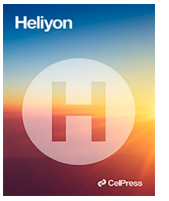
Heliyon 9 (2023) e20307

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Review article

Influence of edentulism on the structure and function of temporomandibular joint

Huiyun Zheng [a,1], Lei Shi [b,1], Hongye Lu [b], Zhichao Liu [a], Mengfei Yu [a], Yu Wang [a,**], Huiming Wang [a,*]

[a] *Department of Oral Implantology, Stomatology Hospital, School of Stomatology, Zhejiang University School of Medicine, Zhejiang Provincial Clinical Research Center for Oral Diseases, Key Laboratory of Oral Biomedical Research of Zhejiang Province, Qiutao North Road 166, Hangzhou 310020, China*

[b] *Department of Prosthodontics, Stomatology Hospital, School of Stomatology, Zhejiang University School of Medicine, Zhejiang Provincial Clinical Research Center for Oral Diseases, Key Laboratory of Oral Biomedical Research of Zhejiang Province, Qiutao North Road 166, Hangzhou 310020, China*

A R T I C L E I N F O

Keywords:
edentulism
Temporomandibular joint
Temporomandibular disorders
Complete denture

A B S T R A C T

Background: With the acceleration of the aging process of the population, the number of edentulous patients continuously increased. Edentulism induces the loss of occlusal relationship and cause adverse effects on the stomatognathic system. Temporomandibular joint (TMJ), as a significant component of this system, may also be affected by edentulism in the process of supporting mandibular movement.

Purpose: Provide a comprehensive review of the structure and function of TMJ in the edentulous population, as well as the prevalence of temporomandibular joint disorder (TMD) in edentulous group.

Study selection: An electronic search was conducted on articles prior to December 2022 to filter all papers relevant to the structure and function of TMJ in edentulous population. The internet databases (PubMed, Cochrane Library, Embase) were searched using various combinations of keywords for "edentulism" or "edentulous" and "TMJ" or "TMD".

Results: Firstly, 522 articles were selected from the internet database, and finally, a total of 44 articles met the inclusion and exclusion criteria. The research content of these articles mainly focuses on the structure and function of TMJ in edentulous patients, as well as the clinical signs and symptoms of TMD.

Conclusions: Edentulous arch induces the loss of occlusal relationship, which may lead to degenerative changes of TMJ components consisting of changes in morphology and bone mass density of condyle, articular fossa, and articular eminence. In addition, the condyle could be shifted backward and upward, and displacement of the articular disc may occur after dentition loss. And the condyle and the articular disc may be guided back to the normal position after effective prosthodontic treatment. But the conclusions of the study on the function of TMJ and the prevalence of TMD in edentulous people are inconsistent. The condition of TMJ, especially the position of condyle-fossa and the symptoms and signs of TMD should not be ignored. If necessary, radiographic examinations should be performed.

* Corresponding author.
** Corresponding author.
E-mail addresses: wangyuzju@zju.edu.cn (Y. Wang), whmwhm@zju.edu.cn (H. Wang).
[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.heliyon.2023.e20307
Received 25 January 2023; Received in revised form 11 September 2023; Accepted 18 September 2023
Available online 23 September 2023

1. Introduction

The proportion of elderly people aged 65 and above is increasing globally. In 2015, it was estimated that this proportion was 8.5%, and it is expected to increase to 12% in 2030 and 16.7% in 2050 [1]. The dramatic increase in the elderly population makes edentulism a more prominent public health problem, which needs to be actively addressed [2]. Edentulism refers to the absence of any natural teeth or roots on the entire dental arch. Loss of occlusal relationship in edentulous patients will disrupt the balance of stomatognathic system. The temporomandibular joint (TMJ), together with the teeth, masticatory muscles, and nerves of the oral and maxillofacial regions, constitutes the stomatognathic system, which involves in diverse oral and maxillofacial functional movements such as chewing, swallowing, and pronunciation. Tooth contact directly affects the force and movement of TMJ. During the process of adapting to changes in occlusal function, the TMJ often undergoes structural remodeling and degenerative changes. When the structural modification of TMJ exceeds the physiological limits of the human body, pathological degenerative changes will occur [3]. Consequently, in the mandibular movement of edentulous patients, changes in the stress environment of TMJ may lead to anatomical structural changes and functional disorders. TMD is a general term for a group of diseases whose etiology is not yet fully understood and which have the same or similar clinical symptoms. Generally, its symptoms are mainly local pain in joint area or masticatory muscle, mandibular movement abnormalities, and joint sounds [4]. The most common types of TMD are pain-related diseases (such as, joint pain, headache attributed to muscle dysfunction, and TMD) and structural disorders related to the TMJ (mainly articular disc displacements and degenerative changes) [5]. According to a systematic review and meta-analysis conducted in 2011, the prevalence of TMD in adults was 31%, and in children and adolescents it was 11% [6]. For a long time, the impact of occlusion on TMJ has been a controversial topic. Similarly, the results on the impact of edentulous jaws on TMJ are inconsistent. Given that TMJ is a pivotal structure in the stomatognathic system, dentists need to pay attention to the health of TMJ before and after prosthetic treatment for edentulous patients. The purpose of this review is to comprehensively summarize the structure and function of TMJ and the current research status of the prevalence of TMD in edentulous people, so as to offer a reference for therapy of edentulous patients.

2. Material and methods

2.1. Search strategy

In December 2022, we conducted a non-systematic literature review without using bias risk tools, as some authors consider that this type of review may not include quality assessment [7,8]. Manual and electronic searches were conducted on PubMed, Cochrane Library, and Embase databases for literature prior to December 2022. The main keywords used for retrieval were as follows: ('edentulism' OR 'edentulous' OR 'edentulousness') AND ('TMJ' OR 'TMD'). These searches were conducted to identify studies exploring influence of edentulism on structure and function of TMJ. Furthermore, we aimed to discuss the relationship between prosthetic treatment and TMD in edentulous patients. Then, we reviewed the bibliography of the included articles and browsed the websites of relevant journals for further manual searches.

2.2. Inclusion criteria

Literature prior to December 2022 were searched. The selection criteria for articles are as follows: (a) English peer-reviewed publications; (b) literatures evaluating the structural changes of the TMJ in edentulous patients, including the condyle, articular fossa, articular eminence, condyle-fossa position, and articular disc; (c) studies investigate the effect of edentulous jaws on functional changes in TMJ such as condylar movement capacity, masticatory function, and functional disorders; (d) studies evaluating the impact of edentulous prosthetic treatment on TMD. This review studies articles relevant to the structure, function, clinical signs, and symptoms of TMJ in edentulous arch, and there are no age restrictions on the study population in the literature. The types of research include animal research, in vitro research, and clinical research, although these studies have limitations on experimental subjects,

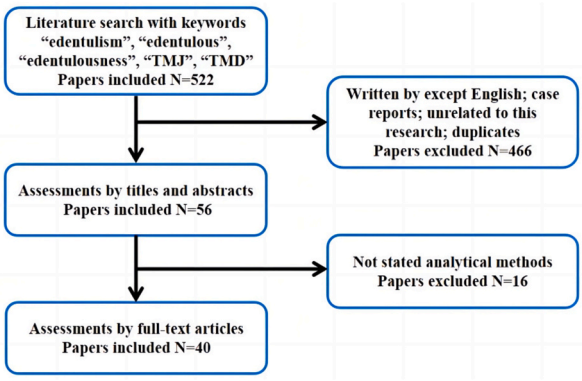


Fig. 1. A flow-chart used for the review to identify studies.

approaches, and sample size.

2.3. Exclusion criteria

Case reports and articles in languages other than English have been excluded. Observational studies that did not describe analytical methods were not included in this review.

3. Results

Fig. 1 shows the literature search strategy used in this study. A total of 522 studies were identified in the literature, of which 56 were selected for full-text screening. 16 studies were excluded and a total of 40 articles were finally selected (Fig. 1). The identified researches focused on several aspects related to TMJ in edentulous arch, namely the structure, function, and clinical signs and symptoms of TMD. The literature retrieval strategy used in this study is shown in Fig. 1. A total of 522 literatures were searched based on search terms, and 56 articles were selected for full text reading after reading titles and abstracts. According to the inclusion and exclusion criteria, 40 articles were ultimately determined (Fig. 1). The main research content included in the literature was the structure, function of TMJ in edentulous patients, and signs and symptoms of TMD.

3.1. Influence of edentulism on structure of TMJ

3.1.1. Changes of bone tissue

The human TMJs often undergo structural reconstruction and degenerative changes. The remodeling process represents the adaption to altered functional demands. However, once the remodeling is beyond the physiological limits, pathological degenerative changes will happen [3]. The degenerative changes of bone structure mainly include subchondral cysts, erosion, sclerosis, and osteophytes. In addition, flattening is an uncertain finding of degenerative changes, as it may imply normal changes, aging,

Table 1
Influence of edentulism on structure of TMJ.

Authors	Year	Type of research	Samples	Methods	Main conclusions
Related to mandibular condyle					
Yalcin ED, et al.	2019	Clinical study	910 subjects	CBCT images	Edentulism could be associated with condylar morphologies in a South-Eastern Anatolian Population.
Hatjigiorgis CG, et al.	1987	Clinical study	27 subjects	X-ray images	In the edentulous group, 63.33% of condyles had reconstruction, and 13.33% of condyles exhibited degenerative changes.
Soikkonen K, et al.	1994	Clinical study	124 subjects	X-ray images	Deviations from normal condylar structure were found in 17% edentulous subjects. Findings indicating osteoarthrosis were found in 16% edentulous subjects.
Soikkonen K, et al.	1996	Clinical study	293 subjects	X-ray images	There were no significant differences in the condylar changes between the dentate and edentulous groups.
Whittaker DK, et al.	1985	Vitro study	204 skulls	Skulls study	There was a good correlation between teeth lost on one side of the arch and severity of form and surface change in the contralateral condyle.
Grunert I, et al.	2000	Vitro study	22 subjects	Autopsy study	In cases when pathological findings are found in both joints, the most common location in the joint with severe pathology is in the lateral third, whereas the contra-lateral joint reveals pathological findings in the medial and central parts.
Aggarwal H, et al.	2015	Clinical study	20 subjects	CT images	The cortical and medullary densities of the mandibular condyle were less in edentulous than that in the dentulous jaws.
Coşgunarslan A, et al.	2021	Clinical study	68 subjects	CBCT images	The mean FD value of the mandibular condyles in the edentulous group was significantly lower than the dentate group.
Related to articular fossa					
Rosado LPL, et al.	2021	Clinical study	100 subjects	CBCT images	Edentulous participants showed a higher mandibular fossa lateral inclination and lower roof thickness than dentate participants.
Raustia AM, et al.	1998	Clinical study	85 subjects	X-ray images	The position of the glenoid fossa was more anterior in edentulous subjects than in dentate ones and its anterior position correlated significantly with the period of edentulousness.
Magnusson C, et al.	2012	Vitro study	259 skulls	Skulls study	Degenerative changes in form and surface of condyles and temporal components strongly correlate occlusal support in women but not in men.
Magnusson C, et al.	2010	Vitro study	259 skulls	Skulls study	Loss of occlusal support is a causative factor for degenerative changes in the TMJs in female subjects at higher ages.
Related to articular eminence					
Unal EZ, et al.	2020	Clinical study	100 subjects	X-ray images	Edentulous patients had lower AEI than dentate patients, and it was more prominent in female than male patients.
Csadó K, et al.	2012	Clinical study	30 subjects	X-ray images	The flattening of the AE could be correlated with age; however, the decline of AEI is significantly more in completely edentulous patients than in patients with maintained occlusion.

remodeling, or its precursors The degenerative changes in bone structure mainly include subchondral cyst, erosion, sclerosis, and osteophyte. Moreover, flattening is an uncertain finding for degenerative changes as it may imply normal changes, aging, remodeling, or its precursor [9]. Many literatures [10–23] have reported various degenerative changes in the bone structure of TMJ in edentulous people. The selected studies are summarized in Table 1.

3.1.1.1. Mandibular condyle. The condylar head rotates within the encompassing meniscus and together they translate against the articular eminence [24]. According to the classification given by Yale et al. [25,26], the morphology of the condyle was classified as flat, round, convex, and angled in coronal sections. A study found that angled condyle was the mostcommon in partial edentulism and complete edentulism, and flat condyle was more common in partial edentulism compared to complete edentulism [10]. Another study found that 63.33% of condyles in the edentulous patients had reconstruction that included flattening of the posterior surface and superior surface, and 13.33% of condyles in the edentulous patients exhibited degenerative changes [11]. In addition, Soikkonen K et al. [12] studied the radiographic materials of 124 clinically edentulous old patients and found degenerative changes in 20 persons (16%). While, they included the dentate group in another study [13] and discovered that there were no obvious contrasts in the condylar changes between the dentate and edentulous groups.

TMJ is the only bilateral linkage joint in the human body, so changes in the left and right joints may also be related to each other. A study found through analysis of 204 skulls that tooth loss on one side of the arch of the foot is related to the severity of changes in the shape and surface of the contralateral condylar head A study discovered that teeth loss on one side of the arch was related to the severity of changes in the shape and surface of the contralateral condylar head by analyzing 204 skulls [14]. Another study reported that remodeling of the condyle was found in 65% joints and osteoarthrotic changes in 10% joints according to an investigation of both joints of 22 edentulous individuals. In cases when both joints have pathological results, the most common severe pathological site in the joint is the lateral third, while the contralateral joint has pathologic results in the central and medical areas [15]. This may be the reason for lateral movement of the mandible, which can lead to local overload of bilateral joints.

The internal structure of bones is adapted to the constantly changing functional loads and mechanical environment [27]. So the condylar bone structure will also adapt to the reduced occlusal load of completely edentulous jaws. The cortical and medullary densities of the edentulous condyle were lower than that of the dentulous jaws [16]. In addition, the internal bone structure of mandibular condyles was influenced by edentulism [17]. The fractal dimension (FD) value is a quantitative parameter used to measure the complexity of self-similar structures such as trabeculae, and is related to bone density, trabecular porosity, and connectivity. Previous studies have shown that FD increases with increasing bone complexity [28]. According to their results, the average FD value of the mandibular condyles in the edentulous group was significantly lower than the dentate group. Therefore, the TMJ may cause condylar remodeling during the process of adapting to reduced occlusal load. When remodeling exceeds physiological limits, degenerative diseases will occur in the joints [3].

3.1.1.2. Articular fossa. The articular fossa is a bone structure located above the mandibular condyle, and in front of it is articular eminence. A comparative study of CBCT in 100 patients showed a higher proportion of bone changes such as osteophytes, resorption, and sclerosis in condyle, lower mandibular roof thickness, and higher mandibular fossa lateral inclination in edentulous patients compared with dentate patients [18]. In the presence of bone resorption in condyle, the bone at the top of the articular fossa thickened, and this compensatory bone formatted to support increased TMJ stress due to changes in the condylar bone [29,30]. However, most edentulous patients are aging people with weakened ability of tissue regeneration and metabolic function, the bone at the top of the articular fossa cannot be effectively compensated. Abnormal changes in bone structure of TMJ will increase the stress of the joint, then lead to functional changes of TMJ. When the function of edentulous patients is significantly changed, the mandibular fossa, as a part of the functional entity, was a remodeling unit [19]. A study analyzed 259 skulls and observed the morphology and surface degenerative changes of the condyle and joint fossa [20,31]. They found a strong correlation between occlusal support and the degenerative changes in women, but not in men. This may be the cause of hormones.

3.1.1.3. Articular eminence. The condylar head together with articular disk translate against the articular eminence (AE) during the mandibular movements [32]. The inclination of the articular eminence (AEI) is related to the Frankfort horizontal plane [33], which affects the trajectory of condylar movement and the rotation of the articular disk [22,32,34–36]. The AEI shows significant individual differences with the value ranging from 30° to 94° [37]. Virlan MJR et al. [33] c onsidered that although biological gender or age as confounding factors might influence the results in some papers [20–23,35,38,39], edentulism had a significant role on the decline of the AEI. Other studies found that AEI values in edentulous patients were lower than that in dentate patients via imaging studies [22, 23]. However, Unal EZ et al. [22] found no significant positive correlation between the duration of edentulism and AEI. Csadó K et al. [23] stated that the flat AE may be related to age. However, they found that tooth loss had a stronger impact on the flat posterior slope of the AEthan aging. These different outcomes may be due to various sources and quantities of samples and different measurement methods.

3.1.1.4. Condyle-fossa position. In edentulous patients, both apical and posterior occlusal contact positions are absent. The position of the condyle in the joint fossa may alter when the residual alveolar ridges of the maxilla and mandible approach. A group of researchers studied Schuller's positional radiographs of ten edentulous patients to determine the positional relationship of TMJ in two situations: (1) complete dentures are occluded in the correct horizontal and vertical position, (2) the residual alveolar ridges of the maxilla and mandible are as close as possible [40]. They defined latter position as "the edentulous position of TMJ". They found that the posterior

and upper joint spaces of the edentulous position decreased obviously when compared with that of intercuspal position in edentulous patients with complete dentures. But there was no significant increase in the anterior joint spaces in the edentulous position compared with that of intercuspal position in edentulous patients with complete dentures. It suggested that the condyle in the edentulous position of the TMJ can rotate backward and upward with the forward and backward movement of the mandible, it may result in the decrease of the posterior articular space, increase of anterior articular space, and anterior displacement of the articular disc (Fig. 3). The normal TMJ structure is shown in Fig. 2. Another study investigated radiographic data of 20 edentulous subjects and 49 dentate subjects [19]. They found that compared to subjects with teeth, edentulous subjects had a more anterior position of the joint fossa, and its anterior position was significantly correlated with the edentulous period. These studies show that accurate occlusal vertical distance and intercuspal position are important not only for the functional and aesthetic recovery of dentures, but also for maintaining the normal position of the condyle in the joint fossa, so as to prevent TMJ disorders.

3.1.2. Changes of articular disc

The TMJ articular disc can be divided into anterior zone, intermediate zone, posterior zone, and bilaminar zone (BZ) in sagittal direction. The BZ of the TMJ consists of two layers. The upper layer consists of loosely arranged fibrous-elastic tissue; the lower layer is composed of dense connective tissue with few elastic fibres [41]. A study observed 14 dentulous adults (GI) and 14 edentulous elderly adults (GII) by light microscopy and electron microscopy scanning [42]. They found that compared to GII, the vascular spaces in GI is smaller and the elastic fibers are thicker and more abundant. Another research studied displacement, deformation and perforation of articular disk, and bone tissue of 248 joints removed from fresh cadavers [43]. While the results showed that tooth loss seemed to have no effect on the amount of morphologic changes in the TMJ at the end of life.

The articular disc is a cartilaginous spacer in the TMJ, which is used to weaken a and disperse forces acting on it [44]. A study compared the presence of vascular endothelial growth factor (VEGF), proteoglycan versican, and collagen type 1 in the articular discs which were removed from 17 donated human bodies [44]. Their results indicated that when the occlusal support area had been lost, the presence of the neoangiogenesis factor VEGF and proteoglycan versican increased. In contrast, the amount of collagen type 1 decreased. The decrease of collagen type 1 and the increase of versican and VEGF indicated that degeneration was exacerbated due to tooth loss.

3.2. Influence of edentulism on function of TMJ

The loss of occlusal support has been regarded as one of the causes of masticatory system dysfunction. The importance of occlusal support in the masticatory system is obvious, but its role in the development of temporomandibular dysfunction or TMD remains controversial. TMD is the general name of a class of diseases, which refers to the structural and functional disorders related to the TMJ, masticatory muscles or both [45,46]. These are also known as temporomandibular pain dysfunction disorders. There is another disease with similar signs and symptoms to TMD, namely craniomandibular disorders (CMD). CMD exists in all ages, and its most common signs and symptoms are clicking and crepitation of TMJ, TMJ pain, irregular mandibular movement, pain on movement of the mandible, in addition to facial pain and headache [47]. One of the purposes of this review is to investigate the influence of edentulous jaws on functional changes in TMJ. Consequently, these two diseases will be involved in this review.

There are different opinions on the association between TMD and teeth loss. A study found that TMJ dysfunction was associated with fewer teeth, especially posterior teeth [48]. In addition, another study found that people with fewer posterior teeth loss but more quadrants, especially young women, had a higher risk of developing TMD [49]. The absence of mandibular posterior teeth was positively correlated with disk displacement [50]. But no results showed that repairing missing posterior teeth could prevent the development of TMDs. However, the loss of mandibular posterior teeth may accelerate the development of degenerative diseases in TMJ. On the contrary, some studies have found no reliable evidence to suggest any correlation between loss of occlusal support and TMJ dysfunction, although the loss of posterior dentition cannot be ignored [51,52].

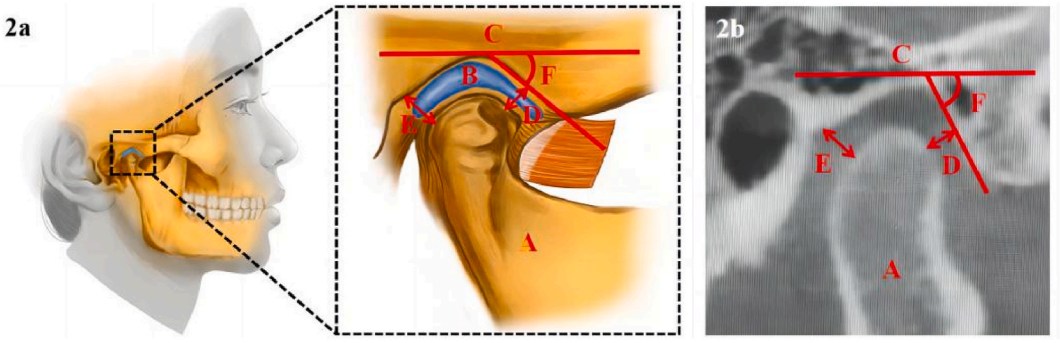


Fig. 2. Normal structure of TMJ with natural teeth. 2a) Diagrammatic sketch of normal TMJ with natural teeth. 2b) CBCT of normal TMJ with natural teeth. A: mandible; B: articular disc; C: glenoid fossa; D: anterior joint space; E: posterior joint space; F: AEI.
TMJ: temporomandibular joint. CBCT: Cone Beam Computed Tomography. AEI: angle of articular eminence inclination.

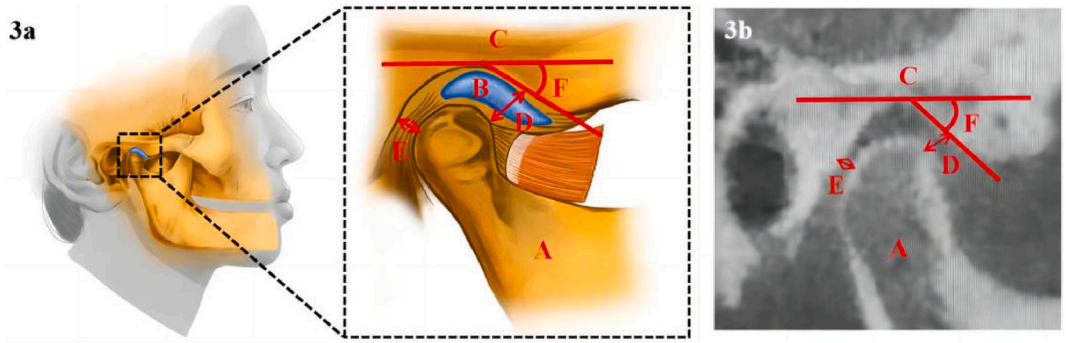


Fig. 3. The structure of TMJ with dentition loss. 3a) Diagrammatic sketch of TMJ with dentition loss. 3b) CBCT of TMJ with dentition loss. A: mandible; B: articular disc; C: glenoid fossa; D: anterior joint space; E: posterior joint space; F: AEI. After the dentition loss, the condyle may rotate upward and backward with the symphysis of the mandible moving forward and upward, it may result in the increase of anterior articular space, decrease of the posterior articular space, and anterior displacement of the articular disc. In addition, edentulism may also result in the decrease of AEI.
TMJ: temporomandibular joint. CBCT: Cone Beam Computed Tomography. AEI: angle of articular eminence inclination.

The influence of dentition loss on the structure of TMJ has been described above. What about the influence of dentition loss on the function of TMJ? How does it relate to TMD? The existing literatures show that the association between edentulism and TMD symptoms and signs remain contradictory. The main points of the included studies are shown in Table 2.

3.2.1. Condylar movement capacity

Many authors have shown that in dentulous subjects, the movement ability of the condyle is influenced by the morphological characteristics of mandibular movement and disk-condyle assembly [53–55]. A study analyzed the translation and rotation of the hinge axis during the opening and closing processes of dentulous subjects and edentulous subjects [56]. They found that the average length of rotation and translation of the hinge axis in the opening and closing movements of edentulous group was smaller than that of edentulous group. It showed that the condylar movement ability of edentulous patients reduced. Another study recorded the condylar shape, inclination, and motion characteristics of completely edentulous patients receiving a new set of complete dentures during protrusive movement [57]. The results indicated that the age and edentulous state of patients have a significant impact on the characteristics of the condylar pathway during the process of condylar protrusion. When the condyle protruded forward, the most

Table 2
Influence of edentulism on function of TMJ.

Authors	Year	Type of research	Samples	Methods	Main conclusions
Related to condylar movement capacity					
Matsumoto A, et al.	1995	Clinical study	100 subjects	Computer-aided diagnostic axiograph	The mean length of translation and the rotation of hinge axis in opening and closing movements was smaller in edentulous subjects than in dentulous ones. No significant difference was shown between two groups on translative quantity in protrusive movement.
Hüe O	2011	Clinical study	60 subjects	Electronic axiograph	In completely edentulous patients, the condylar path patterns during protrusive movement were different than conventionally described patterns. The sinusoidal form condylar path was most frequently found, and the condylar slope incline was low.
Related to masticatory function					
Klemetti E, et al.	1995	Clinical study	355 subjects	Clinical examination	Decreasing functional exercise of the jaws after dentition loss was more found to diminish the size of the masticatory muscles making them disposed to mandibular dysfunction symptoms.
Tortopidis D, et al.	1999	Clinical study	21 subjects	EMG and bite force measurement	The maximum bite force was low in edentulous subjects and was further reduced in edentulous TMD subjects; endurance time and fatigue resistance of the masseter muscles were reduced in edentulous TMD subjects.
Gökçe B, et al.	2009	Clinical study	80 subjects	Mandibular goniometer test	Tooth loss resulted in a decrease in angle of mouth opening values independent of gender and age.
Tzakis MG, et al.	1994	Clinical study	35 subjects	Clinical examination, and questionnaire	In this group of 90-year-old, their masticatory ability is good in spite of a reduced bite force and most of them had no severe signs and symptoms of TMD.
Related to functional disorders					
Shetty R, et al.	2010	Clinical study	100 subjects	Clinical examination	In edentulous patients, 59% had one or as many as three signs of temporomandibular dysfunction. The most commonly seen joint dysfunction was the joint sounds which was 47%.

common path was the sinusoidal condyle path, with a lower slope of the condyle. They suggested that among complete denture wearers, these features have a direct effect on the occlusal morphology of the posterior teeth, and dentists need to consider them in the final occlusal selective grinding stage.

3.2.2. Masticatory function

Research has found that reducing mandibular functional exercise after dentition loss can reduce the size of the masticatory muscles, making them more prone to symptoms of mandibular dysfunction [58]. A study evaluated bite force and electromyography (EMG) activity of 11 healthy edentulous subjects and 10 edentulous patients with TMD [59]. There results showed that compared with edentulous subjects, edentulous patients with TMD have a reduced maximum bite force and a decreased fatigue resistance of the masseter muscles. There are two possible explanations for their results. Firstly, pain in the masticatory muscles of TMD patients may indirectly influenced fatigue tolerance of muscle, as these muscles are unable to function for a long time due to limited use [60]. Secondly, in this group, discomfort with dentures and transducers may be more severe as they are unwilling to tolerate greater discomfort than existing ones [59].

In addition, another study compared the opening angles of similarly aged subjects dentate and edentulous subjects [61]. They found that the opening angle values of dentate group were significantly higher than those of subjects without teeth. The research results indicated that regardless of gender and age, tooth loss can lead to a decrease in opening angle values, and if the dentition is maintained in good condition, oral function may be well preserved with age.

On the contrary, a team examined function and dysfunction of the masticatory system of 35 90-year-old subjects [62]. The results showed that in addition to a decrease in bite force, this group of subjects thought their chewing function was good, and most of them did not have obvious signs and symptoms of TMD.

3.2.3. Functional disorders

Epidemiological studies have shown that approximately 75% of the population has at least one sign of dysfunction (such as joint noise, abnormal mouth opening, intermittent locking), and approximately 33% have at least one symptom of TMD (such as facial pain, pain in jaw) [45]. A study examined 100 asymptomatic edentulous subjects and found that 59% of them showed one to three signs of temporomandibular dysfunction [63]. The most common joint dysfunction was joint sound, with a prevalence rate of 47%. Although TMD is common in the general population [45], the prevalence of TMD in complete denture patients is still uncertain. Epidemiological data indicates that the incidence rate of TMD in this population varies greatly (15%–94%) [64–68]. Different prevalence of TMD may be due to different diagnostic criteria, various sample sizes, and measurement errors. The globally recognized gold standard for the diagnosis of TMD are research diagnostic criteria for temporomandibular disorders (RDC/TMD) and diagnostic criteria for temporomandibular disorders (DC/TMD) [5,46]. Given the limited quantity of researches applying these two diagnostic methods in the identified studies, studies using incomplete diagnostic methods will be included together.

Table 3
Edentulousness and prosthetic treatment were related to TMD.

Authors	Year	Type of research	Samples	Methods	Main conclusions
Sipilä K, et al.	2013	Clinical research	6313 subjects	Clinical examination and home interview	Edentulousness, wearing of complete dentures and poor condition of dentures associated with pain-related TMD findings among women.
Divaris K, et al.	2012	Clinical research	873 subjects	Clinical examination and historic records	Edentulousness was strongly associated with mandibular but not maxillary residual ridge resorption, as well as TMD development.
Goiato MC, et al.	2010	Clinical research	20 subjects	RDC/TMD questionnaire and clinical examination	The intensity and number of occurrences of joint vibrations were reduced after 5 months of wearing new complete dentures.
Faulkner KD, et al.	1991	Clinical research	201 subjects	Anamnestic and clinical examination	Edentulous subjects with a history of fewer sets of complete dentures worn appeared to be correlated with an increase in the number of signs and symptoms of CMD.
Taddei C, et al.	1991	Vitro study	54 TMJs	histomorphometric study	Complete dentures had a favorable protective effect on TMJ structures.
Tervonen T, et al.	1988	Clinical research	1600 subjects	Clinical examination and interview	Subjects with complete dentures had signs and symptoms of dysfunction more often than those with natural dentition.
Klemetti E, et al.	1995	Clinical research	355 subjects	Clinical and anamnestic examinations	Clicking noises in the TMJ and tension in the neck were more common complaints among denture wearers than among dentate subjects.
Amorim VCP, et al.	2003	Clinical research	12 subjects	Tomographic examination	After prosthetic rehabilitation, more pronounced decreases in posterior condylar positions and increases in concentric condylar positions were observed in the maximal intercuspal position in edentulous subjects without symptoms of TMDs
Yan C, et al.	2008	Clinical research	20 subjects	fMRI	Sensory and motor feedback to the central nervous system can be restored by implant-supported full dentures.

3.3. Influence of prosthodontic treatment after dentition loss on TMJ

There are three common restoration options for edentulous patients: complete denture, implant overdenture, and implant-supported fixed denture. Although implant overdenture and implant-supported fixed denture can reduce bone resorption levels, improve retention and stability, and provide patients with a higher degree of satisfaction [69–73], complete denture is the conventional prosthodontic treatment for edentulism and is widely utilized around the world [74]. However, traditional complete dentures have obvious drawbacks, such as the lack of stability and retention of mandibular dentures, bone resorption of residual alveolar ridges and low chewing efficiency [75].

3.3.1. Edentulousness and prosthetic treatment were related to TMD

From the current literature, the influence of whether to accept complete denture treatment after dentition loss and denture characteristics on TMD are uncertain. On the one hand, many studies [76–84] showed that edentulousness and prosthetic treatment were related to TMD. The key points for included studies are shown in Table 3.

Some studies [76,77] showed that the edentulousness was related to the signs and symptoms of TMD. A research suggested that in women, edentulism, complete denture wearing, and poor dentural condition are associated with pain-related TMD manifestations [76]. Another study suggested that the duration of edentulism was associated with a significant increase in the incidence of TMD [77]. Their multivariate analysis of the development of TMD showed that, regardless of age and gender, edentulousness increases the risk of developing TMD. This estimate is equivalent to a 30% increase in TMD risk in edentulous patients over a 10-year period.

In addition, some studies [78–80] suggested that appropriate complete denture restoration was beneficial to the health of TMJ in edentulous patients, while unsatisfactory dentures may lead to signs and symptoms of TMD. Goiato MC et al. [78] found that after wearing a new denture for 5 months, the intensity and frequency of joint vibration decreased. A study examined 201 completely edentulous patients and discovered that wearing fewer complete dentures seems to be related to a higher number of signs and symptoms of CMD [79]. Another study conducted a histomorphometric study of 54 TMJs and found that complete denture restoration had a favorable protective action on the structure of TMJ [80]. In edentulous without prosthodontic therapy group, flattening of the mandibular fossa and thinning of cortical, sponge bones, and fibrocartilage were observed. The mean measured values of the cortical and spongy bones and fibrocartilages in edentulous with complete dentures group were similar to the values in dentate group. It indicated that restoration treatment after dentition loss is helpful to protect the structure of TMJ.

In addition, Tervonen T et al. [81] evaluated the prevalence rate of signs and symptoms of mandibular dysfunction in adults aged 25, 35, 50 and 65. The results showed that the incidence of all clinical symptoms of mandibular dysfunction, except for joint sounds, was lower in natural dentition subjects than in complete denture subjects. The reason for this result may be that long-term use of dentures may lead to unstable dentures, reduced vertical dimension, and incorrect mandibular positioning. These changes may induce muscular changes and joint noise [85]. Therefore, unsatisfactory removable dentures may be a contributor to the development of mandibular dysfunction [86].

A study conducted clinical and anamnestic tests on 355 postmenopausal women [82]. The results suggested that clicking sound and neck tension of TMJ were more common among denture wearers than among dentate subjects. However, they found that the duration of dentition loss was not related to the prevalence of memory related TMD symptoms. The high incidence of those symptoms may be due to loss of vertical dimension or incorrect mandibular position which are common problems among complete denture wearers [67,87,88].

Amorim VCP et al. [80] examined tomographic materials of 12 women before and after the use of a new maxillary complete denture and a mandibular removable partial denture (RPD). They observed that prosthetic rehabilitation caused significant alterations in the condyle-fossa relationship, increased the incidence of concentric condylar positions and reduced the incidence of posterior condylar positions. A group of researchers scanned 20 edentulous patients by functional magnetic resonance imaging (fMRI) and found that

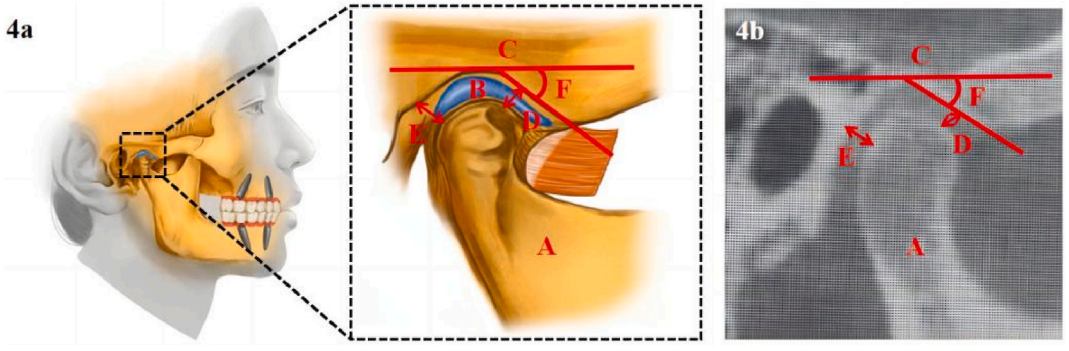


Fig. 4. The structure of TMJ after rehabilitation in edentulous patient. 4a) Diagrammatic sketch of TMJ after restoration in edentulous patient. 4b) CBCT of TMJ after restoration in an edentulous patient. A: mandible; B: articular disc; C: glenoid fossa; D: anterior joint space; E: posterior joint space; F: AEI. The recovery of vertical dimension after rehabilitation will guide the condyle of TMJ to move forward. Then, the anterior articular space is decreased, the posterior space is increased, and the condyle undergo adaptive reconstruction in the functional movement of TMJ.
TMJ: temporomandibular joint. CBCT: Cone Beam Computed Tomography. AEI: angle of articular eminence inclination.

blood oxygen level dependent signals in the primary sensorimotor cortex were increased in implant-supported fixed dentures group compared with complete dentures group [84]. They believe that implant-supported dentures can restore sensory and motor feedback to the central nervous system. The activation of the primary sensory motor cortex in implant-supported dentures wearers may be beneficial for improving tactile, three-dimensional cognitive abilities, and chewing function, which is more similar to natural dentition. Consequently, prevention of complete edentulism is crucial for minimizing the local risk factors for TMD. Enhancing the retention and stability of dentures may be achieved through implant supported overdentures or implant supported fixed dentures, which may help alleviate symptoms of TMD. The structure of TMJ after implant-supported fixed dentures rehabilitation in edentulous patients is shown in Fig. 4. Currently, the research methods for edentulous patients mostly rely on clinical examinations, CBCT, panoramic radiographs, and MRI, with very little use of fMRI. Perhaps in the future, fMRI can be used to evaluate the sensory and chewing function of edentulous patients after restoration, as well as the progression of TMJ dysfunction, from the perspective of changes in cortical activity.

3.3.2. Edentulousness and prosthetic factors were unrelated to TMD

A related review [89] suggested that treatment with new complete dentures does not always provide an improvement in the symptoms of TMD. Another review [87] pointed out that restoration treatment for TMD patients was not suitable for primary therapy of TMD, and should only be performed on prosthetic indications after reversible therapy reduced dysfunction and pain. And some studies [64,90–93] suggested that there were no statistically significant correlations between denture parameters and TMD related signs and symptoms. The key points of the included studies are shown in Table 4.

There a study suggested that there was no positive relation between TMDs prevalence and many prosthetic parameters such as the vertical dimension of occlusion in edentulous subjects, the experience of denture wearing, the amount of used dentures, and the age of the present dentures [90]. Dervis E [64] also pointed out that there was no statistically significant correlation between signs and symptoms of TMD and these factors such as retention and stability of dentures, usage time of present dentures, amount of used dentures, occlusal errors, or freeway space, In addition, another study reported that there were no significant correlations between the deep pain sensitivity of the masticatory muscles and denture quality or vertical dimension of occlusion, but the Oral-Health-Related Quality of Life (OHRQoL) [91].

A group evaluated the masticatory system of 64 edentulous subjects before new complete dentures restoration and after a year of follow up [92]. They found no statistically significant correlation between CMD and the duration of edentulism and the amount of complete denture. Another group studied the prevalence of TMD in 92 subjects with both maxillary and mandibular complete dentures [93]. The RDC/TMD were applied to examine patients. The statistical analysis showed that there were no significant correlation between prosthetic factors and the presence of TMD.

4. Conclusion

The literatures reviewed in this study show that there are different conclusions about the effects of dentition loss on various structures of TMJ. In general, many studies showed that dentition loss would bring degenerative changes to the bone structure of TMJ, the morphology of condyle and mandibular fossa will change, and the density of bone will also be affected. In addition, some researchers observed that in edentulous patients, the condyles move backward and upward, the mandibles rotate forward and upward, and the articular discs move forward with it. After effective prosthodontic treatment, the condyle and the articular disc will be guided back to the normal position.

On the other hand, the literatures reviewed in this study reveal that the prevalence of signs and symptoms of TMD in the edentulous group is still inconsistent. The discrepancies may be caused by various reasons, but the most common are differences in patient

Table 4
Edentulousness and prosthetic factors were unrelated to TMD.

Authors	Year	Type of research	Samples	Methods	Main conclusions
Yannikakis S, et al.	2009	Clinical research	51 subjects	Clinical examination	There was no positive relation between TMDs prevalence and many prosthetic parameters such as the denture experience, the number of dentures used, the age of the present denture and the vertical dimension of occlusion in edentulous subjects.
Dervis E	2004	Clinical research	250 subjects	Clinical examination	No statistically significant correlations were found between signs and symptoms of TMD and denture retention, stability, occlusal errors, freeway space, age of present denture, or number of sets of dentures.
Costa YM, et al.	2015	Clinical research	29 subjects	digital dynamometer test, questionnaire, clinical examination	The deep pain sensitivity of masticatory muscles in complete dentures wearers is associated with OHRQoL, but not with prosthetic factors.
Raustia AM, et al.	1997	Clinical research	62 subjects	Clinical examination	Few complete denture wearers had severe signs and symptoms of CMD. No statistically significant correlation was noted between CMD and either the duration of edentulousness or the number of sets of dentures.
Ribeiro JAM, et al.	2014	Clinical research	92 subjects	Clinical examination based on RDC/TMD	No robust association between prosthetic factors and TMD was found.

selection, TMD diagnostic criteria, clinical examination methods, as well as diversity of the study population, sample size, and different time frames for retrospective studies.

Traditionally, joint load is generated by the interaction of teeth and muscles. The absence of dental arch leads to changes in the biomechanical environment of the masticatory system, which affects the structural characteristics of the loading area, and even leads to pathological changes. However, to what extent the stress changes lead to pathological changes, resulting in TMD symptoms or signs that cannot be quantitatively evaluated. Moreover, based on the limitations of current clinical research and the contradiction of research results, it is impossible to directly link the structural change with the decline of function in TMJ. In addition, in view of the complex aetiologies of TMD, we are unable to make more than general recommendations on prosthetic treatment or TMJ treatment for edentulous patients. However, it should be noted that for edentulous patients, the condition of TMJ, especially the position of condyle-fossa and the symptoms and signs of TMD, should not be ignored. If necessary, radiographic examinations should be carried out to evaluate the condition of the joint in time.

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Data availability statement

No data was used for the research described in the article.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Huiming Wang, Yu Wang and Mengfei Yu report financial support was provided by the National Natural Science Foundation of China under Grant No. 82122014, 82071085, 81800934 and the Joint Founds of the Zhejiang Provincial Natural Science Foundation of China under Grant No. LHDMY23H070003.

References

[1] M. Dunn, K.J. Mulrooney, C. Forlini, K. van de Ven, M. Underwood, The pharmaceuticalisation of 'healthy' ageing: Testosterone enhancement for longevity, Int. J. Drug Pol. 95 (2021), 103159.
[2] A. Porwal, K. Sasaki, Current status of the neutral zone: a literature review, J. Prosthet. Dent 109 (2013) 129–134.
[3] S.B. Milam, Pathogenesis of Degenerative Temporomandibular Joint Arthritides, vol. 93, Odontology, 2005.
[4] T. List, R.H. Jensen, Temporomandibular disorders: old ideas and new concepts, Cephalalgia 37 (2017) 692–704.
[5] E. Schiffman, R. Ohrbach, E. Truelove, J. Look, G. Anderson, J.-P. Goulet, 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 28 (2014).
[6] L.F. Valesan, C.D. Da-Cas, J.C. Réus, A.C.S. Denardin, R.R. Garanhani, D. Bonotto, et al., Prevalence of temporomandibular joint disorders: a systematic review and meta-analysis, Clin. Oral Invest. 25 (2021) 441–453.
[7] M.J. Grant, A. Booth, A typology of reviews: an analysis of 14 review types and associated methodologies, Health Inf. Libr. J. 26 (2009).
[8] M. Pautasso, Ten simple rules for writing a literature review, PLoS Comput. Biol. 9 (2013), e1003149.
[9] R.D. Leeuw, Orofacial Pain: Guidelines for Assessment, Diagnosis, and Management, Quintessence, 2008.
[10] E.D. Yalcin, E. Ararat, Cone-Beam computed tomography study of mandibular condylar morphology, J. Craniofac. Surg. 30 (2019) 2621–2624.
[11] C.G. Hatjigiorgis, R.J. Grisius, R.K. Fenster, P.A. Neff, A tomographic study of the temporomandibular joint of edentulous patients, J. Prosthet. Dent 57 (1987) 354–358.
[12] K. Soikkonen, A. Ainamo, J. Wolf, Q. Xie, R. Tilvis, J. Valvanne, et al., Radiographic findings in the jaws of clinically edentulous old people living at home in Helsinki, Finland, Acta Odontol. Scand. 52 (1994) 229–233.
[13] K. Soikkonen, K. Hiltunen, A. Ainamo, Radiographic condylar findings and occlusal imbalance in old people, J. Oral Rehabil. 23 (1996) 856–859.
[14] D.K. Whittaker, G. Davies, M. Brown, Tooth loss, attrition and temporomandibular joint changes in a Romano-British population, J. Oral Rehabil. 12 (1985) 407–419.
[15] I. Grunert, G.J. Grubwieser, H. Ulmer, Bilateral investigation of the temporomandibular joint. An autopsy study of edentulous individuals, J. Oral Rehabil. 27 (2000) 671–681.
[16] H. Aggarwal, R.D. Singh, M. Kumar, R. Singh, R. Siddhartha, S.K. Jurel, et al., Three-dimensional quantitative analysis of the bone density of mandibular condyle in dentulous and edentulous jaws: an in vivo study, J. Clin. Densitom. 18 (2015) 50–53.
[17] A. Coşgunarslan, D. Soydan Çabuk, E.M. Canger, Effect of total edentulism on the internal bone structure of mandibular condyle: a preliminary study, Oral Radiol. 37 (2021) 268–275.
[18] L.P.L. Rosado, I.S. Barbosa, R.B. Junqueira, A.P.V.B. Martins, F.S. Verner, Morphometric analysis of the mandibular fossa in dentate and edentulous patients: a cone beam computed tomography study, J. Prosthet. Dent 125 (2021) 758, e1-.e7.
[19] A.M. Raustia, P. Pirttiniemi, M.A. Salonen, J. Pyhtinen, Effect of edentulousness on mandibular size and condyle-fossa position, J. Oral Rehabil. 25 (1998) 174–179.
[20] C. Magnusson, M. Nilsson, T. Magnusson, Degenerative changes of the temporomandibular joint. Relationship to ethnicity, sex and occlusal supporting zones based on a skull material, Acta Odontol. Scand. 70 (2012) 207–212.
[21] C. Magnusson, M. Nilsson, T. Magnusson, Degenerative changes in human temporomandibular joints in relation to occlusal support, Acta Odontol. Scand. 68 (2010) 305–311.

[22] Z. Unal Erzurumlu, P. Celenk, A radiological evaluation of the effects of edentulousness on the temporomandibular joint, J. Oral Rehabil. 47 (2020) 319–324.
[23] K. Csadó, K. Márton, P. Kivovics, Anatomical changes in the structure of the temporomandibular joint caused by complete edentulousness, Gerodontology 29 (2012) 111–116.
[24] R. Pertes, Disorders of the Temporomandibular Joint, Temporoman Dibular Disorders & Orofacial Pain, 1995.
[25] S.H. Yale, M. Ceballos, C.S. Kresnoff, J.D. Hauptfuehrer, Some observations on the classification of mandibular condyle types, Oral Surg. Oral Med. Oral Pathol. 16 (1963) 572–577.
[26] S.H. Yale, B.D. Allison, J.D. Hauptfuehrer, An epidemiological assessment of mandibular condyle morphology, Oral Surg. Oral Med. Oral Pathol. 21 (1966) 169–177.
[27] W.G. Geraets, Comparison of two methods for measuring orientation, Bone 23 (1998) 383–388.
[28] B. Arsan, T.E. Köse, E. Çene, İ. Özcan, Assessment of the trabecular structure of mandibular condyles in patients with temporomandibular disorders using fractal analysis, Oral Surg Oral Med Oral Pathol Oral Radiol 123 (2017) 382–391.
[29] A. Tsuruta, K. Yamada, K. Hanada, A. Hosogai, R. Tanaka, J. Koyama, et al., Thickness of the roof of the glenoid fossa and condylar bone change: a CT study, Dentomaxillofacial Radiol. 32 (2003) 217–221.
[30] M. Paknahad, S. Shahidi, M. Akhlaghian, M. Abolvardi, Is mandibular fossa morphology and articular eminence inclination associated with temporomandibular dysfunction? J. Dent. 17 (2016) 134–141.
[31] C. Magnusson, M. Nilsson, T. Magnusson, Degenerative changes in human temporomandibular joints in relation to occlusal support, Acta Odontol. Scand. 68 (2010) 305–311.
[32] E.G. Katsavrias, Changes in articular eminence inclination during the craniofacial growth period, Angle Orthod. 72 (2002) 258–264.
[33] M.J.R. Vîrlan, D.L. Păun, E.N. Bordea, A. Pellegrini, A.D. Spînu, R.V. Ivaşcu, et al., Factors influencing the articular eminence of the temporomandibular joint (Review), Exp. Ther. Med. 22 (2021) 1084.
[34] J. Kranjčić, D. Vojvodić, D. Žabarović, M. Vodanović, D. Komar, K. Mehulić, Differences in articular-eminence inclination between medieval and contemporary human populations, Arch. Oral Biol. 57 (2012) 1147–1152.
[35] M.A. Sümbüllü, F. Cağlayan, H.M. Akgül, A.B. Yilmaz, Radiological examination of the articular eminence morphology using cone beam CT, Dentomaxillofacial Radiol. 41 (2012) 234–240.
[36] N. Pandis, J. Karpac, R. Trevino, B. Williams, A radiographic study of condyle position at various depths of cut in dry skulls with axially corrected lateral tomograms, Am. J. Orthod. Dentofacial Orthop. 100 (1991) 116–122.
[37] D. Zabarović, V. Jerolimov, V. Carek, D. Vojvodić, K. Zabarović, D. Bukovič, The effect of tooth loss on the TM-joint articular eminence inclination, Coll. Antropol. 24 (Suppl 1) (2000) 37–42.
[38] EDd Costa, P.D. Peyneau, G.D. Roque-Torres, D.Q. Freitas, L.R. Ramírez-Sotelo, G.M.B. Ambrosano, et al., The relationship of articular eminence and mandibular fossa morphology to facial profile and gender determined by cone beam computed tomography, Oral Surg Oral Med Oral Pathol Oral Radiol 128 (2019) 660–666.
[39] D. İlgüy, M. İlgüy, E. Fişekçioğlu, S. Dölekoğlu, N. Ersan, Articular eminence inclination, height, and condyle morphology on cone beam computed tomography, Sci. World J. 2014 (2014), 761714.
[40] L. Hongchen, Z. Jilin, L. Ning, Edentulous position of the temporomandibular joint, J. Prosthet. Dent 67 (1992) 401–404.
[41] L. Yang, H. Wang, M. Wang, Y. Ohta, F. Suwa, Development of collagen fibers and vasculature of the fetal TMJ, Okajimas Folia Anat. Jpn. 69 (1992) 145–155.
[42] M.I. Benigno, R.A. Azeredo, J.L. Lemos, B. König Júnior, E.A. Liberti, The structure of the bilaminar zone in the human temporomandibular joint: a light and scanning electron microscopy study in young and elderly subjects, J. Oral Rehabil. 28 (2001) 113–119.
[43] S.E. Widmalm, P.L. Westesson, I.K. Kim, F.J. Pereira, H. Lundh, M.M. Tasaki, Temporomandibular joint pathosis related to sex, age, and dentition in autopsy material, Oral Surg. Oral Med. Oral Pathol. 78 (1994) 416–425.
[44] M. Michaelis, R. Lucius, J. Wiltfang, F. Birkenfeld, Determination of VEGF, collagen type 1 and versican in the discus articularis of the temporomandibular joint in relation to dental status, J. Cranio-Maxillo-Fac. Surg. 46 (2018) 67–74.
[45] C. McNeill, Management of temporomandibular disorders: concepts and controversies, J. Prosthet. Dent 77 (1997) 510–522.
[46] S.F. Dworkin, L. LeResche, Research diagnostic criteria for temporomandibular disorders: review, criteria, examinations and specifications, critique, J. Craniomandib. Disord. 6 (1992) 301–355.
[47] M. Helkimo, Epidemiological Surveys of Dysfunction of the Masticatory System, 1979.
[48] L.P. Harriman, D.A. Snowdon, L.B. Messer, D.M. Rysavy, S.K. Ostwald, C.H. Lai, et al., Temporomandibular joint dysfunction and selected health parameters in the elderly, Oral Surg. Oral Med. Oral Pathol. 70 (1990) 406–413.
[49] M.Q. Wang, F. Xue, J.J. He, J.H. Chen, C.S. Chen, A. Raustia, Missing posterior teeth and risk of temporomandibular disorders, J. Dent. Res. 88 (2009) 942–945.
[50] R.H. Tallents, D.J. Macher, S. Kyrkanides, R.W. Katzberg, M.E. Moss, Prevalence of missing posterior teeth and intraarticular temporomandibular disorders, J. Prosthet. Dent 87 (2002) 45–50.
[51] R. Ciancaglini, E.F. Gherlone, G. Radaelli, Association between loss of occlusal support and symptoms of functional disturbances of the masticatory system, J. Oral Rehabil. 26 (1999) 248–253.
[52] J. Levorová, V. Machoň, A. Guha, R. Foltán, Osteoarthrosis of temporomandibular joint related to the defects of posterior dentition: a retrospective study, Prague Med. Rep. 117 (2016) 176–184.
[53] W.B. Farrar, Characteristics of the condylar path in internal derangements of the TMJ, J. Prosthet. Dent 39 (1978) 319–323.
[54] E. Piehslinger, R.M. Celar, T. Horejs, R. Slavicek, Orthopedic jaw movement observations. Part II: the rotational capacity of the mandible, Cranio 11 (1993) 206–210.
[55] E. Piehslinger, W. Bigenzahn, A. Celar, R. Slavicek, The effect of occlusal splint therapy on different curve parameters of axiographic TMJ tracings, Cranio 13 (1995) 35–41.
[56] A. Matsumoto, R.M. Celar, A. Celar, S. Sato, Y. Suzuki, R. Slavicek, An analysis of hinge axis translation and rotation during opening and closing in dentulous and edentulous subjects, Cranio 13 (1995) 238–241.
[57] O. Hüe, Condylar paths during protrusion in edentulous patients: analysis with electronic axiography, J. Prosthodont. 20 (2011) 294–298.
[58] E. Klemetti, E. Heikelä, Craniomandibular disorders, edentulousness and the clinically estimated size of the masseter muscle, Cranio 13 (1995) 173–176.
[59] D. Tortopidis, M.F. Lyons, R.H. Baxendale, Bite force, endurance and masseter muscle fatigue in healthy edentulous subjects and those with TMD, J. Oral Rehabil. 26 (1999) 321–328.
[60] G.W. Kroon, M. Naeije, Electromyographic evidence of local muscle fatigue in a subgroup of patients with myogenous craniomandibular disorders, Arch. Oral Biol. 37 (1992) 215–218.
[61] B. Gökçe, U.I. Destan, B. Ozpinar, M. Sonugelen, Comparison of mouth opening angle between dentate and edentulous subjects, Cranio 27 (2009) 174–179.
[62] M.G. Tzakis, T. Osterberg, G.E. Carlsson, A study of some masticatory functions in 90-year old subjects, Gerodontology 11 (1994) 25–29.
[63] R. Shetty, Prevalence of signs of temporomandibular joint dysfunction in asymptomatic edentulous subjects: a cross-sectional study, J. Indian Prosthodont. Soc. 10 (2010).
[64] E. Dervis, Changes in temporomandibular disorders after treatment with new complete dentures, J. Oral Rehabil. 31 (2004) 320–326.
[65] G. Agerberg, L. Viklund, Functional disturbances in complete denture patients, Int. J. Prosthodont. (IJP) 2 (1989) 41–50.
[66] M.I. MacEntee, R. Weiss, B.J. Morrison, N.E. Waxler-Morrison, Mandibular dysfunction in an institutionalized and predominantly elderly population, J. Oral Rehabil. 14 (1987) 523–529.
[67] T. Magnusson, Change in recurrent headache and mandibular dysfunction after treatment with new complete dentures, J. Oral Rehabil. 9 (1982).
[68] M.D. Mercado, K.D. Faulkner, The prevalence of craniomandibular disorders in completely edentulous denture-wearing subjects, J. Oral Rehabil. 18 (1991) 231–242.

[69] M. Cune, F. van Kampen, A. van der Bilt, F. Bosman, Patient satisfaction and preference with magnet, bar-clip, and ball-socket retained mandibular implant overdentures: a cross-over clinical trial, Int. J. Prosthodont. (IJP) 18 (2005).
[70] F.A. Fontijn-Tekamp, A.P. Slagter, M.A. van't Hof, M.E. Geertman, W. Kalk, Bite forces with mandibular implant-retained overdentures, J. Dent. Res. 77 (1998) 1832–1839.
[71] V.F. Ferrario, G.M. Tartaglia, M. Maglione, M. Simion, C. Sforza, Neuromuscular coordination of masticatory muscles in subjects with two types of implant-supported prostheses, Clin. Oral Implants Res. 15 (2004) 219–225.
[72] L. Tang, J.P. Lund, R. Taché, C.M. Clokie, J.S. Feine, A within-subject comparison of mandibular long-bar and hybrid implant-supported prostheses: psychometric evaluation and patient preference, J. Dent. Res. 76 (1997) 1675–1683.
[73] M. Bakke, B. Holm, K. Gotfredsen, Masticatory function and patient satisfaction with implant-supported mandibular overdentures: a prospective 5-year study, Int. J. Prosthodont. (IJP) 15 (2002) 575–581.
[74] M.A. Awad, J.P. Lund, S.H. Shapiro, D. Locker, E. Klemetti, A. Chehade, et al., Oral health status and treatment satisfaction with mandibular implant overdentures and conventional dentures: a randomized clinical trial in a senior population, Int. J. Prosthodont. (IJP) 16 (2003) 390–396.
[75] M.A. van Waas, Determinants of dissatisfaction with dentures: a multiple regression analysis, J. Prosthet. Dent 64 (1990) 569–572.
[76] K. Sipilä, R. Näpänkangas, M. Könönen, P. Alanen, A.L. Suominen, The role of dental loss and denture status on clinical signs of temporomandibular disorders, J. Oral Rehabil. 40 (2013) 15–23.
[77] K. Divaris, A. Ntounis, A. Marinis, G. Polyzois, A. Polychronopoulou, Loss of natural dentition: multi-level effects among a geriatric population, Gerodontology 29 (2012) e192–e199.
[78] M.C. Goiato, A.R. Garcia, D.M. dos Santos, A.A. Pesqueira, TMJ vibrations in asymptomatic patients using old and new complete dentures, J. Prosthodont. 19 (2010) 438–442.
[79] K.D. Faulkner, M.D. Mercado, Aetiological factors of craniomandibular disorders in completely edentulous denture-wearing patients, J. Oral Rehabil. 18 (1991) 243–251.
[80] C. Taddei, R.M. Frank, P.M. Cahen, Effects of complete denture wearing on temporomandibular joints: a histomorphometric study, J. Prosthet. Dent 65 (1991) 692–698.
[81] T. Tervonen, M. Knuuttila, Prevalence of signs and symptoms of mandibular dysfunction among adults aged 25, 35, 50 and 65 years in Ostrobothnia, Finland, J. Oral Rehabil. 15 (1988) 455–463.
[82] E. Klemetti, Signs of temporomandibular dysfunction related to edentulousness and complete dentures: an anamnestic study, Cranio 14 (1996) 154–157.
[83] V.C.P. Amorim, D.C. Laganá, J.V. de Paula Eduardo, A.L. Zanetti, Analysis of the condyle/fossa relationship before and after prosthetic rehabilitation with maxillary complete denture and mandibular removable partial denture, J. Prosthet. Dent 89 (2003) 508–514.
[84] C. Yan, L. Ye, J. Zhen, L. Ke, L. Gang, Neuroplasticity of edentulous patients with implant-supported full dentures, Eur. J. Oral Sci. 116 (2008) 387–393.
[85] M.C. Goiato, D.M. dos Santos, D.R. Monteiro, Joint sounds in complete denture wearers. Literature review, N. Y. State Dent. J. 76 (2010) 46–49.
[86] T. Magnusson, Prevalence of recurrent headache and mandibular dysfunction in patients with unsatisfactory complete dentures, Community Dent. Oral Epidemiol. 8 (1980) 159–164.
[87] E. Choy, D.E. Smith, The prevalence of temporomandibular joint disturbances in complete denture patients, J. Oral Rehabil. 7 (1980) 331–352.
[88] M. Bakke, E. Möller, Craniomandibular disorders and masticatory muscle function, Scand. J. Dent. Res. 100 (1992) 32–38.
[89] J.C. Türp, J.R. Strub, Prosthetic rehabilitation in patients with temporomandibular disorders, J. Prosthet. Dent 76 (1996) 418–423.
[90] S. Yannikakis, A. Zissis, A. Harrison, The prevalence of temporomandibular disorders among two different denture-wearing populations, Eur. J. Prosthodont. Restor. Dent. 17 (2009) 35–40.
[91] Y.M. Costa, A.L. Porporatti, P.B. Hilgenberg-Sydney, L.R. Bonjardim, P.C.R. Conti, Deep pain sensitivity is correlated with oral-health-related quality of life but not with prosthetic factors in complete denture wearers, J. Appl. Oral Sci. 23 (2015) 555–561.
[92] A.M. Raustia, M. Peltola, M.A. Salonen, Influence of complete denture renewal on craniomandibular disorders: a 1-year follow-up study, J. Oral Rehabil. 24 (1997) 30–36.
[93] J.A.M. Ribeiro, C.M.B.M. de Resende, A.L.C. Lopes, A. Farias-Neto, AdFP. Carreiro, Association between prosthetic factors and temporomandibular disorders in complete denture wearers, Gerodontology 31 (2014) 308–313.