclusions on this topic.

- Due to the heterogeneity of the designs and methodologies of the studies analyzed, it is not possible to assert that the presence of CR-ICP discrepancy and its magnitude is related to the presence of TMDs.
- Cohort studies are required, with higher levels of evidence to determine a possible causal relationship between CR-ICP discrepancy and TMDs.

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The authors report no conflicts of interest.

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References

- [1] Kandasamy S, Boeddinghaus R, Kruger E. Condylar position assessed by magnetic resonance imaging after various bite position registrations. *Am J Orthod Dentofac Orthop.* 2013;144:512–517.
- [2] Rinchuse DJ, Kandasamy S. Centric relation: a historical and contemporary orthodontic perspective. *J Am Dent Assoc.* 2006;137:494–501.
- [3] Henrikson T, Nilner M. Temporomandibular disorders, occlusion and orthodontic treatment. *J Orthod.* 2003;30:129–137. Discussion 127.
- [4] Sonnesen L, Bakke M, Solow B. Malocclusion traits and symptoms and signs of temporomandibular disorders in children with severe malocclusion. *Eur J Orthod.* 1998;20:543–559.
- [5] Caldas W, Conti ACCF, Janson G, et al. Occlusal changes secondary to temporomandibular joint conditions: a critical review and implications for clinical practice. *J Appl Oral Sci.* 2016;24:411–419.
- [6] 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.
- [7] Magnusson T, Egermarki I, Carlsson GE. A prospective investigation over two decades on signs and symptoms of temporomandibular disorders and associated variables. A final summary. *Acta Odontol Scand.* 2005;63:99–109.
- [8] McNamara JA, Seligman DA, Okeson JP. Occlusion, Orthodontic treatment, and temporomandibular disorders: a review. *J Orofac Pain.* 1995;9:73–90.
- [9] 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.
- [10] Conti A, Freitas M, Conti P, et al. Relationship between signs and symptoms of temporomandibular disorders and orthodontic treatment: a cross-sectional study. *Angle Orthod.* 2003;73:411–417.
- [11] Mohlin B, Axelsson S, Paulin G, et al. TMD in relation to malocclusion and orthodontic treatment. *Angle Orthod.* 2007;77:542–548.

- [12] de Sousa ST, de Mello VVC, Magalhães BG, et al. The role of occlusal factors on the occurrence of temporomandibular disorders. *Cranio*. 2015;33:211–216.
- [13] The glossary of prosthodontic terms. *J Prosthet Dent*. 2005;94:10–92.
- [14] Dawson PE. New definition for relating occlusion to varying conditions of the temporomandibular joint. *J Prosthet Dent*. 1995;74:619–627.
- [15] Palaskar JN, Murali R, Bansal S. Centric relation definition: a historical and contemporary prosthodontic perspective. *J Indian Prosthodont Soc*. 2013;13:149–154.
- [16] Schiffman E, Fricton J, Haley D. Mandibular dysfunction, occlusal dysfunction, and parafunctional habits in a non-clinical population. *J Dent Res*. 1986;65:306–314.
- [17] Türp JC, Greene CS, Strub JR. Dental occlusion: a critical reflection on past, present and future concepts. *J Oral Rehabil*. 2008;35:446–453.
- [18] Andrews LF. The six keys to normal occlusion. *Am J Orthod*. 1972;62:296–309.
- [19] Dawson PE. Optimum TMJ condyle position in clinical practice. *Int J Periodontics Restorative Dent*. 1985;5:10–31.
- [20] Celenza FV. The centric position: replacement and character. *J Prosthet Dent*. 1973;30:591–598.
- [21] Serrano PT, Nicholls JI, Yuodelis RA. Centric relation change during therapy with corrective occlusion prostheses. *J Prosthet Dent*. 1984;51:97–105.
- [22] Schildkraut M, Wood DP, Hunter WS. The CR-CO discrepancy and its effect on cephalometric measurements. *Angle Orthod*. 1994;64:333–342.
- [23] Weffort SYK, de Fantini SM. Condylar displacement between centric relation and maximum intercuspation in symptomatic and asymptomatic individuals. *Angle Orthod*. 2010;80:835–842.
- [24] Ferreira A, de F, Henriques JCG, et al. Comparative analysis between mandibular positions in centric relation and maximum intercuspation by cone beam computed tomography (CONE-BEAM). *J Appl Oral Sci*. 2009;17:27–34.
- [25] Garrido García VC, García Cartagena A, González Sequeros O. Evaluation of occlusal contacts in maximum intercuspation using the T-scan system. *J Oral Rehabil*. 1997;24:899–903.
- [26] Fantini SM, de Paiva JB, de Rino Neto J, et al. Increase of condylar displacement between centric relation and maximal habitual intercuspation after occlusal splint therapy. *Braz Oral Res*. 2005;19:176–182.
- [27] Utt TW, Meyers CE, Wierzb TF, et al. A three-dimensional comparison of condylar position changes between centric relation and centric occlusion using the mandibular position indicator. *Am J Orthod Dentofacial Orthop*. 1995;107:298–308.
- [28] Lila-Krasniqi ZD, Shala KS, Pustina-Krasniqi T, et al. Differences between centric relation and maximum intercuspation as possible cause for development of temporomandibular disorder analyzed with T-scan III. *Eur J Dent*. 2015;9:573–579.
- [29] Cordray FE. Centric relation treatment and articulator mountings in orthodontics. *Angle Orthod*. 1996;66:153–158.
- [30] Crawford SD. Condylar axis position, as determined by the occlusion and measured by the CPI instrument, and signs and symptoms of temporomandibular dysfunction. *Angle Orthod*. 1999;69:103–115. Discussion 115–16.
- [31] Wang C, Yin X. Occlusal risk factors associated with temporomandibular disorders in young adults with normal occlusions. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2012;114:419–423.
- [32] Roth RH. Functional occlusion for the orthodontist. *J Clin Orthod*. 1981;15:32–51.
- [33] Williamson EH. Occlusion: understanding or misunderstanding. *Angle Orthod*. 1976;46:86–93.
- [34] Jarabak JR. An electromyographic analysis of muscular and temporomandibular joint disturbances due to imbalances in occlusion. *Angle Orthod*. 1956;26:170–190.
- [35] Turasi B, Ari-Demirkaya A, Biren S. Comparison of increased overjet cases and controls: normative data for condylar positions. *J Oral Rehabil*. 2007;34:129–135.
- [36] Wood GN. Centric relation and the treatment position in rehabilitating occlusions: a physiologic approach. Part II: the treatment position. *J Prosthet Dent*. 1988;60:15–18.
- [37] Carlson GL. Insights into occlusal problems through the use of centric relation procedures. Part two. *Northwest Dent*. 2007;86:31–34, 37, 39.
- [38] Sadowsky C, Polson AM. Temporomandibular disorders and functional occlusion after orthodontic treatment: results of two long-term studies. *Am J Orthod*. 1984;86:386–390.
- [39] Magnusson T, Egermark I, Carlsson GE. A longitudinal epidemiologic study of signs and symptoms of temporomandibular disorders from 15 to 35 years of age. *J Orofac Pain*. 2000;14:310–319.
- [40] Henriques JCG, Fernandes Neto AJ, Almeida G, et al. Cone-beam tomography assessment of condylar position discrepancy between centric relation and maximal intercuspation. *Braz Oral Res*. 2012;26:29–35.
- [41] Newcastle Ottawa Scale. [cited 2016 May 9]. Available from: http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp
- [42] Costea CM, Badea ME, Vasilache S, et al. Effects of CO-CR discrepancy in daily orthodontic treatment planning. *Clujul Med*. 2016;89:279–286.
- [43] Ciavarella D, Parziale V, Mastrovincenzo M, et al. Condylar position indicator and T-scan system II in clinical evaluation of temporomandibular intracapsular disease. *J Craniomaxillofac Surg*. 2012;40:449–455.
- [44] Gusmão PS, Cruz FLG, Dias IM, et al. Influência da placa interoclusal nas relações estáticas maxilo-mandibulares e na sintomatologia dolorosa de pacientes com desordem temporomandibular. *HU Rev*. 2011;37.
- [45] Winocur E, Davidov I, Gazit E, et al. Centric slide, bite force and muscle tenderness changes over 6 months following fixed orthodontic treatment. *Angle Orthod*. 2007;77:254–259.
- [46] Clark JR, Evans RD. Functional occlusal relationships in a group of post-orthodontic patients: preliminary findings. *Eur J Orthod*. 1998;20:103–110.
- [47] Huber MA, Hall EH. Comparison of the signs of temporomandibular joint dysfunction and occlusal discrepancies in a symptom-free population of men and women. *Oral Surg Oral Med Oral Pathol*. 1990;70:180–183.
- [48] Yamada K, Fukui T, Tsuruta A, et al. The relationship between retarded contact position and intercuspation position in patients with TMJ osteoarthritis. *Cranio*. 2003;21:240–247.
- [49] Artun J, Hollender LG, Truelove EL. Relationship between orthodontic treatment, condylar position, and internal derangement in the temporomandibular joint. *Am J Orthod Dentofacial Orthop*. 1992;101:48–53.
- [50] Sigaroudi K, Knap FJ. Analysis of jaw movements in patients with temporomandibular joint click. *J Prosthet Dent*. 1983;50:245–250.
- [51] Chisnoiu AM, Buduru S, Lascu L, et al. Influence of occlusal characteristics on temporomandibular joint disorder development: a cross-sectional study. *Hum Vet Med*. 2015;3:197–201.
- [52] Lim WH, Choi B, Lee JY, et al. Dentofacial characteristics in orthodontic patients with centric relation-maximum intercuspation discrepancy. *Angle Orthod*. 2014;84:939–945.
- [53] Haralur SB, Addas MK, Othman HI, et al. Prevalence of malocclusion, its association with occlusal interferences and temporomandibular disorders among the Saudi sub-population. *Oral Health Dent Manag*. 2014;13:164–169.
- [54] Manfredini D, Perinetti G, Guarda-nardini L. Dental malocclusion is not related to temporomandibular joint clicking: a logistic regression analysis in a patient population. *Angle Orthod*. 2014;84:310–315.
- [55] Haralur SB. Digital evaluation of functional occlusion parameters and their association with temporomandibular disorders. *J Clin Diagn Res*. 2013;7:1772–1775.
- [56] Zonnenberg AJJ, Mulder J. The incidence of centric slides in healthy individuals and TMD patients. *Eur J Prosthodont Restor Dent*. 2013;21:109–113.
- [57] Costa MD, Torres R, Junior F, et al. Evaluation of occlusal factors in patients with temporomandibular joint disorder. *Dental Press J Orthod*. 2012;17:61–68.

- [58] Padala S, Padmanabhan S, Chithranjan AB. Comparative evaluation of condylar position in symptomatic (TMJ dysfunction) and asymptomatic individuals. *Indian J Dent Res.* 2012;23:122.
- [59] He SS, Deng X, Wamalwa P, et al. Correlation between centric relation–maximum intercuspation discrepancy and temporomandibular joint dysfunction. *Acta Odontol Scand.* 2010;68:368–376.
- [60] Selaimen CMP, Jeronymo JCM, Brilhante DP, et al. Occlusal risk factors for temporomandibular disorders. *Angle Orthod.* 2007;77:471–477.
- [61] Visser A, McCarroll RS, Oosting JNM. Masticatory electromyographic activity in healthy young adults and myogenous craniomandibular disorder patients. *J Oral Rehabil.* 1994;21:67–76.
- [62] Pullinger AG, Seligman DASW. Temporomandibular disorders. Part II: occlusal factors associated with temporomandibular joint tenderness and dysfunction. *J Prosthet Dent.* 1988;59:363–367.
- [63] Bush FM. Malocclusion, masticatory muscle, and temporomandibular joint tenderness. *J Dent Res.* 1985;64:129–133.
- [64] Maruyama T. Analysis of the mandibular relationship of TMJ dysfunction patients using the Mandibular Kinesiograph. *J Oral Rehabil.* 1982;9:217–223.
- [65] Rinchuse DJ, Kandasamy S. Articulators in orthodontics: an evidence-based perspective. *Am J Orthod Dentofacial Orthop.* 2006;129:299–308.
- [66] Alexander SR, Moore RN, DuBois LM. Mandibular condyle position: comparison of articulator mountings and magnetic resonance imaging. *Am J Orthod Dentofacial Orthop.* 1993;104:230–239.
- [67] Keshvad A, Winstanley RB. An appraisal of the literature on centric relation. Part III. *J Oral Rehabil.* 2001;28:55–63.
- [68] de Leeuw R, Klasser GD. Orofacial pain: guidelines for assessment, diagnosis and management. Hannover Park (IL): Quintessence Editorial International; 2013.
- [69] Dworkin SF, LeResche L. Research diagnostic criteria for temporomandibular disorders: review, criteria, examinations and specifications, critique. *J Craniomandib Disord.* 1992;6:301–355.
- [70] Schiffman E, Ohrbach R, Truelove E, et al. Diagnostic criteria for temporomandibular disorders (DC/TMD) for clinical and research applications: recommendations of the International RDC/TMD Consortium Network and Orofacial Pain Special Interest Group. *J Oral Facial Pain Headache.* 2014;28:6–27.
- [71] Goldreich H, Gazit E, Lieberman MA, et al. The effect of pain from orthodontic arch wire adjustment on masseter muscle electromyographic activity. *Am J Orthod Dentofacial Orthop.* 1994;106:365–370.
- [72] Vandenborne K, Elliott MA, Walter GA, et al. Longitudinal study of skeletal muscle adaptations during immobilization and rehabilitation. *Muscle Nerve.* 1998;21:1006–1012.
- [73] Fujii T. The relationship between the occlusal interference side and the symptomatic side in temporomandibular disorders. *J Oral Rehabil.* 2003;30:295–300.
- [74] Fujii T. Occlusal conditions just after the relief of temporomandibular joint and masticatory muscle pain. *J Oral Rehabil.* 2002;29:323–329.
- [75] Mobilio N, Catapano S. Effect of experimental jaw muscle pain on occlusal contacts. *J Oral Rehabil.* 2011;38:404–409.
- [76] Lund JP, Donga R, Widmer CG, et al. The pain-adaptation model: a discussion of the relationship between chronic musculoskeletal pain and motor activity. *Can J Physiol Pharmacol.* 1991;69:683–694.
- [77] Stohler CS. Craniofacial pain and motor function: pathogenesis, clinical correlates, and implications. *Crit Rev Oral Biol Med.* 1999;10:504–518.
- [78] Hodge LC, Mahan PE. A study of mandibular movement from centric occlusion to maximum intercuspation. *J Prosthet Dent.* 1967;18:19–30.
- [79] Rieder CE. The prevalence and magnitude of mandibular displacement in a survey population. *J Prosthet Dent.* 1978;39:324–329.
- [80] Manfredini D, Lobbezoo F. Relationship between bruxism and temporomandibular disorders: a systematic review of literature from 1998 to 2008. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2010;109:e26–e50.
- [81] Jiménez-Silva A, Peña-Durán C, Tobar-Reyes J, et al. Sleep and awake bruxism in adults and its relationship with temporomandibular disorders: a systematic review from 2003 to 2014. *Acta Odontol Scand.* 2017;75:36–58.
- [82] Manfredini D, Segù M, Arveda N, et al. Temporomandibular joint disorders in patients with different facial morphology. A systematic review of the literature. *J Oral Maxillofac Surg.* 2016;74:29–46.
- [83] Iodice G, Danzi G, Cimino R, et al. Association between posterior crossbite, masticatory muscle pain, and disc displacement: a systematic review. *Eur J Orthod.* 2013;35:737–744.
- [84] Türp JC, Schindler H. The dental occlusion as a suspected cause for TMDs: epidemiological and etiological considerations. *J Oral Rehabil.* 2012;39:502–512.