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CONTENT

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An evolutionary perspective on craniomandibular dysfunctions *

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Abstract

Craniomandibular dysfunctions (CMDs) are a set of clinical disorders primarily affecting the masticatory muscles and the temporomandibular joints manifesting as pain syndrome, functional limitations and hard and soft tissues degeneration. CMDs have a high impact on the patients' quality of life as they limit important functions like chewing and deglutition, respiration, speech and social interaction, stress management and postural control. In industrialized societies, the incidence of adult CMD patients needing treatment is estimated to be about 5%, with females showing at least twice the prevalence of males. A review of the anthropological, clinical and biological evidence was carried out to elucidate adaptive aspects of the evolutionary origin of CMDs. The effects of modern lifestyle on the health and function of the stomatognathic system was evaluated and the hypothesis that CMDs should be considered diseases of civilization was tested within a theoretical framework. To prove this assumption, it must be shown that cultural and technological changes have affected the orofacial structures and that these changes have had negative functional effects that are causal to CMDs. Compared to pre-industrial populations, contemporary modern humans are characterized by smaller, retrognathic mandibles, with narrower dental arches and deeper palates and the presence of malocclusion. Anthropological and experimental animal research has shown that such changes are associated with a highly refined diet, typical of industrialized societies. The functional implications of these morphological changes can be derived from experimental and clinical studies. In the medical setting, CMDs' etiological factors have long been discussed however, occlusion's role in the onset and maintenance of these disorders remains controversial. Yet, the interrelationship between the morphology of the masticatory structures and CMDs can be clarified by close examination and deductive reasoning applied to the available anthropological, clinical and biological evidence.

Keywords: temporomandibular disorders; disease of civilization; malocclusion; diet; function

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Introduction

The stomatognathic system has evolved to accomplish various vital functions allowing chewing and food ingestion while breathing. It engages in activities such as speech and stress management and is of great importance for facial expression and social interaction. Moreover, it plays a crucial role in postural control. Therefore, disturbances of the stomatognathic system altering its performance such as craniomandibular disorders (CMDs) compromise the individual's well-being.

CMDs are a set of pathologies affecting the musculoskeletal structures of the face and neck. The presenting signs and symptoms can include muscle pain or spasm, temporomandibular joint (TMJ) derangement, bony degeneration and/or pain in the TMJ and surrounding areas (1). Recently, the classification of CMD has expanded to include headaches aggravated by mastication (2). CMDs are most prevalent in adults between 20 to 50 years and affect females 2 to 4 times more than males (3, 4). In modern societies, CMDs have become a widespread problem, with up to 75% of the general adult population presenting at least one sign or symptom, however, the reported incidence of CMD requiring treatment ranges between 5 to 10% (4, 5). In 2002, 6% of women and 3% of men in the USA general population presented CMD-related pain (6). These results were confirmed in a 2020 report which estimated that 5% of the general USA adult population would require treatment for CMDs (7).

CMDs affect a complex suite of structures working in a concerted manner, showing individual, sexual and possibly geographical and cultural variation. The associated signs and symptoms are heterogeneous and show variable degrees of expression, often exhibiting an intermittent character throughout the life span of an individual (1). They have been compared to back pain in terms of pain quality and intensity (7). Similarly, their impact on the individual's ability to function can be measured in terms of the global financial burden that was recently estimated as comparable to that of cardiovascular diseases and diabetes (8). CMDs are regarded as multicausal diseases: occlusion, parafunctional habits (such as bruxism), emotional stress, deep pain input and trauma have been considered critical CMD risk factors whose effects can be buffered by the level of adaptability of each individual depending on their genetic, structural, hormonal and psychological condition (1).

Among these etiological factors, occlusion is the most debated and its role in the onset and maintenance of CMD is still poorly understood. However, in modern societies, malocclusions are highly prevalent (9, 10), thus, it is important to consider and explore their possible functional implications. Within dentistry, there is no consensus on the magnitude of the effects of malocclusion on the function of the masticatory system and it is even debated whether malocclusion has to be considered an etiological determinant of CMD, which profoundly affects oral health decision-making (11, 12). In the last decades, there has been a shift in paradigm from an occlusion-based approach to CMD treatment (12) to the most recent biopsychosocial model (13), which has led to focusing on the psychological and social aspects of CMD instead of its mechanistic determinants (14). Given the lack of general consensus on the CMD determinants and consequent disagreement on how to treat them, there is a substantial need to investigate CMDs and identify their risk factors (15).

Seeing CMDs through the lenses of evolutionary medicine might help explain both the mechanistic and evolutionary origin of the traits leading to vulnerability to these disorders (16). Understanding the origin of modern pathologies in the light of evolution enhances our knowledge of the adaptive mechanisms via the evaluation of phenomena such as phenotypical plasticity and biological constraints and provides fundamental knowledge informing the treatment and prevention of diseases in modern societies. By reflecting on the current anthropological, biological and clinical evidence, I aim to discuss both proximate (mechanistic) and ultimate (evolutionary) causes of CMD with focus on occlusion. My working hypothesis is that cultural and technical advancements in food processing have affected the orofacial structures leading to an increased prevalence and expression of malocclusions. In turn, malocclusions have functional implications and are associated with or, even, cause CMDs. In conclusion, I aim to discuss whether CMDs can be considered diseases of civilization.

Materials and Methods

In this narrative review, I refer to the literature published within the fields of biology, anthropology and dentistry, to reason upon the collective evidence providing us with key knowledge to understand CMDs from the perspective of evolutionary medicine. In

particular, I will consider publications that allow addressing the following questions:
- Has civilization affected the orofacial structures?
- Do dietary-related changes in orofacial structures such as malocclusion and dysgnathia have functional implications?
- Are malocclusions and dysgnathia causal to CMD?

In this work, the term CMD is used to refer to conditions such as myalgia, derangements of the articular disc, arthralgias and secondary osteoarthritic changes of the TMJ and will not include disorders with clear etiology other than occlusion, such as malignancies of the stomatognathic system, systemic metabolic diseases, centrally mediated neuropathic pain and acute trauma.

Results

Has civilization affected the orofacial structures?

It is estimated that food consumed in modern societies is at least 10 times softer than that regularly eaten by hunter-gatherers (17). Modern humans engage in complex extra-oral food preparations such as pounding, grinding, cutting and, especially, cooking (18). The techniques for extra-oral food preparation have undergone crucial revolutions through human evolution, allowing the production of increasingly more refined and softer food. Cooked food items are easier to reduce to minute particles and provide more energy than raw food, thereby ensuring a higher energy balance.

Changes in diet and food properties affect the masticatory structures in two main ways. On the one hand, modern food influences craniodental phenotypic expression as it requires low chewing effort (19) thereby exerting limited masticatory forces on the facial and dental structures during growth, leading to low bite force, reduced jaw development and diminished stimuli for dental eruption (20-24). On the other hand, the high occurrence of genetic factors contributing to dental anomalies and dysgnathia in industrial societies can be explained by the dramatic reduction of selective pressure on the masticatory system, (see for example, 25, 26).

The idea that cultural and technological changes have influenced the shape of the maxillofacial complex is not recent (21-24). The anthropological research (27-31) indicated a trend towards a general gracilization of the masticatory system, where modern humans in industrialized societies are mostly characterized by longer faces, smaller jaws, narrow dental arches and a deep and narrow palate. Moreover, a reduced amount of wear is thought to be an additional cause of imbalance resulting in dental crowding and crown tilting in children and adults (32). Mandibular shape differences between hunter-gatherers and agriculturists, the latter possessing a slenderer and more posteriorly inclined mandibular ramus, reflect the remarkable changes in quality and texture of food occurred with the emergence of agriculture (about 12,000 years ago) (33, 34). Experimental animal research investigating the effect of a soft diet on growing individuals has confirmed this general trend of reduction of the maxillofacial structures, including the jaws and hard palate, increased prevalence of malocclusion, as well as decreased bone density (35-41).

Growth studies have highlighted that, as a result of superior and backward growth, the maxilla is displaced downward and forward promoting the advancement of the mandible (42). Moreover, a positive correlation between the inclination of the occlusal plane and the inclination of the mandible was found and a reduced vertical growth of the posterior region of the maxilla has been associated with a retrognathic mandible (43) (defined as skeletal Class II facial type in dentistry). These observations highlight the developmental relationship between the structures of the lower face and occlusion and can help clinical interpretation of dysgnathia. In summary, there is evidence supporting the hypothesis that changes in diet and food properties resulting from cultural and technical advancements have affected the stomatognathic structures.

Do dietary-related changes in the orofacial structures have functional implications?

The effects of a modern diet on dental occlusion have been demonstrated by Silvester et al. (44) using quantitative approaches for the investigation of the occlusal pattern (45, 46). This study showed that a refined diet alters the dental occlusal pattern, which results in reduced macrowear associated with power stroke in Phase I of mastication (shearing and crushing) relative to Phase II (grinding). A simulation of the power stroke of the chewing cycle revealed that molar occlusion as found in medieval populations, consuming tougher, less refined foods, was associated with a greater lateral component of mandibular movements. Conversely, post-industrial individuals consuming softer bread possessed a dropshaped chewing cycle, reflecting a reduced lateral excursion of the mandible during the power stroke. This shape is commonly depicted in dentistry books (e.g., 47) confirming that it represents the chewing cycle of recent populations well. Already in 1984, Smith noticed that agriculturalists showed steeper, more oblique occlusal facets than hunter-gatherers and claimed that that was associated with the consumption of processed and cooked grains. Clinical feeding studies, such as that by Laird et al. (49) found that tougher and harder foods are chewed with a larger lateral component of jaw movement than soft foods. Thus, it is reasonable to assume that harder and tougher foods, requiring a higher shearing component for comminution, cause the occlusal surfaces to become flatter, in turn allowing movements with a larger lateral component.

A study testing occlusal forces in Punjabis, India, has demonstrated lower chewing forces in the people living in urbanized settings and consuming processed food with respect to those in rural sites, consuming less refined food items (50). Differently from the urban sample, the rural group showed sexual dimorphism in both habitual chewing forces and maximum bite forces, both higher in males than females. Moreover, bite forces, were correlated with body size and jaw size within the various studied groups. A rat-model laboratory experiment showed that masticatory function is reduced in individuals exposed to a soft diet, even if later rehabilitated on a hard diet (51) confirming a tight relationship between food mechanical properties and texture and masticatory function and showing that chewing dexterity is developed early in the lifespan of an individual. In fact, this skill might be established in humans already in the first two years of life following tooth eruption (52).

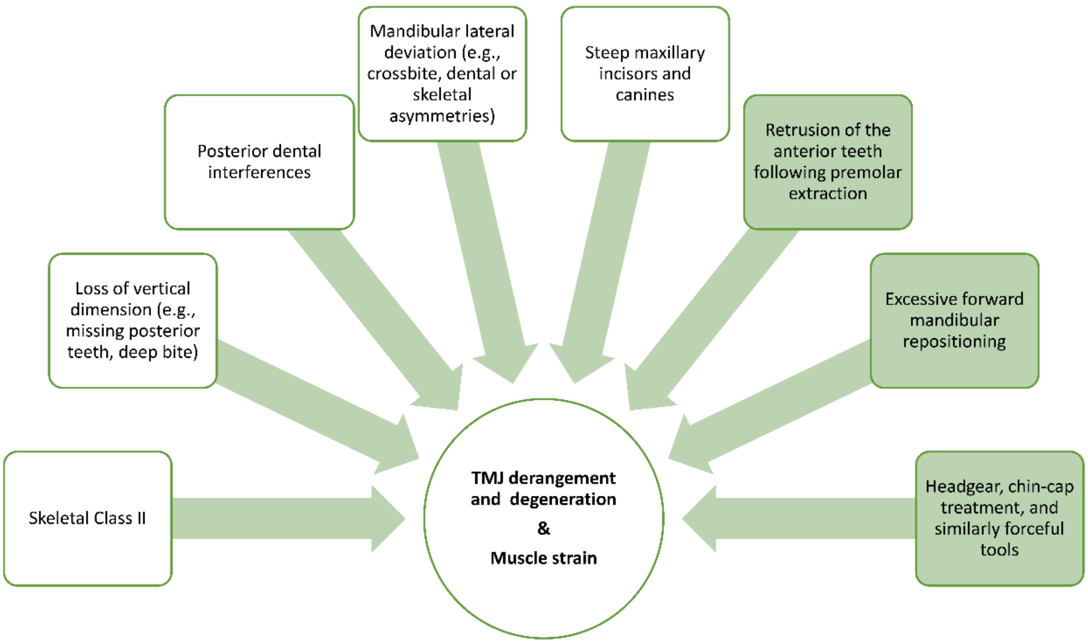

Figure 1. Scheme of the main occlusal conditions leading to craniomandibular dysfunctions. In this illustration, the main natural (open boxes) and iatrogenic (closed boxes) occlusal conditions leading to disturbances of the temporomandibular joint (TMJ) and neuromuscular disruption with consequent muscle strain are indicated.

The functional relevance of dental arches anomalies has been variously shown. Deep bite malocclusion in children causes higher-than-expected masseter and anterior temporalis muscle electromyogram activity during chewing (53). According to Bakke (54), malocclusions reduce bite forces. High dyskinetic chewing patterns are known to characterize individuals affected by posterior crossbite, who present a reverse direction of mandibular closure and altered neuromuscular activity (55). Open bite has been shown to impoverish speech quality by distorting the pronunciation of consonants (56). Based on condylographic tracings, Londoño et al. (57) showed that mandibular kinematics is disrupted by premolar extraction performed before orthodontic treatment, in the absence of other kinds of malocclusion.

Are malocclusions causal to CMD?

Establishing causality in complex biological phenomena is challenging especially when the subjects of study are humans because of ethical limitations in the design of the investigation (58). However, some occlusal determinants have been consistently associated with CMDs, as summarized in Figure 1 and discussed as follows. Ricketts (59-61) was among the first to clearly define natural and iatrogenic occlusal conditions leading to CMDs. He reported molar interferences and lack of posterior support as direct causes of condylar degeneration in the cases in which these conditions would compress the condyle to a posterior or posterosuperior position within the glenoid fossa. Similarly, he considered excessive orthodontic retrusion of incisors and canines following premolar extraction – a common practice for correction of skeletal Class II malocclusion – as a possible cause of iatrogenic TMJ degeneration, when constraining the condyles backward or upward. Relatively steep maxillary anterior teeth were also shown to be associated with high sleep bruxism activity (62).

Ricketts also mentioned excessive mandibular forward repositioning - placing the condyle below the anterior eminence - as a cause of condylar resorption and flattening. Additionally, he observed that, in individuals presenting skeletal Class II, the condyle was subjected to larger displacements during opening and closing movements than the controls and postulated that this would require a more intense muscular activity and thus be a possible cause for muscle strain, especially while talking. This assumption is well supported by a recent study (63) showing the antagonist activity of the lateral and medial pterygoids during speech. In the same way, Ricketts thought that irregularities of the opening-closing pattern owing to lateral deviations of the mandible would cause muscle disturbances. Individuals affected by unilateral TMJ disc displacement have been consistently described as characterized by facial asymmetry with a deviation of the mandible toward the side of the displaced disc (64-66). Moreover, TMJ disc displacement is associated with higher prevalence of degenerative joint diseases which is compatible with the idea of possible local mechanical damage (67).

The dental literature on the association between these and other kinds of malocclusions in relation to CMD is vast and highly heterogeneous, making it difficult to assess its cumulative outcome (68). Lack of standardization and, in some instances, poor scientific rigor have contributed to the confusion surrounding the topic (e.g., 69). However, a clear cause-effect pattern emerges from experimental animal models, in which CMDs are routinely induced via alterations of the dental occlusion (70). In particular, the unilateral crossbite model has been used to induce TMJ degeneration (71, 72), while neuromuscular pain is caused by the insertion of an occlusal interference (73). Clinical studies have also shown that sudden changes in occlusion by the insertion of artificial interferences can cause acute muscle pain (74). Similarly, the introduction of loss of dental support induces degenerative changes comparable to those observed in human subjects' with osteoarthritic TMJs (75).

It is often noted that CMD can cause malocclusions, as in the case of temporomandibular disc displacement leading to progressive worsening of dentognathic asymmetries during growth (76) and anterior open bite resulting from primary osteoarthrosis or osteoarthrosis associated with disc displacement and disc degeneration (77). The presence of a bidirectional influence between occlusion and CMD reinforces the idea of a tight relationship between the masticatory structures and their functions.

Discussion

Are CMDs diseases of civilization?

Based on the circumstantial evidence discussed in this review, it is apparent that the consumption of soft and refined food, which is usual in modern societies, is mostly responsible for the reduction of the stomatognathic system and the concomitant higher prevalence of malocclusions, altering the dentognathic relationship in the vertical, transversal and anteroposterior directions (see flowchart in Figure 2). It is also reasonable to think that these relaxed selection pressures on the masticatory apparatus might result in functionally suboptimal configurations of the stomatognathic system, leading some individuals to clinically relevant CMDs. Thus, the hypothesis that CMDs are diseases of civilization is supported by this theoretical framework.

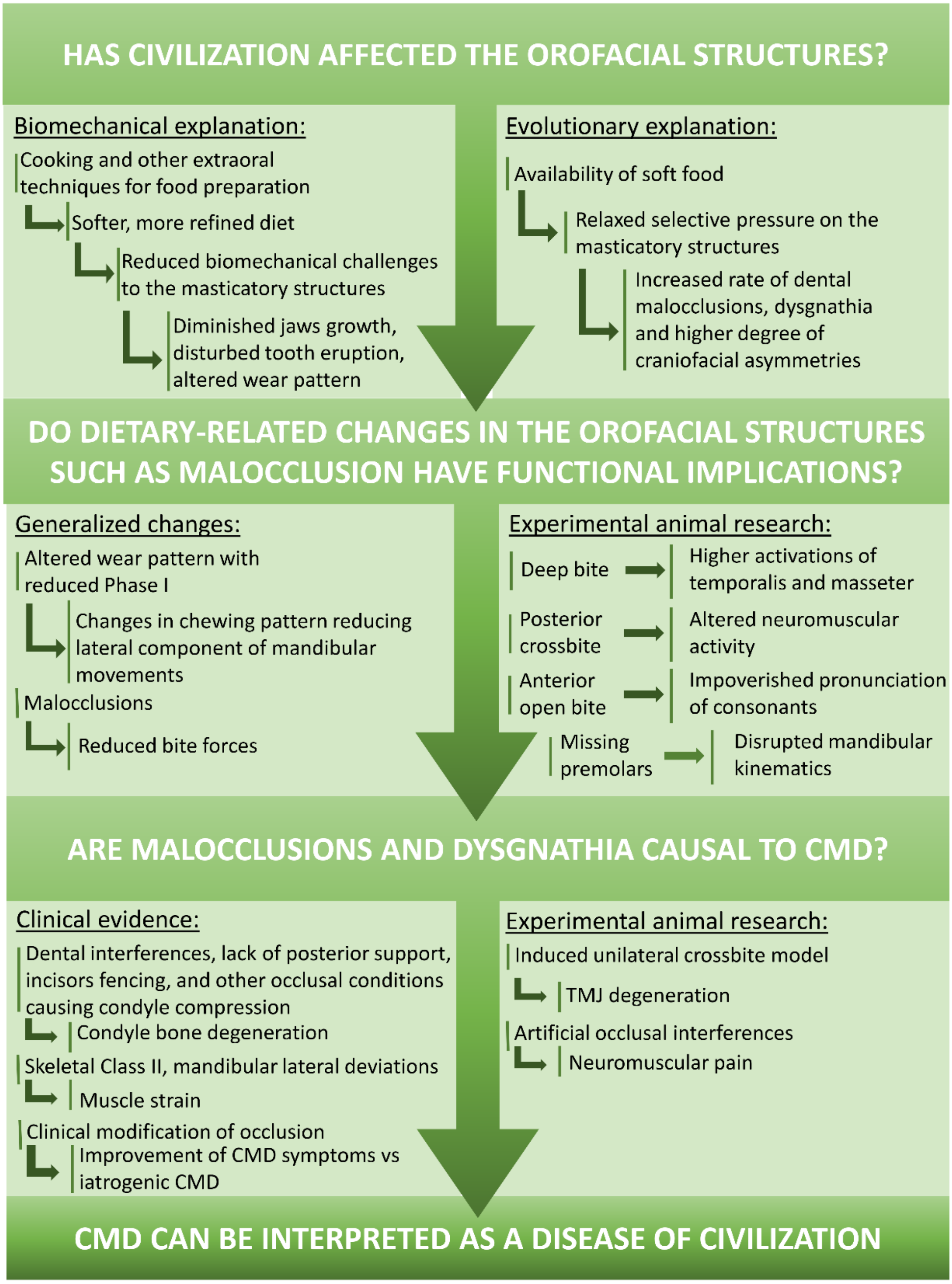

Figure 2. Deductive reasoning for craniomandibular dysfunctions (CMDs) as diseases of civilization. This schematic representation summarizes the deductive reasoning supporting the hypothesis that CMDs are diseases of civilization. In particular, it is shown that civilization has had effects on the craniomandibular structures that in turn have functional implications associated with or causal to CMD.

A direct validation of this reasoning based on hard evidence would require a comparison of the current CMD prevalence and occurrence in pre-industrial societies. However, the assessment of

CMD prevalence in ancient populations is not possible because symptoms cannot be recorded from osteological remains and most of the signs are lost. Structural asymmetries might still be observed (e.g., 78) and signs of bone degeneration might preserve making it possible to score TMJ osteoarthrosis. The current evidence suggests that the prevalence of TMJ osteoarthrosis in different hunter-gatherer groups varied between 11% and 40% (79-81) and was positively correlated with age, female sex and loss of teeth. However, Suby and Giberto (79), who investigated hunter-gatherer Patagonians following standardized criteria for assessment of the severity of osteoarthritic changes (80), detected only mild bone alterations and no manifestation of eburnation.
For an indirect demonstration of the higher prevalence of CMD in recent modern humans with respect to ancient populations, a two-phased project should be designed: first, a comprehensive investigation assessing the risk factors in CMD patients should be conducted focusing on the dental, facial and cranial morphological phenotypes; then, the prevalence of such risk factors should be assessed in past populations for inferring possible prevalence of CMD. Such an endeavour would respond to the need to unravel the mechanistic causes of CMD for improving health care (8, 82).

How should occlusion be interpreted?

The way teeth occlude in maximum intercuspation determines the direction of forces during clenching. It was demonstrated that the degree of wear influences the distribution of forces so that in worn crowns strains are better dissipated, thereby protecting their cervical region (83, 84). Moreover, the inclination of teeth within the dental row is relevant for the strains generated on the alveolar bone, where a lingual tilting might cause buccal alveolar bone resorption and might also be considered at the origin of non-carious cervical lesions (85-87). In clinical settings, the concepts of stable occlusion and TMJ orthopaedic stability, rather than simply malocclusion, have been postulated in relation to CMD (1, 12, 47). In this regard, dental occlusion is interpreted with respect to its functional implication on the TMJ and masticatory muscles. The teeth should allow for TMJ orthopaedic stability when occluding. The TMJ is in orthopaedic stability when the disc is correctly positioned between the condyle and the glenoid fossa and thus the condyle is positioned superoanteriorly and is not in posterior or superior compression. Moreover, during function, neuromuscular-strain-free movements of the jaw should be possible. It is important to remember, that occlusion should withstand strain and stresses generated during functions that are constantly performed during day- and night-time in addition to chewing, such as speech, deglutition, bruxism and clenching (88). Some of the mandibular movements are unconscious and, as in sleep bruxism, the generated occlusal forces might be maintained for several seconds (89). Thus, the functional implication of occlusal relationships should be considered in future studies rather than the mere presence of malocclusion, hence dynamic occlusal determinants should be analyzed in addition to the static ones (12, 86). Investigating the occlusal relationship dynamically would allow exploring the kinematics of the jaw during the initial excursion phase when jaw movements are guided by the slopes of the upper teeth (90). The functional implications of occlusion through the various stages of dental eruption should also be evaluated.
Interventional studies, showing the functional effects of treatments aimed at reaching functional occlusion and orthopaedic stability of the TMJ shall reinforce the outcomes. Additionally, geographical variation in CMDs should be explored by comparing populations with different facial types (91), taking into account their genetic background (25, 26) while the role of diet could be further explored by studying current populations with different subsistence strategies.

Conclusions

The modern human masticatory system shows great phenotypical plasticity. Its shape, robusticity and range of variation within a population are mostly measures of the functional demands to which it is subjected, although the role of genetics should not be disregarded (e.g., 26). Culture and technology have dramatically increased the capability of modern humans to adapt to different environments by exploiting available foods and resources. Nonetheless, they also created a mismatch between the functions of the anatomical structures that were established through adaptive evolutionary processes and their actual use in industrialized societies. As fathomed already by gnathologists of the last century, this incongruity has significant implications for the modern human masticatory system (47, 92, 93). Yet, since this generally recognized idea has not been implemented in clinical practice successfully (94-96), collaborative research efforts should be directed to interdisciplinary research for the understanding of CMD mechanistic and evolutionary origins. CMD patients' quality of life depends on the ability of the medical community to prevent or timely address disorders of their stomatognathic system.

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Declaration of Interest

None

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