

Article

An Observational Study of Age-Related Changes in Bite Force During Stabilization Splint Therapy in Patients with Unilateral Temporomandibular Joint Osteoarthritis

Kun-Hwa Kang ¹ , Jae-Kwang Jung ¹, Jin-Seok Byun ¹ and Ji Rak Kim ^{1,2,*} ¹ Department of Oral Medicine, School of Dentistry, Kyungpook National University, Daegu 41940, Republic of Korea² Craniofacial Nerve-Bone Network Research Center, Kyungpook National University, Daegu 41940, Republic of Korea

* Correspondence: jirak@knu.ac.kr

Featured Application

This study suggests that in older patients with TMJ osteoarthritis, clinical evaluation should include not only symptom improvement and joint function but also confirmation of whether bite force recovers to age-appropriate levels. Monitoring bite force during splint therapy may help guide treatment duration, assess functional progression, and support individualized management strategies for older adults.

Abstract

Age-related differences in temporomandibular joint osteoarthritis (TMJ OA) have been suggested; however, age-specific patterns of functional recovery following occlusal splint therapy remain insufficiently characterized. This retrospective observational study evaluated longitudinal changes in bite force across different age groups in patients with unilateral TMJ OA undergoing stabilization splint therapy. Thirty-two patients diagnosed according to the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) were categorized into three age groups (20–39, 40–59, and ≥ 60 years). Maximum bite force was measured repeatedly from baseline to 2 weeks and up to 6 months during the observation period following splint application. Patients aged 60 years and older exhibited significantly lower baseline maximum bite force compared with younger groups ($p = 0.011$), but demonstrated a gradual and statistically significant increase over the observation period ($p = 0.011$). In contrast, patients aged 20–39 years showed a significant improvement in bite force asymmetry after 2 weeks of treatment ($p = 0.047$), which was maintained throughout follow-up. These findings suggest that functional recovery patterns in unilateral TMJ OA may vary according to age, with younger patients showing earlier improvement and older patients demonstrating slower but progressive functional gains. Bite force assessment may serve as a complementary functional parameter for characterizing age-related differences in functional change in patients with unilateral TMJ OA.



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Keywords: age; bite force; osteoarthritis; stabilization splint; temporomandibular disorders

1. Introduction

Temporomandibular disorders (TMD) comprise a heterogeneous group of musculoskeletal and neuromuscular conditions affecting the masticatory muscles, the temporomandibular joint (TMJ), and associated structures, and represent the most prevalent cause

of chronic non-odontogenic orofacial pain [1,2]. The etiology of TMD is multifactorial, involving biological and anatomical factors as well as psychological, behavioral, and social influences [3].

Epidemiological studies have demonstrated age-related variations in both the prevalence and clinical presentation of TMD. While earlier reports suggested that TMD prevalence peaks in younger adults, more recent studies indicate a shift toward middle-aged and older populations [4–8]. Notably, although self-reported TMJ pain tends to decrease with advancing age, radiographic evidence of TMJ degeneration increases, resulting in a discrepancy between symptom severity and structural joint changes [9,10]. Degenerative joint disease of the TMJ, particularly temporomandibular joint osteoarthritis (TMJ OA), is therefore more frequently observed in older adults, even though clinical symptoms are often mild or self-limiting [11–14].

TMJ OA has been shown to impair masticatory function, including reduced occlusal force and discomfort during chewing [15,16]. Although masticatory performance generally declines with age, this decline is largely influenced by systemic or local conditions—such as tooth loss, salivary dysfunction, and neuromuscular impairment—rather than chronological aging alone [17]. Accordingly, evaluation of masticatory function has gained increasing clinical importance, and population-based tools to assess chewing ability have been developed [18]. However, despite the high prevalence of TMJ OA in older adults, age-specific patterns of functional recovery following conservative treatment remain insufficiently characterized.

When diagnosing and managing TMJ OA, consideration of the patient's masticatory function is essential. However, age-specific patterns of functional change during conservative management have not been sufficiently characterized. On this basis, we postulated that occlusal force and its temporal patterns of change may differ between younger and older patients with TMJ osteoarthritis, with older adults potentially exhibiting a slower course of functional change. Accordingly, this observational study aimed to examine longitudinal changes in bite force across different age groups during stabilization splint therapy in patients with unilateral TMJ OA.

2. Materials and Methods

2.1. Subjects

This retrospective observational study analyzed previously collected clinical data from patients who visited the Department of Oral Medicine, Kyungpook National University Dental Hospital due to pain or discomfort of the TMJ and related structures between August 2022 and July 2023. Patients were divided into three groups based on age: the young group (20–39 years), the middle-aged group (40–59 years), and the older adult group (60 years and older). To control psychological factors that could influence TMD, the Symptom Checklist-90-Revised (SCL-90-R) assessment was conducted, and patients scoring 60 or higher in any category were excluded from the study. Patients with systemic pain that could influence bite force were excluded. Additionally, patients with malocclusion, such as open bite or cross bite, and those with missing teeth, except for premolars extracted as part of orthodontic treatment, were also excluded. Non-response to conventional therapy was operationally defined as the persistence of clinically relevant temporomandibular joint pain despite initial conservative management, which included pharmacological treatment and physical therapy. Because bite force is strongly influenced by pain, inclusion of patients with uncontrolled pain would confound the evaluation of occlusal force and its recovery pattern; therefore, only patients who achieved a pain-controlled state were included in the analysis. Furthermore, patients who exhibited additional or progressive condylar bone destruction on follow-up cone-beam computed tomography (CBCT) during the six-month

observation period were excluded (Figure 1). Progressive structural deterioration of the mandibular condyle may independently alter occlusal relationships and bite force; thus, these patients were excluded to allow assessment of occlusal force recovery under relatively stable joint conditions. This study received approval from the Institutional Review Board of Kyungpook National University Dental Hospital (IRB No. KNUDH-2024-10-05-00).

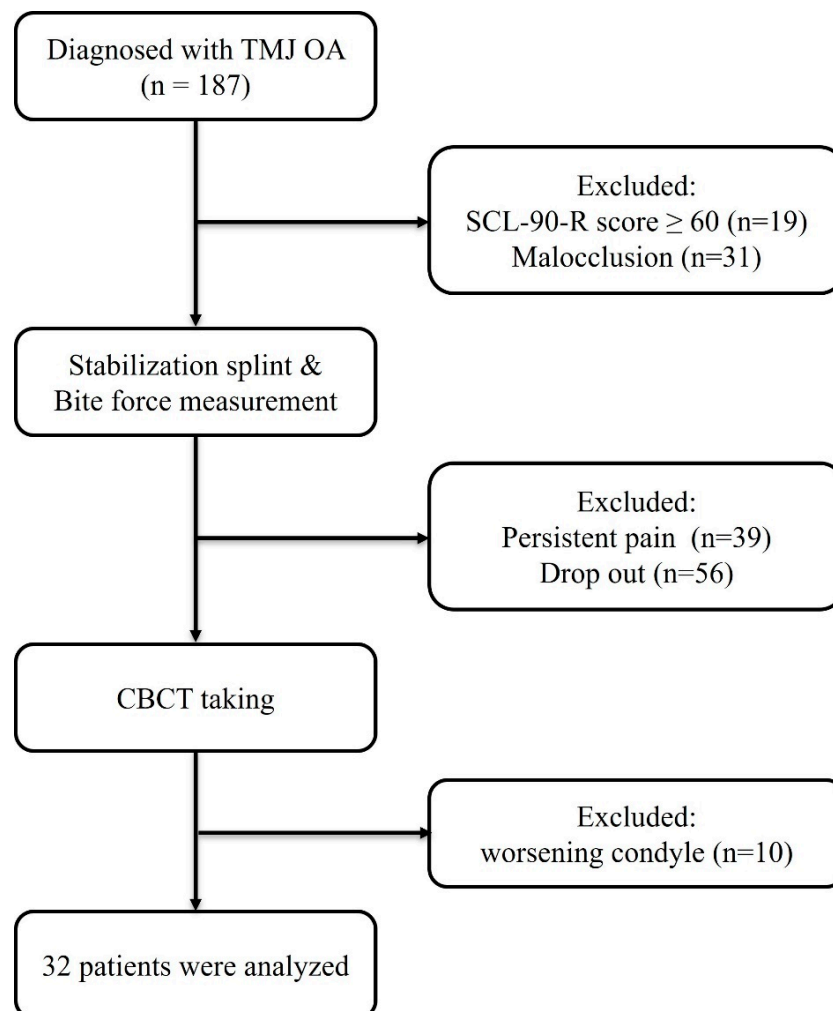


Figure 1. Flow diagram of subjects included and excluded. TMJ OA, temporomandibular joint osteoarthritis; SCL-90-R, symptom checklist-90-revised; CBCT, cone-beam computed tomography.

2.2. Clinical Assessment

Clinical examinations were performed on each patient based on the DC/TMD protocol by one specialist (JRK) of oral medicine [19]. All patients were diagnosed with 3. Joint diseases A. Degenerative joint disease 2. Osteoarthritis.

2.3. Radiological Assessment

TMJ osteoarthritis was defined when degenerative symptoms including erosion, osteophyte, and subchondral cyst on the mandibular condyle were observed by using the CBCT (MercuryRay, Hitachi, Osaka, Japan) with the following parameters, 120 kVp, 15 mA, 19 cm field of view, 0.377 mm voxel, and 9.6 s scanning time [20]. Images were taken in a standing position, with the horizontal plane collateral to the ground and the teeth in maximum occlusion. The diagnosis was made by consensus between two oral and maxillofacial radiologists and an oral medicine specialist.

2.4. Treatment with Stabilization Splint

Occlusal stabilization splint therapy was initiated only after patients had achieved a pain-free state through initial conservative management, including pharmacological treatment and physical therapy. Pharmacological treatment primarily consisted of nonsteroidal anti-inflammatory drugs (NSAIDs), prescribed for 5 to 14 days depending on individual pain severity and limited to the symptomatic period. Physical therapy was applied 2–3 times per week and included heat therapy, electrical muscle stimulation, and low-level laser therapy (LLLT) to the joint area. These initial interventions were intended to control acute pain and inflammation, thereby minimizing the influence of pain on subsequent bite force measurements and allowing assessment of functional recovery during stabilization splint therapy. Mandibular flat plane stabilization splints were fabricated with acrylic resin to ensure coverage of all teeth. The splint was designed with a thickness of 2 mm between the maxillary and mandibular second molars and was adjusted to achieve even contact points across all occluding posterior teeth. Anterior teeth contact was slightly removed; canine guidance was achieved in eccentric movement. Patients were instructed to wear the device for 10 h per day, including during sleep.

2.5. Measurement of Maximum Bite Force

Maximum bite force was assessed using the occlusal force measurement system (Dental Prescale II, GC Corp., Tokyo, Japan). This system comprises 150 µm-thick pressure-sensitive film sheets, constructed with three layers of polyethylene terephthalate that encase a developer layer and a microcapsule layer. The microcapsules, varying in size and thickness, contain red dye-producing agents that are released in response to occlusal pressures up to 120 MPa [21].

Subjects were seated with back support and instructed to clench maximally in the intercuspal position for approximately 3 s, focusing on sustained maximum force rather than instantaneous peak force during clenching. To minimize potential variability related to measurement timing, each participant was consistently assessed either in the morning or in the afternoon across all visits. Prior to measurement, standardized instructions were provided using video-based explanations, and participants were allowed to practice the clenching procedure to ensure familiarity with the protocol. Maximum bite force was assessed using a single sustained clenching trial, as this method has been shown to be sufficient for obtaining reliable maximum bite force values [22]. Repeated measurements within a single visit were not performed, as repeated maximal clenching may induce masticatory muscle fatigue or sensitization, particularly in patients with temporomandibular joint osteoarthritis. After the participant had bitten down, the film was analyzed using image analysis software (Bite Force Analyzer, GC Corp., Tokyo, Japan) and an optical image scanner (GT-X830, Seiko Epson Corp., Tokyo, Japan) (Figure 2). The number of occlusal contact points, area of occlusion (mm²), mean occlusal pressure (MPa), and integrated occlusal load (N) were automatically calculated.

Patients underwent maximum bite force measurement in a pain-free state prior to splint use. The same measurement protocol was repeated at 2 weeks, 1 month, 2 months, 3 months, and 6 months after splint application, with patients confirmed to be in a pain-free state at each time point. Then, the asymmetry index is calculated as a ratio between the OA and normal side [Asymmetry index = (OA side/normal side)].

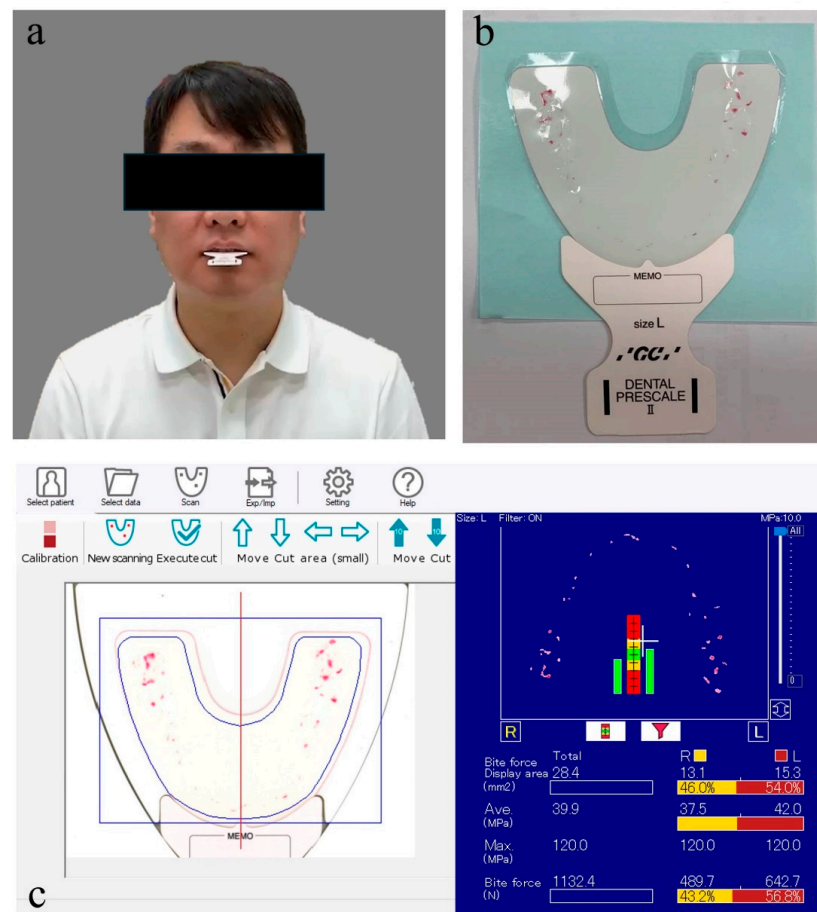


Figure 2. Dental Prescale II System. (a) Bite force measurement process (b) Occlusal film with red markings (c) Bite force analysis results (Bite Force Display Area (mm²); area of occlusion, Ave (MPa); mean occlusal pressure, Max (MPa); maximum occlusal pressure, and Bite Force (N); integrated occlusal load, R (yellow); right bite force, L (red); left bite force).

2.6. Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows, version 27.0 (IBM Corp., Armonk, NY, USA). The normality of continuous variables within each age group was assessed using the Shapiro–Wilk test. Repeated Measures ANOVA, a parametric test, was applied to evaluate longitudinal changes in maximum bite force when the normality assumption was satisfied. In the young and older adult groups, the raw maximum bite force data did not meet the normality assumption; therefore, logarithmic transformation was applied prior to parametric analysis. Repeated Measures ANOVA after log transformation was subsequently used for longitudinal comparisons in these two groups. In contrast, the middle-aged group and the overall patient group met normality assumptions without transformation, and Repeated Measures ANOVA was applied directly to the raw data. For within-group pairwise comparisons between specific time points, the Wilcoxon signed-rank test was used when data did not meet parametric assumptions. No formal correction for multiple comparisons was applied, as these analyses were conducted in an exploratory manner. The Friedman test was applied to assess overall non-parametric longitudinal differences across multiple time points. For between-group comparisons of age-related differences at baseline and at 6 months, one-way ANOVA was used for variables meeting the normality assumption, while the Kruskal–Wallis test was applied for variables that did not meet this assumption. A p -value < 0.05 was considered statistically significant.

3. Results

3.1. Demographic and Clinical Characteristics

A total of 32 participants (8 males and 24 females, mean age 45.8 ± 16.3 years) were enrolled in this study. Table 1 shows the demographic findings of the subjects. The gender ratio did not differ significantly between groups. Additionally, no significant differences were observed in other clinical characteristics, including mouth opening range, pain intensity, and pain duration. There were also no significant differences in the SCL-90-R assessment results between groups (Table 2).

Table 1. Demographic and clinical characteristics.

Variables	Young (n = 13)	Middle-Aged (n = 10)	Older Adult (n = 9)	p-Value
Age (years)	29.3 ± 6.0	49.0 ± 5.6	66.2 ± 4.6	$<0.001^a$
Gender (% of female)	76.9	60	88.9	0.148^b
CMO (mm)	30.3 ± 10.1	37.0 ± 11.0	35.9 ± 8.0	0.117^c
MMO (mm)	43.9 ± 9.6	44.4 ± 8.6	42.4 ± 8.0	0.883^a
Pain intensity (NRS)	4.1 ± 3.0	5.0 ± 2.7	4.2 ± 2.1	0.717^a
Pain duration (days)	43.5 ± 57.1	69.7 ± 65.1	79.5 ± 53.9	0.256^c

CMO, comfortable mouth opening; MMO, maximum mouth opening; NRS, numeric rating scale; Values are given as mean $\pm$ SD. ^a p-value was obtained from ANOVA test. ^b p-value was obtained from Chi-square test. ^c p-value was obtained from Kruskal-Wallis test.

Table 2. Comparison of SCL-90-R profiles.

Variables	Young (n = 13)	Middle-Aged (n = 10)	Older Adult (n = 9)	p-Value
SOM	45.6 ± 6.5	45.5 ± 6.5	47.2 ± 5.3	0.957^a
O-C	40.6 ± 7.5	44.7 ± 4.0	42.8 ± 7.0	0.458^a
I-S	42.5 ± 7.9	44.4 ± 5.6	42.0 ± 6.0	0.608^a
DEP	42.0 ± 8.3	44.1 ± 4.7	42.6 ± 5.7	0.908^a
ANX	42.6 ± 6.6	43.9 ± 4.3	42.1 ± 6.5	0.767^b
HOS	42.7 ± 6.1	44.8 ± 4.8	43.0 ± 5.8	0.723^b
PHOB	44.2 ± 6.0	43.8 ± 3.0	43.8 ± 3.8	0.964^b
PAR	14.3 ± 5.6	41.8 ± 4.1	43.8 ± 4.9	0.333^b
PSY	43.2 ± 5.4	44.5 ± 4.5	43.3 ± 5.3	0.802^b
GSI	39.6 ± 13.7	45.1 ± 4.9	43.6 ± 6.8	0.851^a
PSDI	44.5 ± 6.1	48.0 ± 10.7	45.9 ± 6.8	0.978^b
PST	40.6 ± 13.0	44.7 ± 5.0	45.2 ± 13.2	0.787^b

SCL-90-R, symptom checklist-90-revised; SOM, somatization; O-C, obsessive-compulsive; I-S, interpersonal sensitivity; DEP, depression; ANX, anxiety; HOS, hostility; PHOB, phobic anxiety; PAR, paranoid ideation; PSY, psychoticism; GSI, global severity index; PSDI, positive symptom distress index; PST, positive symptom total; Values are given as mean $\pm$ SD. ^a p-value was obtained from ANOVA test. ^b p-value was obtained from Kruskal-Wallis test.

3.2. Comparison of Each Parameter and Asymmetry Index Before Stabilization Splint Therapy

Comparison of measurement values and asymmetry index in each group before stabilization splint therapy are shown in Table 3. Before the initiation of treatment, there were significant age-related differences in occlusal contact area ($p = 0.012$), mean pressure ($p = 0.017$), and maximum bite force ($p = 0.011$), with the older group showing lower values across all parameters compared to other age groups. Asymmetry, which may occur with osteoarthritis, was more pronounced in younger age groups and less so in older individuals, although no significant age-related differences were observed.

Table 3. Comparison of each parameter and asymmetry index before stabilization splint therapy.

Variables	Young (n = 13)	Middle-Aged (n = 10)	Older Adult (n = 9)	p-Value
Each parameter				
Occlusal contact area (mm ²)	14.8 ± 6.6	15.8 ± 10.5	6.0 ± 2.0	0.012 ^a
Occlusal pressure (MPa)	36.2 ± 4.7	37.7 ± 7.0	30.7 ± 5.3	0.017 ^b
Maximum bite force (N)	551.4 ± 305.9	611.0 ± 419.6	187.5 ± 73.0	0.011 ^a
Asymmetry index (OA side/normal side)				
Occlusal contact area ratio (%)	62.0 ± 27.9	67.2 ± 29.3	97.9 ± 70.1	0.165 ^a
Occlusal pressure ratio (%)	94.1 ± 19.6	94.9 ± 36.7	99.7 ± 10.8	0.858 ^a
Maximum bite force ratio (%)	57.0 ± 23.3	69.1 ± 28.5	95.0 ± 65.7	0.116 ^a

OA, osteoarthritis; Values are given as mean ± SD. ^a p-values were obtained from ANOVA test. ^b p-values were obtained from Kruskal-Wallis test.

3.3. Maximum Bite Force

Changes in bite force over time for the entire patient group were not statistically significant throughout the observation period ($p = 0.187$) (Table 4). Although no change in bite force was observed with splint use, a significant increase was noted between the three- and six-month intervals ($p = 0.014$) (Figure 3).

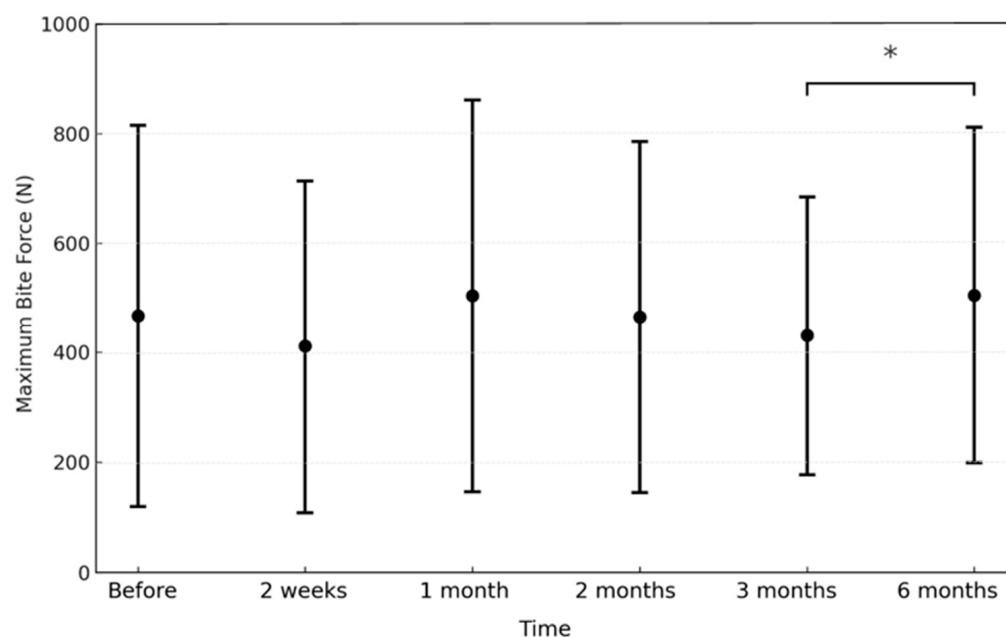


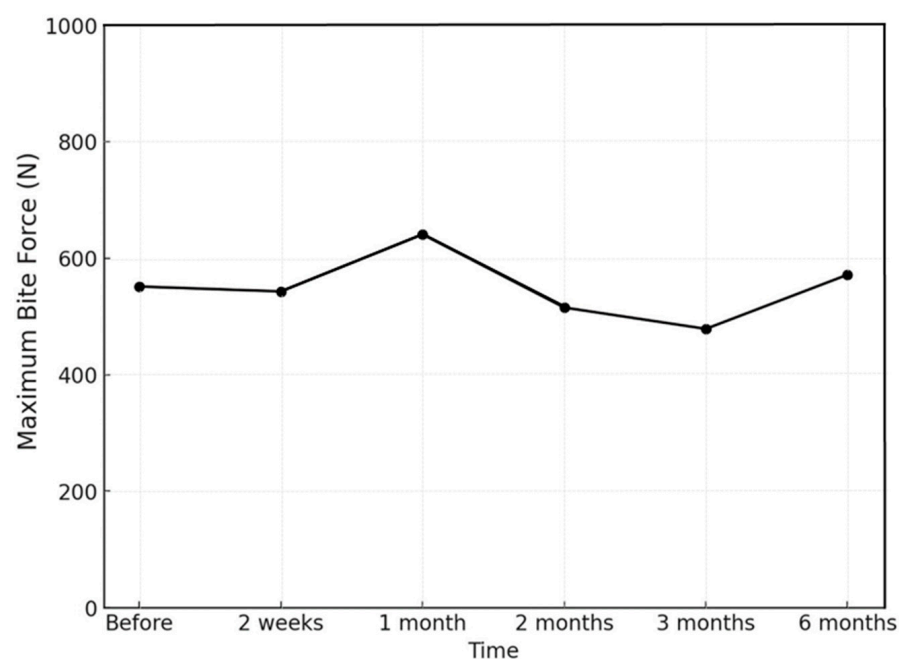
Figure 3. Maximum bite force changes after stabilization splint therapy. * indicates a significant difference between 3 and 6 months ($p = 0.014$; Wilcoxon signed-rank test).

When examining bite force changes by age group, the young and middle-aged groups showed similar patterns without significant differences (Figure 4a,b). However, the middle-aged group exhibited a sharp decrease in bite force at the second week compared to baseline ($p = 0.027$). In contrast, the older adult group showed a statistically significant gradual increase in maximum bite force over time, as determined by repeated measures ANOVA after log transformation ($p = 0.011$) (Table 4). Notably, in the older adult group, bite force showed a significant increase from the second month onward compared to baseline ($p = 0.003$). This pattern of increased bite force continued in both the third month ($p = 0.039$) and sixth months ($p = 0.019$) (Figure 4c).

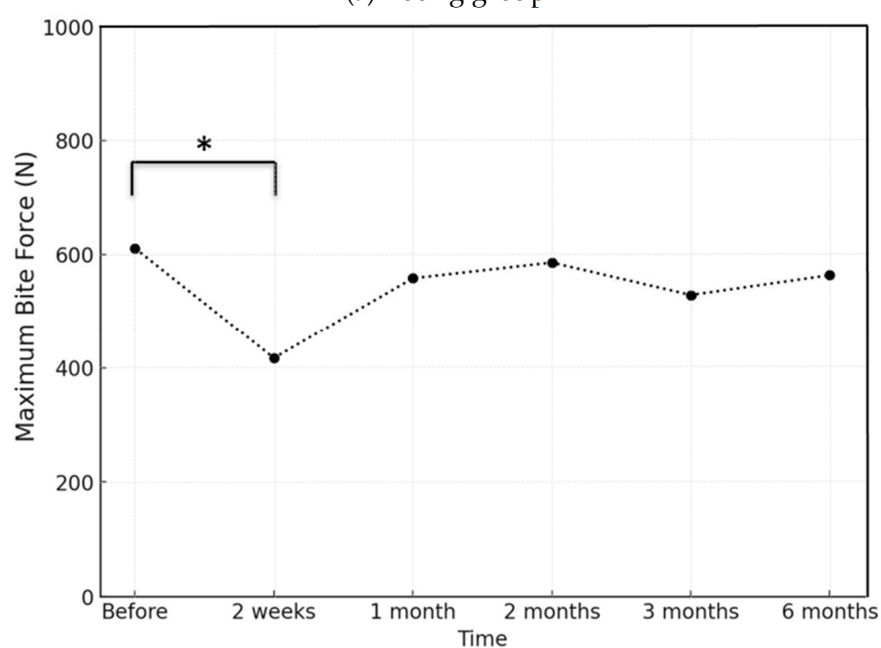
Table 4. Bite force changes after stabilization splint therapy.

	Before	2 W	1 M	2 M	3 M	6 M	<i>p</i> -Value *	<i>p</i> -Value †
Young (n = 13)	551.4 ± 305.9	542.9 ± 350.2	640.9 ± 395.9	515.3 ± 297.8	478.6 ± 233.7	571.6 ± 332.9	0.466 ^a	
Middle-aged (n = 10)	611.0 ± 419.6	417.0 ± 284.0	558.2 ± 331.8	585.9 ± 399.3	528.9 ± 309.7	563.7 ± 354.1	0.219 ^b	0.187 ^b
Older adult (n = 9)	187.5 ± 73.0	213.6 ± 90.7	246.5 ± 165.0	259.9 ± 124.4	253.8 ± 92.9	351.3 ± 151.8	0.011 ^a	

W, weeks; M, months; Values are given as mean ± SD. * *p*-value was reported as time by group. † *p*-value was reported for the overall time effect. ^a *p*-value was obtained from Repeated Measures. ANOVA test after log transformation of variables. ^b *p*-value was obtained from Repeated measures ANOVA test.

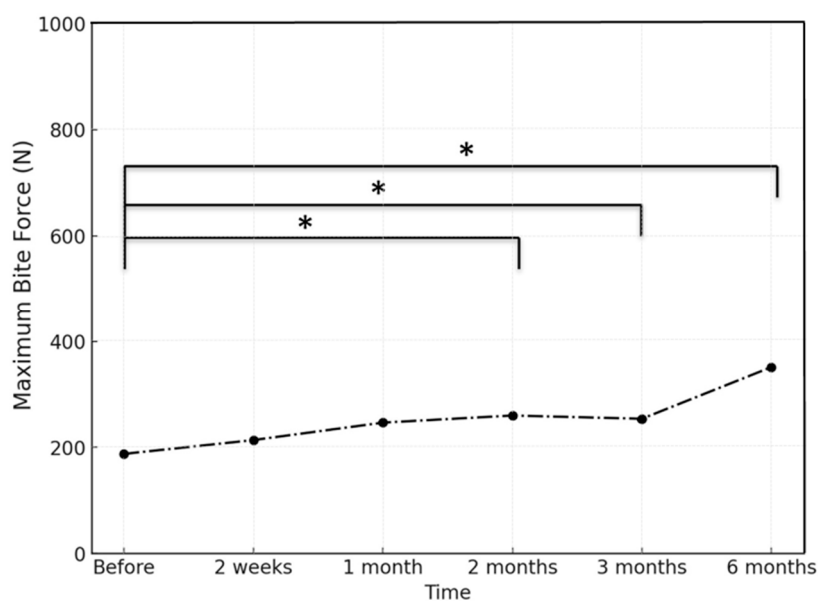


(a) Young group



(b) Middle-aged group

Figure 4. Cont.



(c) Older adult group

Figure 4. Longitudinal changes in maximum bite force after stabilization splint therapy by age group. * indicates a significant difference compared with baseline (Wilcoxon signed-rank test). Middle-aged group: $p = 0.027$ at 2 weeks. Older adult group: $p = 0.003$ (2 month), $p = 0.039$ (3 months), $p = 0.019$ (6 months).

3.4. Maximum Bite Force Ratio

The left-to-right bite force ratio over time for the entire patient group did not show statistically significant changes throughout the observation period ($p = 0.103$). Although there was no overall change in bite force associated with splint use, a significant improvement was observed after two weeks ($p = 0.039$) (Figure 5).

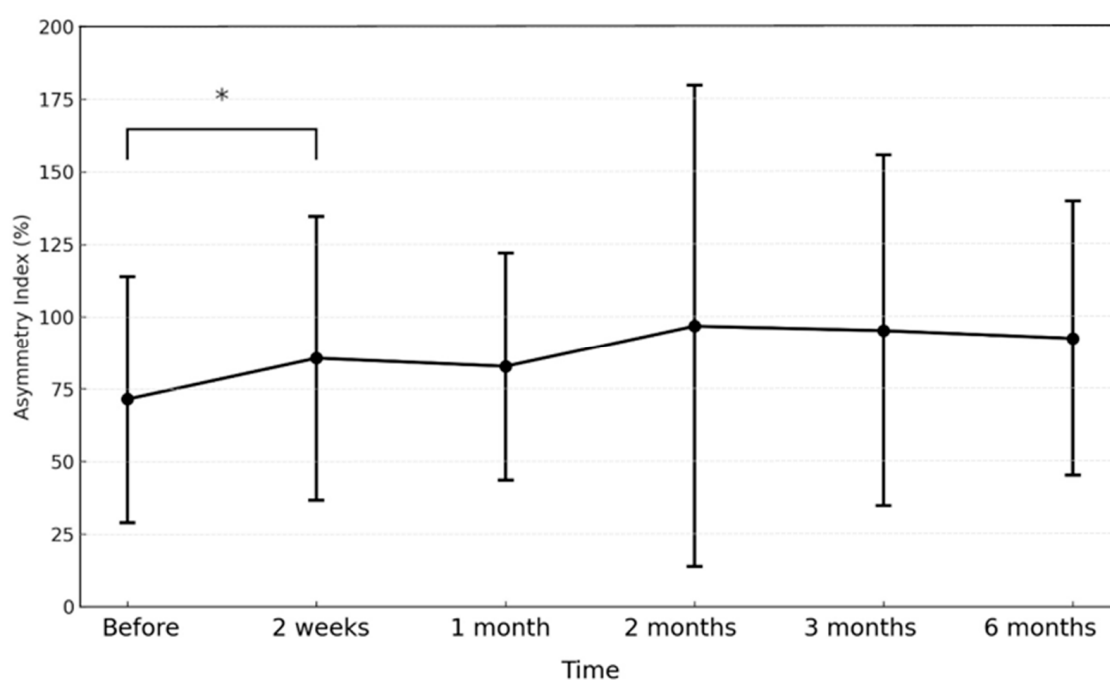
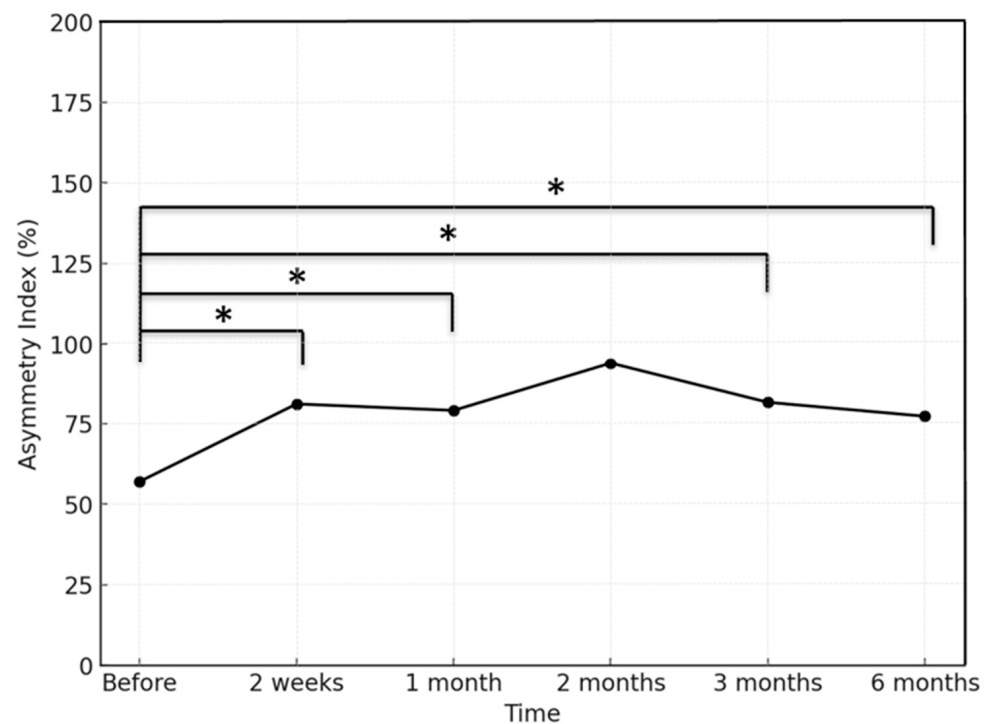
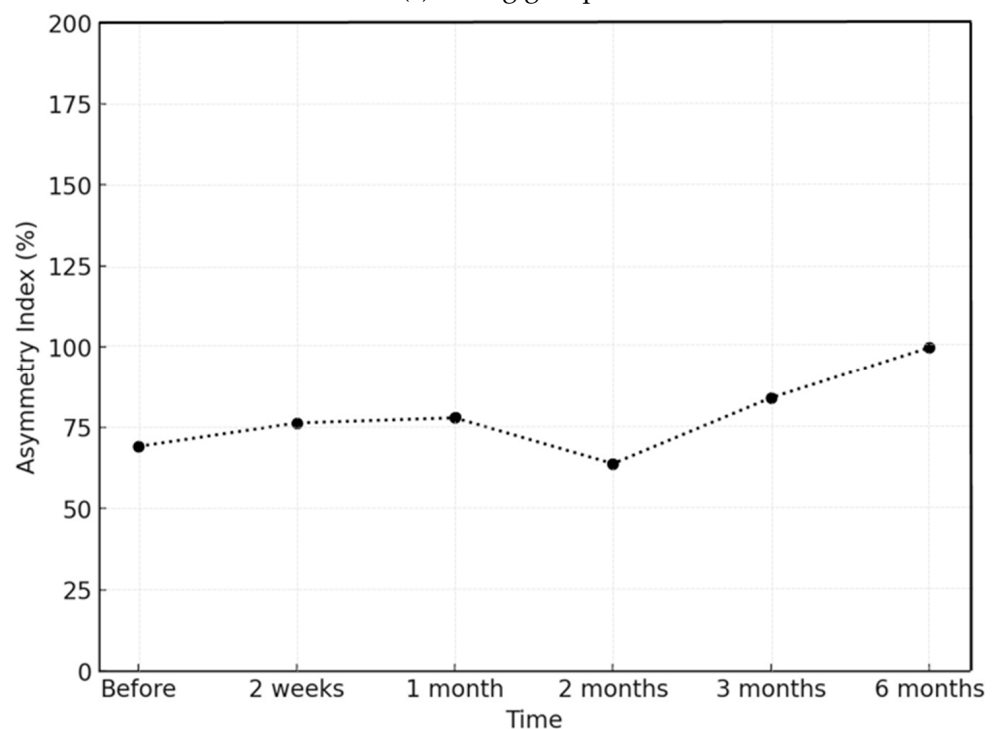


Figure 5. Asymmetry index of maximum bite force after stabilization splint therapy * indicates a significant difference compared with baseline ($p = 0.039$; Wilcoxon signed-rank test).

When examining changes in the left-to-right bite force ratio by age group, the middle-aged and older adult group displayed increased asymmetry at two months, which subsequently returned to baseline levels, with no statistically significant change observed over the entire observation period (Figure 6b,c, Table 5). In contrast, the young group showed an improvement in asymmetry following splint use, with a significant difference compared to baseline observed at 2 weeks ($p = 0.047$), 1 month ($p = 0.017$), 3 months ($p = 0.006$), and 6 months ($p = 0.021$). (Figure 6a).



(a) Young group



(b) Middle-aged group

Figure 6. Cont.

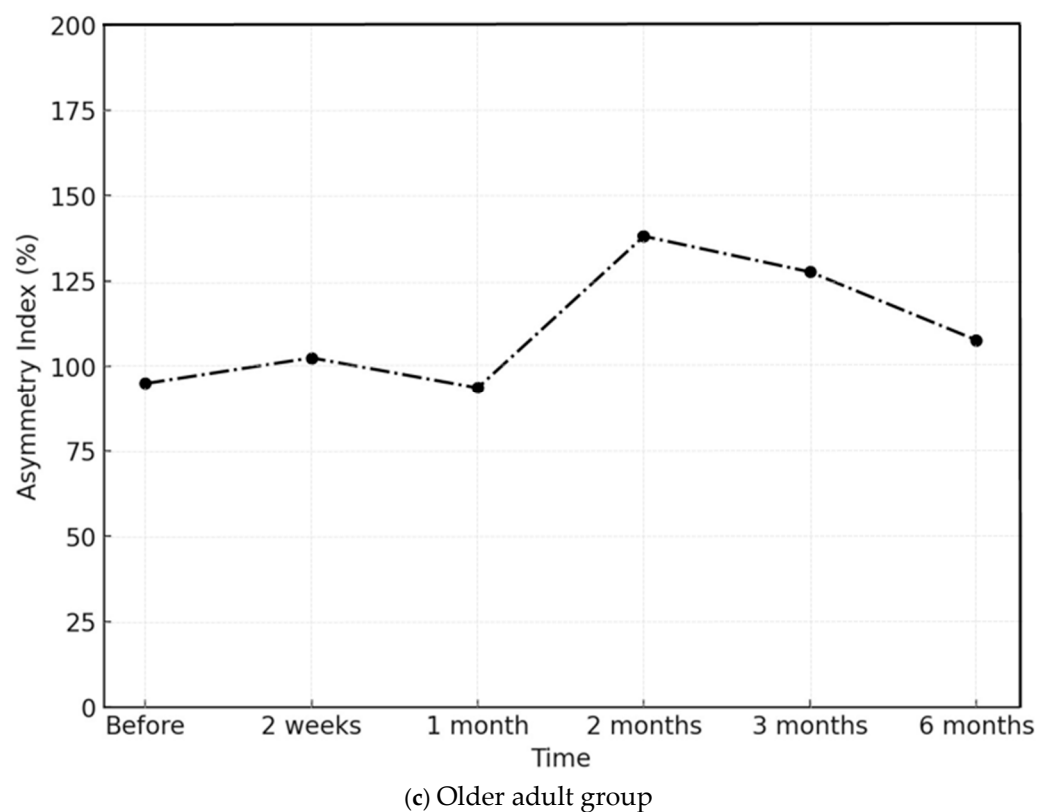


Figure 6. Asymmetry index of maximum bite force after stabilization splint therapy * indicates a significant difference compared with baseline in the young group at 2 weeks, 1 month, 3 months, and 6 months ($p = 0.047, 0.017, 0.006$, and 0.021 , respectively; Wilcoxon signed-rank test).

Table 5. Asymmetry index of maximum bite force changes after stabilization splint therapy.

	Before	2 W	1 M	2 M	3 M	6 M	<i>p</i> -Value
Young (<i>n</i> = 13)	57.0 ± 23.3	81.1 ± 42.4	79.1 ± 33.8	93.8 ± 73.9	81.6 ± 38.0	77.2 ± 30.9	0.114
Middle-aged (<i>n</i> = 10)	69.1 ± 28.5	76.3 ± 35.8	77.9 ± 36.9	63.8 ± 29.5	84.1 ± 34.2	99.8 ± 32.8	0.289
Older adult (<i>n</i> = 9)	95.0 ± 65.7	102.5 ± 68.6	93.7 ± 50.3	138.1 ± 119.1	127.6 ± 95.1	107.7 ± 72.1	0.734

W, weeks; M, months; Values are given as mean ± SD. *p*-values were from Friedman test.

3.5. Comparison of Each Parameter and Asymmetry Index After Stabilization Splint Therapy

Comparison of each parameter and asymmetry index in each group 6 months after stabilization splint therapy are shown in Table 6. Six months after treatment, occlusal contact area, occlusal pressure, and maximum bite force showed no significant differences among the age groups.

Table 6. Comparison of each parameter and asymmetry index after stabilization splint therapy.

Variables	Young (<i>n</i> = 13)	Middle-Aged (<i>n</i> = 10)	Older Adult (<i>n</i> = 9)	<i>p</i> -Value
Each parameter				
Occlusal contact area (mm ²)	14.3 ± 6.8	14.7 ± 8.7	10.3 ± 4.2	0.305 ^a
Occlusal pressure (MPa)	38.6 ± 6.1	37.5 ± 5.6	34.2 ± 3.5	0.179 ^a
Maximum bite force (N)	571.6 ± 332.9	563.7 ± 354.1	351.3 ± 151.8	0.205 ^a

Table 6. Cont.

Variables	Young (n = 13)	Middle-Aged (n = 10)	Older Adult (n = 9)	p-Value
Asymmetry index (OA side/normal side)				
Occlusal contact area ratio (%)	75.7 ± 32.7	93.5 ± 29.0	104.8 ± 66.3	0.530 ^b
Occlusal pressure ratio (%)	105.4 ± 17.3	106.7 ± 15.2	98.9 ± 16.7	0.556 ^a
Maximum bite force ratio (%)	77.2 ± 30.9	99.8 ± 32.8	107.7 ± 72.1	0.372 ^b

OA, osteoarthritis; Values are given as mean ± SD. ^a p-values were obtained from ANOVA test. ^b p-values were obtained from Kruskal-Wallis test.

4. Discussion

Studies on age-related characteristics of TMD have been ongoing for years. TMD etiology is multifactorial, and the specific influence of age remains uncertain. Previous research has investigated variations in TMD prevalence by age, diagnostic distribution by age, and age-related psychosocial factors impacting TMD. However, few studies have examined age-related characteristics and treatment outcomes within the same TMD diagnosis.

This study specifically focuses on TMJ OA patients. Unlike other types of osteoarthritis that commonly manifest in older adults due to joint wear, TMJ OA notably affects not only those in their 20s and 30s but also adolescents. It is common to observe surprise among patients and caregivers about the occurrence of OA in young adults. Consequently, TMJ OA may have unique characteristics compared to other OA types, potentially presenting distinct age-dependent patterns. TMJ OA may show less susceptibility to such age-related effects, allowing for a more objective approach to management through research into pathophysiology and biochemical mechanisms [23–25].

The primary treatment goal for TMD is to restore masticatory function, a vital role in human health as impaired mastication can lead to various systemic diseases [26]. Effective mastication relies on harmonious interaction among the occlusion, TMJ, masticatory muscles, and related nerves, all of which can be compromised by TMJ OA. Although bite force is only one aspect of mastication and does not imply complete restoration of functional mastication, we chose to evaluate maximum bite force in this study because it is a commonly used, objective, and reproducible measure of occlusal function. However, because temporomandibular joint osteoarthritis may affect dynamic chewing more than static clenching, the findings should be interpreted with caution, and future studies incorporating dynamic functional assessments such as chewing efficiency, electromyographic activity, mandibular kinematics, and pain reproduction during chewing are warranted.

However, interpretation of functional changes based on bite force measurements should also consider the limitations inherent to the study design. The most critical limitation of this study is the absence of a control group, which limits causal interpretation of the observed bite force changes. Without a comparison group, the temporal patterns observed may reflect not only stabilization splint therapy but also the natural course of TMJ osteoarthritis, regression to the mean, prior pain management, or placebo effects. Accordingly, these findings should be interpreted as age-related patterns of functional change during conservative management rather than direct evidence of therapeutic efficacy.

Bite force measurements have been utilized in various methods. Initial methods employed stress-strain gauges placed between teeth, which allowed repetitive measurements but had limitations. These gauges often measured force on a single tooth rather than the entire dentition and were influenced by occlusal conditions beyond the sensor site. Furthermore, sensor thickness affects bite force accuracy, as masticatory muscles achieve maximum force in the near-contact state of the intercuspal position. The Dental Prescale II

system mitigates some of these issues, utilizing a thin (150 µm) film that exerts minimal influence on bite force, accommodating open or cross bites, and providing comparative data across different occlusal conditions. However, this method requires care to avoid user errors and incurs film costs per measurement.

For efficient mastication, an appropriate bite force must act on a stabilized TMJ condyle, indicating a complementary relationship between bite force and condylar stability. In animal models, persistently high bite forces can induce TMJ OA [27]. Patients who underwent TMJ replacement surgery exhibited lower maximum bite forces compared to healthy controls, with increased muscle asymmetry and lateral shear forces observed on the operated side, suggesting that condylar condition influences bite force [28].

Masticatory muscles in patients with unilateral TMJ OA experience greater fatigue during sustained clenching compared to healthy individuals [16]. Reduced electromyography (EMG) activity during maximum voluntary contraction was observed on the affected side compared to the non-affected side in patients with unilateral TMD [29]. Such OA development may subsequently reduce bite force, as patients with osteoarthritis demonstrate lower maximum bite forces compared to other TMD, including masticatory muscle disorders [15]. Additionally, unilateral TMJ OA can cause masticatory muscle imbalance, leading to midline deviation and facial asymmetry [25].

However, conservative treatment can restore bite force, as the masticatory system exhibits remarkable adaptability to structural and functional changes, preventing most pathological occlusal alterations [30]. In this study, the observed bite force characteristics showed recovery over the observation period in all age groups, although there were differences in the recovery duration across age groups. However, since the study did not include a control group, it should not be misconstrued that the recovery is solely dependent on splint therapy. This is supported by evidence that adult mandibular condylar fibrocartilage can adapt to mechanical loading changes and undergo remodeling [31]. Furthermore, masticatory muscle-strengthening exercises contribute to mandibular stability, improve occlusion, and may help delay the progression of TMJ OA [32].

This study employed Dental Prescale II to assess the maximum bite force. Initial measurements were not taken at the first visit but after initial interventions, such as medication and physical therapy, had reduced acute pain. As a result, the true baseline bite force under painful conditions was not captured, which may have led to an underestimation of the initial severity of functional impairment. In addition, early changes attributable to stabilization splint therapy may have been partially masked by prior pain reduction, and heterogeneity in the degree of pain relief at the time of baseline measurement could have introduced variability among participants. Patients requiring further interventions, like arthrocentesis, due to persistent pain were excluded. For those experiencing pain recurrence during the observation period, bite force was reassessed after additional pain management. All patients visited the hospital at regular intervals to measure their bite force. However, the bite force measured during these visits may not accurately represent the bite force throughout the entire observation period. Variations in bite force can occur with each measurement, and such variability may be more pronounced in TMJ OA. This limitation of the current study suggests that future research could achieve a more accurate assessment of bite force changes by measuring bite force over multiple days.

Participants were grouped by age as follows: 20–39, 40–59, and over 60 years, with all groups having a higher proportion of female patients, aligning with previous findings of greater TMD prevalence in females [33–35]. While social age based on birthdate may not always represent functional capacity accurately, especially in older populations, this study could not subdivide the older group further due to sample size. Future studies should consider age stratification by functional status, particularly in older adults.

At baseline, older adults exhibited significantly lower occlusal contact area, mean occlusal pressure, and maximum bite force compared to other age groups. Despite the lack of missing teeth among participants, this reduction suggests factors beyond occlusal conditions are responsible. In the Dental Prescale II system, maximum bite force is determined by occlusal contact area and pressure; significant changes in these variables thus result in significant differences in bite force. Reduced occlusal force in older adults has been increasingly discussed within the framework of oral frailty, which refers to age-related declines in oral function that may adversely affect dietary intake and overall health. Even in the absence of missing teeth, diminished bite force can limit food choices and reduce nutritional intake, thereby increasing the risk of malnutrition. Malnutrition in older adults has been associated with systemic dysfunction, functional decline, and poorer health outcomes, particularly when evaluated using comprehensive geriatric assessment frameworks [36]. In this context, impaired occlusal force in older patients with temporomandibular joint osteoarthritis may represent not only a local functional deficit but also a potential contributor to broader geriatric vulnerability [37]. Accordingly, improvement or restoration of bite force may be considered a clinically meaningful functional target that complements nutritional and systemic management in older adults with TMJ OA.

Six months post-treatment, while the older group's measurements remained lower than other groups, the differences were not statistically significant, indicating substantial improvement in response to intervention. As OA treatment extends beyond six months, further improvements are expected with continued therapy. Osteoarthritis treatment is typically concluded when there are no symptoms of temporomandibular disorders and no further degenerative changes are observed on imaging [38]. Based on the results of this study, recovery or further improvement of bite force at the end of the treatment period may serve as a complementary functional reference when evaluating treatment response in patients with TMJ osteoarthritis, alongside established clinical outcomes such as pain intensity, functional limitation, patient-reported measures, and imaging findings.

Across all patients, maximum bite force remained stable, oscillating between slight increases and decreases, with no significant change observed over the observation period. However, the Wilcoxon signed-rank test indicated a significant increase in bite force between the three- and six-month intervals, likely due to variations in measurement intervals. For patients without severe pain, monthly visits were practically challenging, leading to inconsistencies in measurement intervals. Because multiple post-hoc comparisons between baseline and individual time points were performed without formal correction for multiple comparisons, the possibility of an inflated Type I error cannot be excluded, and these post-hoc findings should be interpreted with caution.

By age group, the young and middle-aged groups showed fluctuating bite force levels. The transient decrease in bite force observed at two weeks in the middle-aged group may reflect short-term neuromuscular adaptation or altered occlusal perception during the early phase of stabilization splint use, rather than true functional decline. As patients adapt to the splint over time, bite force appears to recover, supporting the interpretation that early fluctuations represent temporary adaptation effects. In the older adult group, the maximum bite force gradually increased over time, and this change was statistically significant. The apparent improvement in bite force observed after approximately two months in older adults should be interpreted as a descriptive finding rather than a definitive threshold, and may reflect delayed functional adaptation following pain control and continued splint use. While the older group initially showed significantly lower bite force, the difference was negligible by six months, indicating a significant improvement after treatment. However, the results of this study cannot be definitively concluded as the effect of splint therapy. As mentioned earlier in the discussion, to properly assess the effect of splint therapy, a

comparison with other treatment methods or a control group is necessary. This study focused on analyzing the pattern of bite force changes by age in patients with unilateral TMJ OA. The factors contributing to the observed bite force recovery in this study may include natural history, regression to the mean, the sustained effect of pain management that encompasses pharmacological treatment, physical therapy, and splint therapy, or even placebo effects, all of which cannot be excluded.

TMJ OA-related pain and condylar changes can substantially influence left-right bite force symmetry. Unilateral joint pain or condylar damage may lead to asymmetric occlusal loading through contralateral compensation. To evaluate this phenomenon, the present study included only patients with unilateral TMJ OA and assessed asymmetry using the ratio between the affected and unaffected sides. In the overall sample, bite force tended to be lower on the affected side. When stratified by age, the young and middle-aged groups showed asymmetry favoring the unaffected side, whereas the older adult group demonstrated relatively symmetrical bite force distribution; however, these differences did not reach statistical significance. Notably, in the young group, asymmetry improved as early as two weeks after splint therapy and remained stable throughout the observation period, suggesting early and sustained functional adaptation. The interpretation of the asymmetry index requires caution, particularly in patients with low bilateral bite force, as ratio-based metrics may amplify variability and produce unstable values. Moreover, asymmetry in TMJ OA may vary according to disease stage and underlying pathophysiology. In the early phase of TMJ OA, inflammatory responses within the joint cavity and pain-related inhibition may weaken occlusion on the affected side [39]. With progression of degenerative condylar changes, shortening of the condyle and mandibular positional alterations may occur, potentially resulting in increased occlusal loading on the affected side and reduced contact on the contralateral side. In advanced or bilateral TMJ OA, open bite deformities may also develop. In the present study, patients with progressive condylar destruction were excluded, and the analysis focused on individuals who demonstrated clinical recovery without further structural deterioration. Therefore, the observed changes in the asymmetry index are more likely to reflect transient functional imbalance and subsequent recovery rather than permanent occlusal alteration due to condylar collapse. Values exceeding 100% should thus be interpreted as relative changes between sides rather than indicators of absolute functional dominance. Given the relatively short observation period of six months, further longitudinal studies incorporating quantitative assessment of condylar morphology are needed to clarify the long-term relationship between structural changes and bite force asymmetry in TMJ OA.

The limitations of this study are as follows. First, the relatively small sample size in each age group may reduce the generalizability of the findings and limit statistical power, particularly for detecting subtle between-group differences and age-by-time interactions in repeated-measures analyses. Consequently, some non-significant results should be interpreted with caution, as they may reflect a risk of Type II error rather than a true absence of age-related effects. Second, the short observation period could also limit the identification of long-term trends. Third, the lack of quantitative analysis of the condyle restricts a comprehensive evaluation of condylar changes. The absence of quantitative CBCT-based evaluation of condylar morphology limited the ability to directly correlate structural changes with functional recovery. Although follow-up CBCT was used to exclude patients with progressive bone destruction, quantitative assessment of condylar stability was not performed. Future studies incorporating detailed CBCT-based measurements, such as joint space, erosion depth, and condylar morphology, are warranted to better clarify structure-function relationships in TMJ osteoarthritis. Fourth, the narrow diagnostic criteria and patient selection process may limit the applicability of the findings to broader clinical

populations. In this study, patients who exhibited additional condylar bone destruction during the follow-up period were excluded, resulting in a per-protocol analysis of patients with relatively favorable clinical courses. Consequently, the observed recovery patterns reflect only patients with unilateral temporomandibular joint osteoarthritis who showed no further bone destruction and experienced alleviated pain during the six-month observation period. These findings should therefore not be generalized to patients with persistent pain or progressive structural deterioration beyond six months. Additionally, the older adult group evaluated in this study was limited to individuals with preserved dentition and without missing teeth or malocclusion. Therefore, the results cannot be generalized to older patients with TMJ osteoarthritis who have partial tooth loss, use removable or fixed dentures, or represent more frail oral health conditions.

If future studies include larger and more diverse patient populations, age-related recovery patterns in occlusal force could be confirmed with greater statistical reliability and further refined by stratifying older adults according to age, occlusal conditions, dentition status, and functional capacity. Such investigations would help determine whether the delayed pattern of improvement in older patients is consistent across broader clinical settings, thereby strengthening the clinical applicability of age-responsive treatment strategies in temporomandibular joint osteoarthritis. However, a strength of this study is that it excluded factors that could affect bite force, such as pain and psychological influences, and applied strict diagnostic criteria to ensure the reliability and validity of the results.

5. Conclusions

Older patients with TMJ OA exhibited lower baseline bite force compared with younger age groups. During the observation period, gradual increases in bite force were observed in older patients, whereas younger patients demonstrated earlier improvement in bite force asymmetry between the affected and unaffected sides. These findings indicate that age-related differences may exist in the temporal patterns of functional change associated with unilateral TMJ OA. In older adults, unilateral TMJ OA was associated with more global impairment of masticatory function and a slower course of functional change, while in younger patients, functional alterations appeared to be more localized and improved earlier over time. Overall, the patterns of bite force change observed in this study suggest that functional trajectories in TMJ OA may vary according to age, highlighting the potential importance of considering age-specific treatment plans that incorporate functional parameters such as bite force. However, given the observational design and absence of a control group, these findings should be interpreted within the context of the study design and considered hypothesis-generating rather than definitive evidence of causal treatment effects.

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Abbreviations

The following abbreviations are used in this manuscript:

TMD	Temporomandibular disorders
TMJ	Temporomandibular joint
OA	Osteoarthritis
OHRQoL	Oral Health-Related Quality of Life
SCL-90-R	Symptom Checklist-90-Revised
CBCT	Cone-beam computed tomography
EMG	Electromyography
CMO	Comfortable mouth opening
MMO	Maximum mouth opening
NRS	Numeric rating scale
SOM	Somatization
O-C	Obsessive-compulsive
I-S	Interpersonal sensitivity
DEP	Depression
ANX	Anxiety
HOS	Hostility
PHOB	Phobic anxiety
PAR	Paranoid ideation
PSY	Psychoticism
GSI	Global severity index
PSDI	Positive symptom distress index
PST	Positive symptom total

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