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The preliminary study of the effects of individual musculoskeletally stable position in the treatment of temporomandibular disorders

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Abstract

Background Temporomandibular Disorders (TMD) is the dysfunction of group of muscles and bones in the joint area, the main symptoms of TMD are the pain of the chewing muscles and (or) the temporomandibular joints, mandibular movement disorders and joint noise. This study was designed to explore the therapeutic effects following Individual Musculoskeletally Stable (IMS) position stabilization splint therapy for TMD patients using Fricton index, cone beam computed tomography (CBCT) and surface-Electromyogram (sEMG).

Methods In this study, we enrolled 31 TMD patients (ranging from 18 to 26 years old, including 7 males and 24 females), first Fricton index was used to evaluate the clinical curative effect of TMD with the treatment of IMS stabilization splint; then CBCT was used to observe the TMJ condylar position changes of TMD before and after the treatment of IMS stabilization splint; finally sEMG was used to observe the changes of electromyography of anterior temporalis (AT) and masseter muscles (MM) of TMD before and after the treatment of IMS stabilization splint.

Results The course of treatment was 6–8 months, with an average of 7.6 months. After the IMS stabilization splint treatment, TMD symptoms relieved, especially in pain, mandibular movement disorder, but still slightly inferior in the treatment of joint noise. And there was a statistically significant difference in the anterior and inner joint space, the condyle had the tendency of moving forward and outward. AT presented reduction significantly of EMG value at rest position after treatment.

Conclusions IMS stabilization splint is a therapeutic reversible treatment for TMD, especially for pain and mandibular movement disorder; it produces effects of forward and outward condylar movement and elimination of the masticatory muscles antagonism.

Keywords Temporomandibular disorders, Stabilization splint, Cone beam computed tomography (CBCT), Surface Electromyogram (sEMG), Individual musculoskeletally stable position

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Background

Temporomandibular Disorders (TMD) is a common oral-maxillofacial disease [1]. Epidemiology shows that, approximately 75% of the world's population has one sign and at least 33% has one symptom of TMD [2]. TMD is dysfunctions of muscle groups and bones in Temporomandibular Joint (TMJ) areas, main symptoms of TMD are pains in masticatory muscles around TMJs and (or) inside TMJs themselves, which in turn seriously affect the patients' life qualities and social behaviors. According to the classification of risk factors by de Boever [3], occlusal patterns, neuromuscular system disorders, social and emotional statuses, etc., tend to be predominant in TMD occurrences. Unfortunately, a direct correlation between psychophysiological or psychological accounts and TMD is not found yet [4], thus reliable and effective treatments to TMD are not available currently. As to the treatment principle of TMD, reversible comprehensive conservative treatment was taken at first, such as splint therapy and psychotherapy; the final choice is irreversible treatment, including selected grinding, fixed prosthesis treatment, orthognathic surgery and orthodontic treatment.

Clinicians will not start orthodontic treatments until the patients' TMJs are in a better condition, condyles have been repositioned following the changes of relationships between mandibles and maxillae with the method of Roth-Williams (RW) philosophy [5, 6]. The most orthopedically stable joint position which exists when the condyles in the most superoanterior position of the articular fossae, resting against the posterior articular slopes with discs properly interposed. The condyle position when the elevator muscles activated with no occlusal influences is therefore considered to be the most musculoskeletally stable position (MSP) of the mandible [7] and is also the theoretical foundation of RW philosophy. If the condyles are repositioned in MSP by splints, the maximum intercuspal position is formed, healthy TMJ, coordinated occlusion and facial aesthetics could be obtained via this approach in order to achieve long-term stability of orthodontics. However, there may are still a few flaws in RW philosophy: (i) For clinicians, it is difficult to get condyles in the most superoanterior position, so the repeatability cannot be guaranteed; (ii) The most superoanterior position may not be the suitable position since TMJ, muscles, ligaments, facial connections, as well as neural and circulatory innervations are all intimately related [8]; (iii) Acute pain may be caused by huge positional changes between the articular discs and the condyles, bad emotional status is still a significant risk factor leading to TMD [9].

Stomatognathic system, an integral component of the upper body, is basically composed of the head, neck and shoulder girdle. Clinicians should not treat every patient with the same approach, thus Individual Musculoskeletally Stable (IMS) position was innovatively proposed which is different from Dawson's manual reposition [10]. IMS position may not be the most superoanterior position, however, it may be the position where TMJ, muscles, ligaments, facial connections and nerve functions are in harmony corresponding to the individual anatomy.

The aim of this research was to conduct a preliminary understanding of the IMS splint therapeutic effects by evaluation means of Fricton Index [11], Cone-beam Computed Tomography (CBCT) and surface Electromyogram (sEMG). Specifically, we seek to bring into focus the result on the mandibular condyle position in order to break a new path to treat TMD, with both clinical effect and the balance of the stomatognathic system taken into consideration.

Methods

Participants

A group of 31 consecutive patients with TMD (joint structure disorder and masticatory muscle disorders) were identified as members for the study inclusion. All patients received examination and treatment for TMD at the Department of TMJ, West China Hospital of Stomatology, Sichuan University from 2019 to 2022. The research was approved by the Medical Ethics Committee of West China Hospital of Stomatology, Sichuan University (No. WCHSIRB-D-2016-073). The initial TMD diagnosis was based on CBCT in combination with clinical findings obtained from our standardized TMJ clinical examinations at the Department of TMJ. Radiological pathological finding was defined as conditions deviating from the normal TMJ space on two-dimensional CBCT cuts. What's more, the initial TMD diagnosis was made based on clinical examinations, orofacial symptoms were of great importance, and Fricton Index was used in this study for assessment.

Inclusion and exclusion criteria

The inclusion criteria were: (i) TMD diagnosis according to the criteria of American Dental Association [7]; (ii) no inflammation in the mandibular condyle according to the examination of CBCT; (iii) patients were capable of understanding our treatment and willing to co-operate with us.

The exclusion criteria were: (i) patients had been treated with occlusal reconstruction in the way of orthodontics and/or prosthetics; (ii) there was inflammation in the mandibular condyle according to the examination of CBCT; (iii) the score of Symptom Checklist 90 (SCL-90) [12] was more than 160; (iv) patients with TMJ trauma or other systemic disease; (v) patients failed to accept orthognathic surgery which was considered possible; (vi) all patients who meet the inclusion criteria but for some extraordinary reason nevertheless cannot participate in the study.

The usage of stabilization splint

Patients were asked to bite the cotton roll for at least 20 min in order to smash the procedure of masticatory muscles, and then they closed their mouth as freely as they can in order to find a comfortable position, both in muscles and bones, during which the bite recording was made. The stabilization splint used in our study was fabricated from impression of upper dental arch and a silicone rubber bite recording of the IMS position. The splint was fabricated as a "flat" splint with point-to-point contact in the posterior teeth so as to be no interference for occluding guidance, however, there should be incisors guidance in protrusive movement and canine guidance in lateral movement according to the functional occlusion (Fig. 1). Patients were instructed to wear the splint all day long except when they were brushing their teeth or having more serious clinical symptoms. The splint was ground individually, based on functional occlusion, weekly in the first month, then monthly in the next months until stable. Additionally, participants were comforted in each visit.

Clinical curative effect

At pre and post-treatment, all patients completed a standardized questionnaire in combination with clinical examinations by one rater. Fricton Index [11, 13] was implied in this study, which was comprised of Dysfunction Index (DI) and Palpation Index (PI), the Craniomandibular Index (CMI) was developed to provide a standardized measure of problems severity in the mandibular movement, TMJ noise, muscle and joint tenderness for use in epidemiological and clinical outcome studies.

TMJ space distance

At pre and post-treatment, all patients had a radiological examination based on CBCT (Morita, Japan), Joint-space distances between the condyle and glenoid fossa were divided into anterior, upper and posterior spaces in the sagittal plane according to Kamelchuk et al. [14] and the

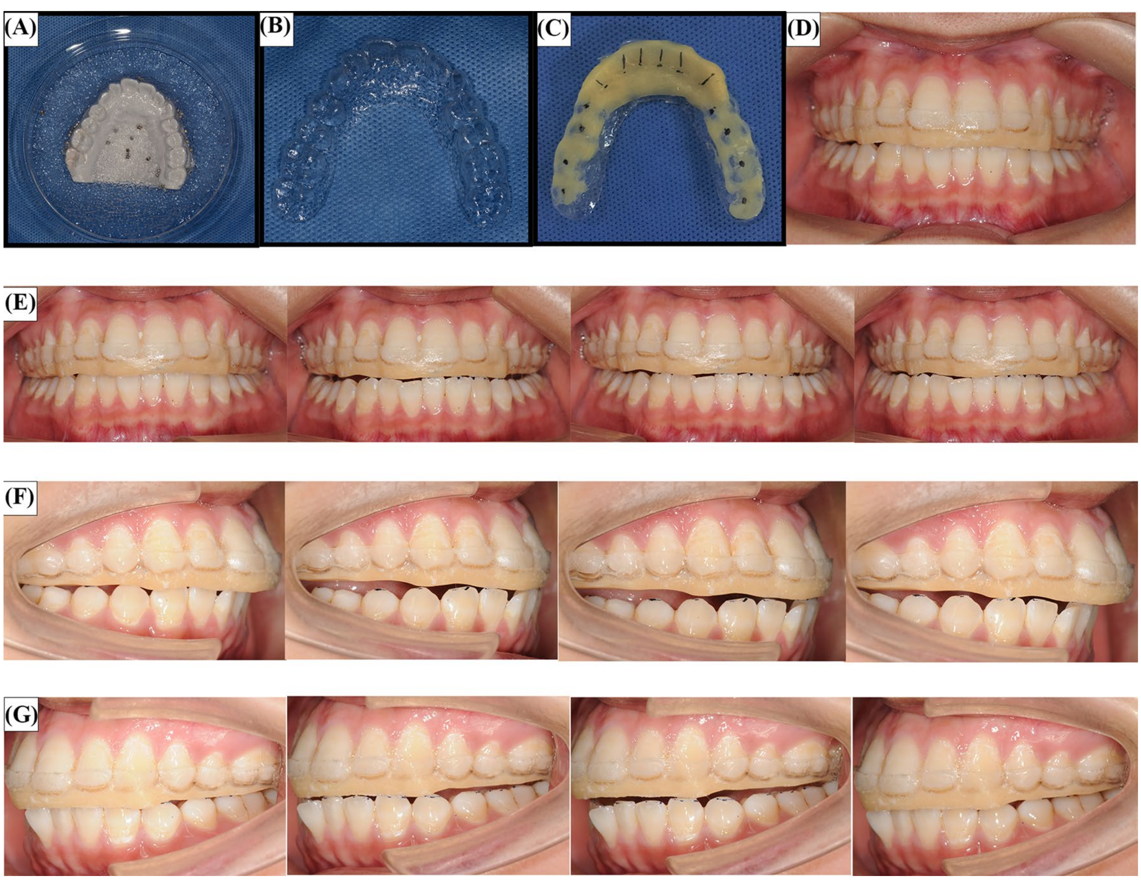

Fig. 1 Manufacturing process and application of IMS stabilization. **A** = 0.8 mm hard acrylic diaphragm molding; **B** = The appliance was trimmed; **C** = The adjustment of the splint is completed; **D** = Frontal view of IMS stabilization splint positioned in the mouth; **E** = Frontal views during Centric Relation (CR) position, incisors guidance in protrusive movement and canine guidance in lateral movement according to the functional occlusion with IMS stabilization splint positioned in the mouth (from left to right); **F** = Right lateral views; **G** = Left lateral views

inner and outer spaces in the coronal plane according to Ikeda et al. [15]. Specific details (Fig. 2).

Surface electromyogram

At pre and post-treatment, all patients were tested in the Chewing Function Room, West China Hospital of Stomatology, Sichuan University where it was silent enough and the temperature was between 22–25℃. Electromyographic devices were applied to the patients in this study (K-7 EMG, Myotronics Noromed, Inc. Kent, WA), and each patient was asked to sit comfortably in an upright chair with eyes slightly closed. The EMG device was used to measure each patient's two paired muscles, anterior temporalis (AT) and masseter muscles (MM). Measurements were performed after each patient was asked to assume a resting mandibular position (mandibular posture position, MPP) where the teeth were not touching. Three successive sets of data were obtained and we took the average of them. Then maximum voluntary clench (MVC) position was performed in order to measure the EMG of the muscles with the device by asking each patient to alternately clench his/her teeth maximally three times for two seconds with two seconds of relaxation between each clench period, which was repeated for three times and we took the average of them (Figs. 3 and 4).

Statistics

Pre and post-treatment outcome variables were compared to themselves by paired Student's t-tests after the data were tested for normal distribution, and $p<0.05$ was considered significant.

Results

Among the 31 patients (ranging from 18 to 26 years old, including 7 males and 24 females), 17 were in the group of joint structure disorders, 14 were in the group of masticatory muscle disorders, the treatment time ranged from 6 to 8 months, with an average of 7.6 months.

Clinical curative effect

The mandibular movement score was 2.45, the joint palpation score was 0.35, the dysfunction index was 0.14, the craniomandibular index score was 0.10 and there was statistical difference ($p<0.05$); the joint noise score (1.03) had the decreasing trend, however, there was no statistical difference ($p > 0.05$) (Table 1; Fig. 5).

TMJ space distance

The anterior space of the left temporomandibular joint became smaller (the difference is -0.61±0.91 mm), and the difference was statistically significant ($p<0.05$); the posterior, upper, inner and outer space became bigger, and the change of the posterior space was the most obvious (0.28±1.42 mm) while the change of the outer space was the smallest (0.04±1.38 mm), however, none of them was statistically different ($p > 0.05$) (Table 2; Fig. 6).

The anterior space of the right temporomandibular joint became smaller (the difference is -0.12±0.90 mm) which had no statistical significant difference ($p > 0.05$); the posterior, upper, inner and outer space all became

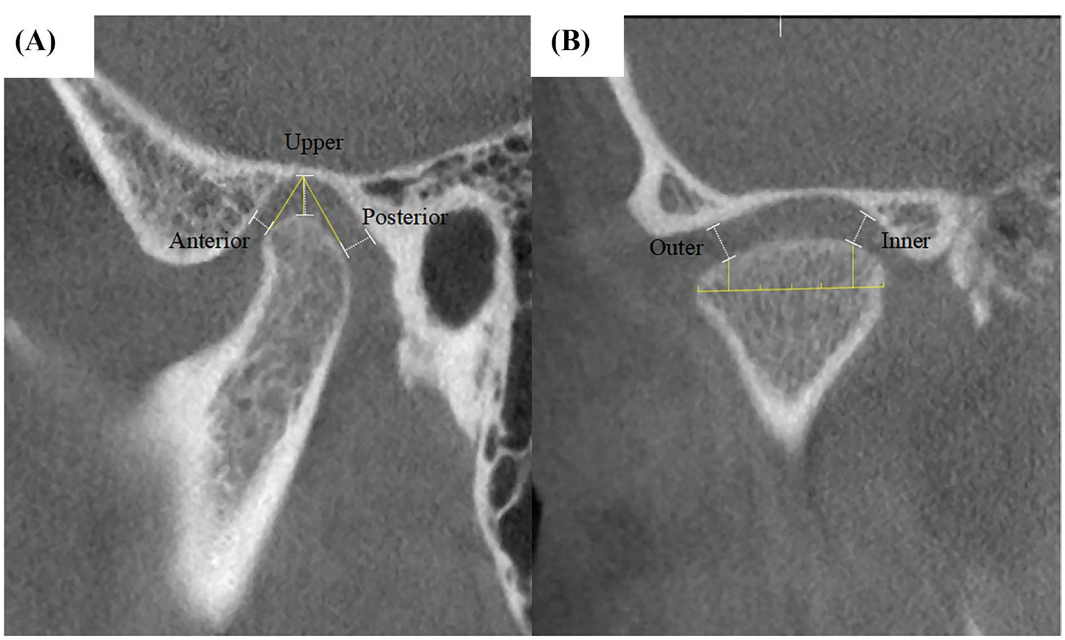

Fig. 2 Methods for measuring joint space. **A** = The anterior, upper and posterior joint spaces were measured according to Kamelchuk [14]; **B** = The outer and inner joint spaces were measured according to Ikeda [15]

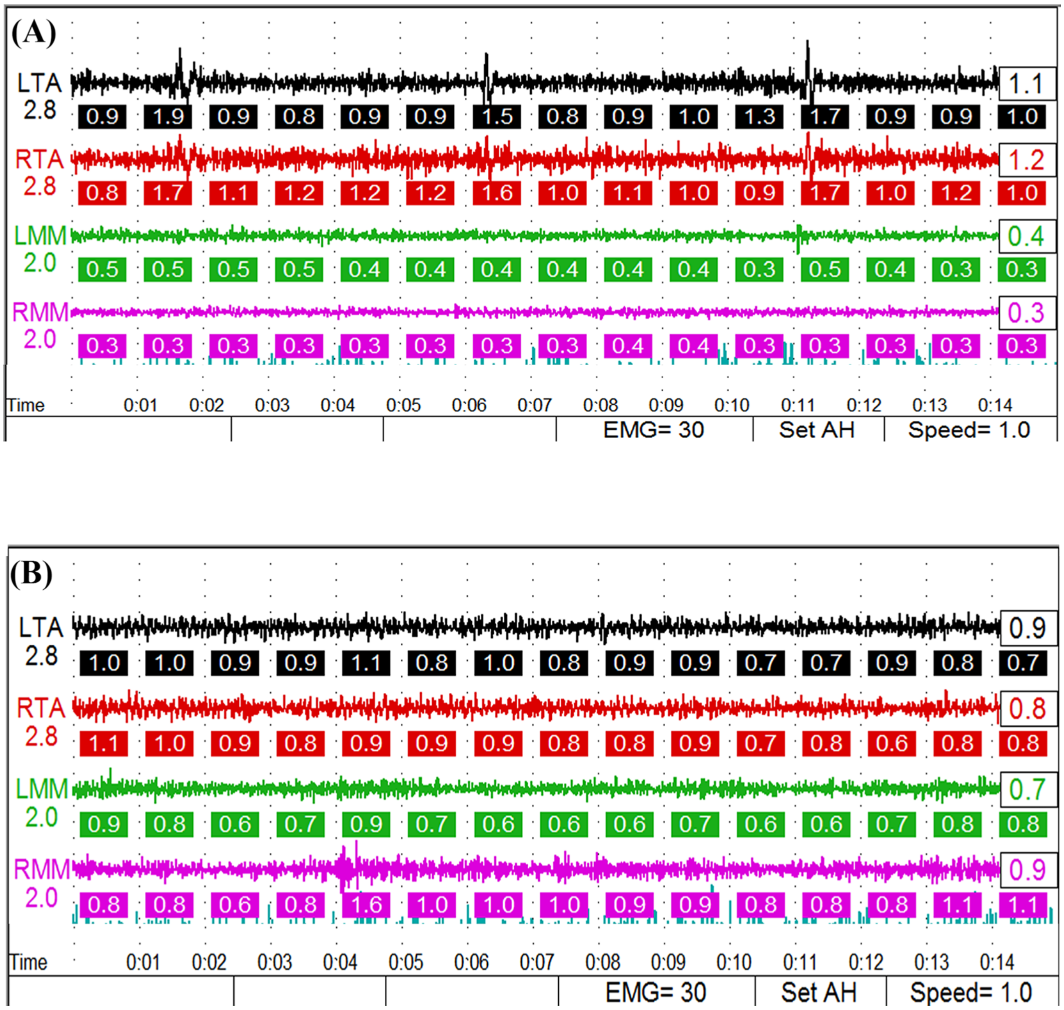

Fig. 3 EMG during mandibular posture position (MPP). The average values of EMG were in the small box on the right of each muscle (LTA: Left Anterior Temporalis; RTA: Right Anterior Temporalis; LMM: Left Masseter Muscles; RMM: Right Masseter Muscles). **A** = Before treatment; **B** = After treatment

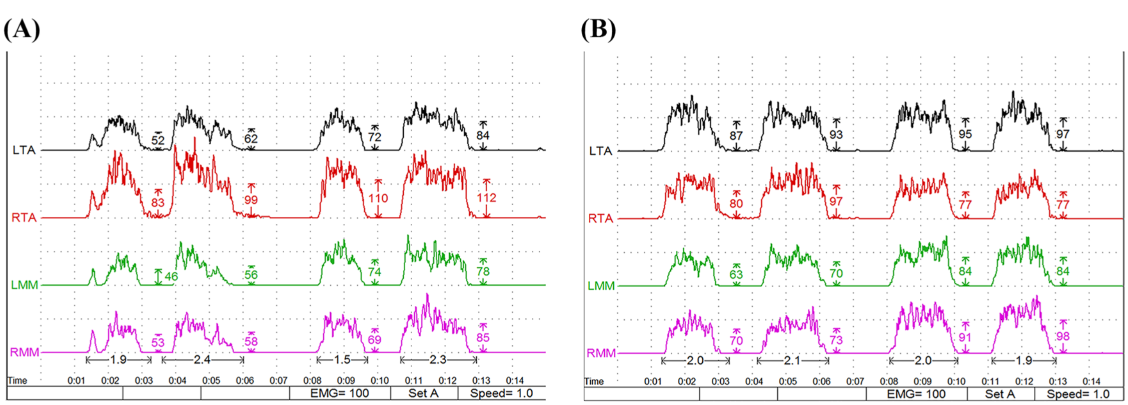

Fig. 4 EMG during maximum voluntary clench (MVC). **A** = Before treatment; **B** = After treatment. The EMG of LTA and RTA were in harmony after the treatment, Anterior Temporalis decreased and Masseter Muscles increased

bigger, and the change of the inner space was the most obvious (0.32±0.81 mm) which had significant statistical difference ($p<0.05$), however, the rest of them had no statistical difference ($p > 0.05$). The posterior and the upper space had smaller changes (0.11±0.70 mm and 0.05±1.01 mm respectively) (Table 2; Fig. 6).

The anterior spaces of both sides of the TMJs became smaller (the difference is -0.36±0.93 mm), which had

Table 1 Comparisons of Fricton Index in patients with TMD before and after treatment ($n=31$)

$\bar{x} \pm s$

Scales	Pre-treatment	Post-treatment	Difference value	*t*	*p*
Mandibular Movement (MM)	5.45 ± 2.50	2.45 ± 1.06	-3.00 ± 2.54	-6.568	0.000
Joint Noise (JN)	1.42 ± 1.12	1.03 ± 0.84	-0.39 ± 1.23	-1.753	0.090
Joint Palpation (JP)	1.03 ± 0.84	0.35 ± 0.48	-0.67 ± 0.98	-3.851	0.001
Dysfunction Index (DI)	0.30 ± 0.11	0.14 ± 0.05	-0.16 ± 0.11	-7.749	0.000
Palpation Index (PI)	0.13 ± 0.06	0.06 ± 0.04	-0.07 ± 0.06	-7.228	0.000
Craniomandibular Index (CMI)	0.21 ± 0.07	0.10 ± 0.03	-0.12 ± 0.07	-9.218	0.000

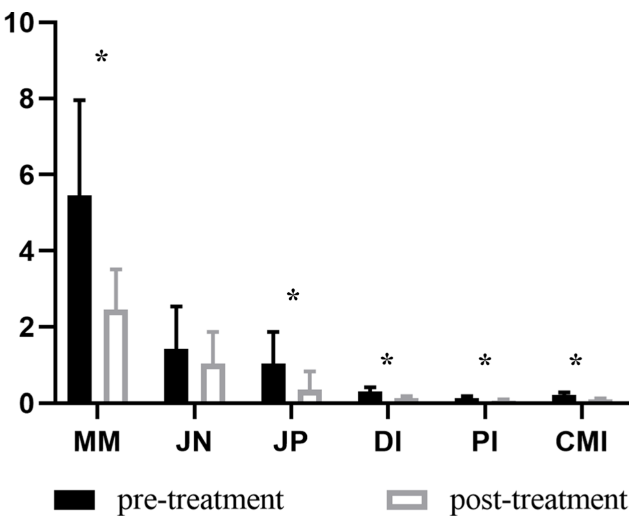

Fig. 5 Comparisons of Fricton Index in 31 patients with TMD before and after treatment (* means $p<0.05$), MM: Mandibular Movement; JN: Joint Noise; JP: Joint Palpation; DI: Dysfunction Index; PI: Palpation Index; CMI: Craniomandibular Index

significant statistical differences ($p<0.05$); the posterior, upper, inner and outer space all became bigger, and the change of the inner space was the most obvious (0.26±0.80 mm) which had the significant statistical difference ($p<0.05$), however, the rest of them have no statistical difference ($p > 0.05$), the outer space had the smallest change (0.08±1.14 mm) (Table 3; Fig. 6).

Surface electromyogram

When the TMJs were in the mandibular postural position, the electromyogram of bilateral anterior temporalis decreased, wherein the right side decreased by 0.587±1.758 μV which had no statistical difference ($p > 0.05$), and the left side decreased by 0.594±0.935 μV which had statistical difference ($p<0.05$); the electromyograms of the left and right masseter muscles increased (0.019±0.323 μV and 0.061±0.451 μV respectively) which had no statistical difference ($p > 0.05$) (Table 4; Fig. 7).

During the maximum voluntary clench, the electromyogram of the left and right anterior temporalis decreased by 3.129±29.212 μV and 6.323±39.219 μV respectively which had no statistical difference ($p > 0.05$); the electromyogram of the left and right masseter muscles increased by 1.613±47.623 μV and 2.290±63.522 μV respectively which had no statistical difference ($p > 0.05$) (Table 5; Fig. 7).

Discussion

Clinical curative effect

Pain, joint noise and limited movement are the common symptoms of TMD, and clinical evaluation of its therapeutic effect is always limited to qualitative description stage, such as obvious effect, effective or ineffective, however, descriptive and subjective reports should be avoided to evaluate the degree of TMD dysfunction or evaluate the TMD therapeutic effect. Fricton index was objective and reliable to a certain extent, which could be used

Table 2 Comparisons of the left and the right temporomandibular joint spaces before and after treatment ($n=31$)

$\bar{x} \pm s$, mm

Space		Pre-treatment	Post-treatment	Difference value	*t*	*p*
Left	Anterior space	2.70 ± 0.79	2.09 ± 0.61	-0.61 ± 0.91	-3.72	0.001
	Posterior space	2.66 ± 1.24	2.95 ± 1.18	0.28 ± 1.42	1.12	0.274
	Upper space	2.56 ± 0.98	2.78 ± 1.06	0.22 ± 1.03	1.20	0.240
	Inner space	2.32 ± 0.61	2.52 ± 0.69	0.20 ± 0.80	1.37	0.181
	Outer space	2.57 ± 1.06	2.61 ± 1.11	0.04 ± 1.38	0.16	0.877
Right	Anterior space	2.71 ± 0.66	2.60 ± 0.76	-0.12 ± 0.90	-0.74	0.466
	Posterior space	2.02 ± 0.64	2.13 ± 0.38	0.11 ± 0.70	0.89	0.383
	Upper space	2.61 ± 1.04	2.66 ± 0.42	0.05 ± 1.01	0.28	0.780
	Inner space	2.47 ± 0.91	2.79 ± 0.64	0.32 ± 0.81	2.16	0.039
	Outer space	2.39 ± 0.62	2.52 ± 0.70	0.13 ± 0.87	0.83	0.412

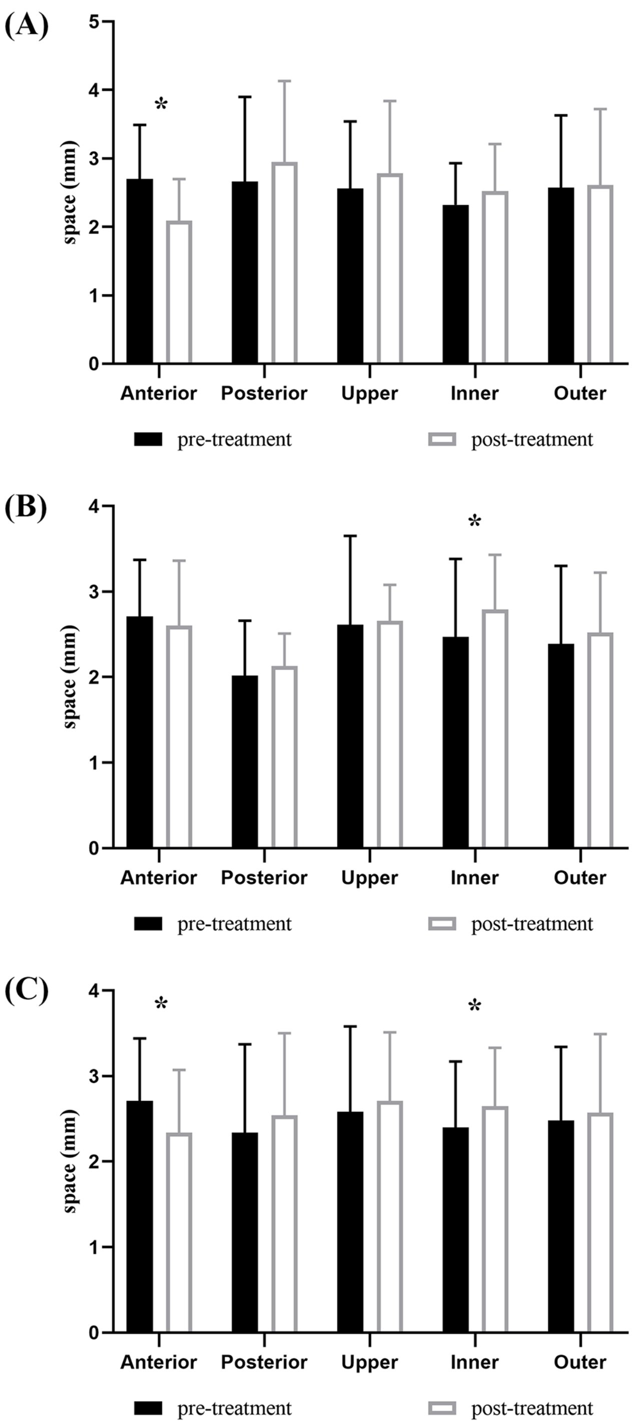

Fig. 6 Measurement results of TMJ spaces before and after treatment (* means $p<0.05$). **A** = Measurement results of the left TMJ space in 31 patients before and after treatment; **B** = Measurement results of right TMJ space before and after treatment; **C** = Measurement results of bilateral TMJ space before and after treatment

in clinical practice to conduct quantitative and objective evaluation of TMD treatment effect [11, 13, 16]. In our research, immediate pain reliefs of 21 patients with TMD were reported. The splint used in the research was mainly stabilization splint covering the entire dentition of the patient's upper jaw which simulated Roth functional occlusion concept. The stabilization splint had a good application prospect in the treatment of maxillofacial pain by other researches [17, 18]. In this research, 24 patients with TMD had joint noises before treatment. After 6–8 months of splint treatment, the joint noises of only 7 patients had disappeared significantly, of which 9 had relieved and 8 had no change. Joint noise mainly indicates bounce, friction and cracking, etc. Bounce was chosen for the research, and there are two pathogenesis, one occurs at the beginning of the opening, which is the anterior disc displacement with reduction, and the other often occurs at the end of the opening with hyper function of pterygoid. In the research, the mandibular movement state of 31 TMD patients had been significantly improved, and the reason may be the separation of upper and lower jaw, the bad muscle memory type of the past was eliminated, then the bad guidance of the musculoskeletal state gradually was eliminated, the open mouth type gradually recovered to be consistent. Moreover, due to the increases of the height between jaws, the negative pressure in the articular fossa was reduced and the adhesive tissue was loosened, thus the mouth opening degree improved. Leite et al. [19] also suggested that the ease of pain of AT maybe a possible potential use of TMD for mouth opening, our study also found the decrease of EMG of AT in MPP.

TMJ space distance

CBCT can reflect the bone changes of temporomandibular joint from three-dimensional direction, and the changes of joint space can be observed easier [20]. It was generally believed that condylar displacement may be one of the important imaging manifestations of TMD [21]. Major et al. [22] found that the change of joint space might be associated with the displacement of articular disc to some extent, and the detection of condyle position by CBCT might be used to predict the location of articular discs. Zhang et al. [23] had found that there was no significant statistical difference between the joint spaces measured by CBCT and those measured by actual impression ($P=0.305$). It can be considered that CBCT has certain reliability and authenticity in measuring temporomandibular joint spaces. The joint space is of great significance in the diagnosis and treatment of TMD, the previous studies showed that the proportion of small posterior space of patients with TMD was significantly higher than that of asymptomatic controls [24], the possible reason is that smaller posterior spaces may produce more pressure to the double plate areas, which is loose connective tissues that is rich in blood vessels and nerves. On the contrary, when the condyle process moves forward, the vein will be filled to provide nutrition for the

Table 3 Comparisons of bilateral temporomandibular joint spaces before and after treatment ($n=62$)

$\bar{x} \pm$ s, mm

Space	Pre-treatment	Post-treatment	Difference value	*t*	*p*
Anterior space	2.71 ± 0.73	2.34 ± 0.73	-0.36 ± 0.93	-3.07	0.003
Posterior space	2.34 ± 1.03	2.54 ± 0.96	0.20 ± 1.11	1.40	0.167
Upper space	2.58 ± 1.00	2.71 ± 0.80	0.14 ± 1.02	1.06	0.294
Inner space	2.40 ± 0.77	2.65 ± 0.68	0.26 ± 0.80	2.51	0.015
Outer space	2.48 ± 0.86	2.57 ± 0.92	0.08 ± 1.14	0.58	0.564

Table 4 Comparisons of EMG during MPP before and after treatment ($n=31$)

$\bar{x} \pm$ s, μV

Muscles	Pre-treatment	Post-treatment	Difference value	*t*	*p*
Left Anterior Temporalis	2.023 ± 1.008	1.429 ± 0.440	-0.594 ± 0.935	-3.534	0.001
Right Anterior Temporalis	2.752 ± 1.872	2.165 ± 0.668	-0.587 ± 1.758	-1.859	0.073
Left Masseter Muscle	0.797 ± 0.266	0.816 ± 0.173	0.019 ± 0.323	0.334	0.741
Right Masseter Muscle	0.984 ± 0.415	1.045 ± 0.234	0.061 ± 0.451	0.756	0.456

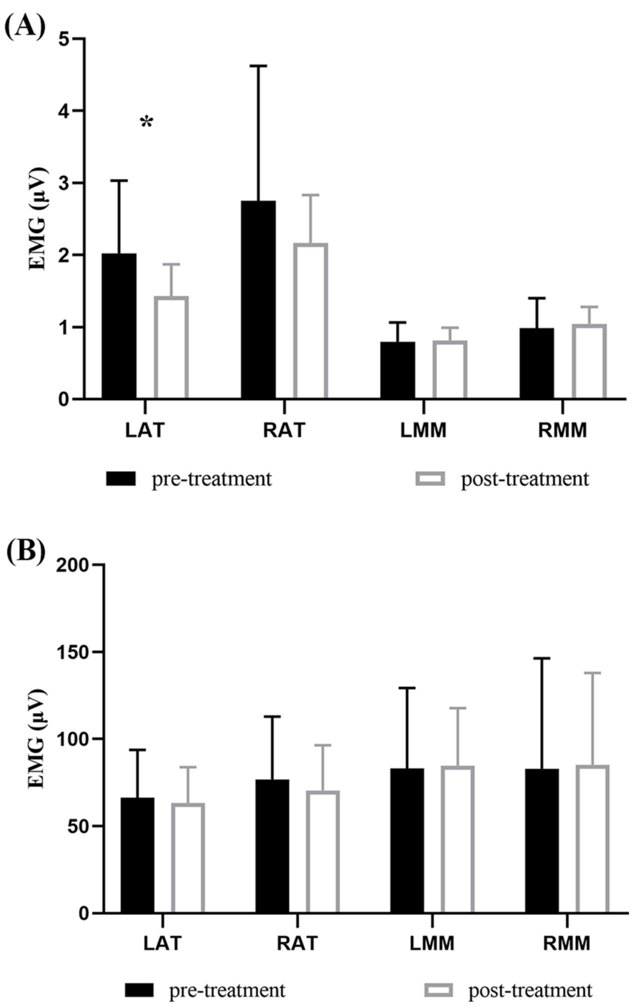

Fig. 7 Comparisons of EMG before and after treatment (* means $p < 0.05$). **A** = Comparisons of EMG in MPP before and after treatment; **B** = Comparisons of EMG in MVC before and after treatment

joint area [25, 26]. When long-term compression causes dysfunction in the bilateral plate area, signs and symptoms related to TMD may appear.

Ikeda et al. [15] had used Kamelchuk method [14] to measure joint spaces in 24 TMJs of 22 healthy people without joint symptoms, and the anterior, posterior and superior joint spaces were 1.3±0.2 mm, 2.1±0.3 mm and 2.5±0.5 mm, respectively. In this research, joint spaces were measured in 31 TMD patients before treatment, and the anterior, posterior, and upper joint spaces were 2.71±0.73 mm, 2.34±1.03 mm and 2.58±1.00 mm respectively. The anterior spaces of TMD patients increased significantly while the mean value of the posterior spaces decreased but the difference was not significant, and it may be related to the morphological changes of condyles in TMD patients. Patients in this research might be subject to occlusion interference or early contact. In order to avoid the nerve-muscle damage, the adaptive change was produced, perhaps the reconstruction of condyle. However, symptoms related with TMD might appear when the change went beyond TMJ physiological tolerance [6].

Recent studies [27, 28] concluded that stabilization splint and anterior deprogrammer resulted in the forward and downward condylar movement, this trend of condyle movement differs from the most superoanterior position by manipulative reduction of the RW-splint [10]. In our research, 31 TMD patients after the treatment of IMS stabilization splint were carried on the statistical analysis in the joint spaces on both sides. It showed that there was a tendency to decrease in the anterior joint space, however, posterior, upper, inner and outer joint space had the trend of increase, the inner space was the most significant. There were different changes on the left and right side of the condylar joint spaces, and the standard deviation was obvious, which indicated that the condylar position had a very high individuation due

Table 5 Comparisons of EMG during MVC before and after treatment ($n = 31$)

$\bar{x} \pm$ s, μV

Muscles	Pre-treatment	Post-treatment	Difference value	*t*	*p*
Left Anterior Temporalis	66.290 ± 27.452	63.161 ± 20.648	-3.129 ± 29.212	-0.696	0.555
Right Anterior Temporalis	76.774 ± 36.179	70.452 ± 25.878	-6.323 ± 39.219	-0.898	0.377
Left Masseter Muscle	83.097 ± 46.180	84.710 ± 32.964	1.613 ± 47.623	0.189	0.852
Right Masseter Muscle	82.968 ± 63.312	85.258 ± 52.686	2.290 ± 63.522	0.201	0.842

to the neuromuscular, anatomical physiological and psychological factors. In the term of one individual, bilateral asymmetry of neuromuscular function, asymmetry of condylar morphology [29, 30] and rotation [31] of condyles would result in the asymmetry of bilateral motion. Although the variation of the bilateral joint spaces is different due to the individual characteristics, the general trend was the forward and outward displacement of condyle, which was consistent with the previous studies [27, 28, 31].

Surface electromyogram

Electromyography was the most reliable and objective technique to evaluate muscle functions and efficacy by monitoring muscle potentials in clinical practices [32], which could evaluate the degree and duration of muscle activities. One method is the sEMG, this non-invasive and painless electrophysiological activity recording the method of muscle requires the electrode as an auxiliary tool, and the non-invasive properties became its most important advantage [33]. The main goal of sEMG is to monitor the electrophysiological signals of muscle fibers in the attached area through the surface electrodes, these signals are the sum of the activities of multiple motor units in this area. Visser et al. [34] conducted statistical analysis on the EMG monitoring values of masseter muscle and temporal muscle in healthy people within 2 days, and the correlation values showed no significant difference or asymmetry. Accurate quantitative analysis of muscle electrophysiological activities by sEMG simplified the quantitative analysis in the stomatognathic system and provided the possibility of objective evaluations of muscle functions [33].

In this research, the EMG of bilateral AT and MM were 2.023 μV, 2.752 μV, 0.797 μV, 0.984 μV respectively when patients are in the mandibular postural position before the treatment. Scopel et al. [35] found that the average EMG of masticatory muscles in normal people without TMD was 1.5 μV, 1.6 μV, 1.3 μV, and 1.2 μV respectively, and patients with TMD might have a higher EMG of masticatory muscles during MPP [36]. In our research, the resting potential of AT in TMD patients before the treatment was consistent with the conclusion [35, 36], but the resting potential of MM tended to be lower than the results of Scopel's [35]. The possible reason is that the patients suffered "disuse atrophy" of the masseter muscle due to the long-term chewing dysfunction caused by TMD, thus reducing the corresponding electrophysiological activities of muscles.

After the treatment, the EMG of bilateral AT tended to decrease and bilateral MM tended to increase during MPP. Pinho et al. [37] measured the EMG of patients with and without TMD in the mandibular rest position, they found that the average EMG of the group without TMD at the mandibular rest position was 1.92 ± 1.20 μV and 2.52 ± 1.25 μV in TMD group. Scopel et al. [35] also found that the EMG values of bilateral AT and MM in TMD patients decreased significantly after wearing the splint during MPP, the difference was statistically significant. In this research, the EMG of AT decreased in the same way with the previous studies [35, 36, 38]. However, the MM EMG increased by 0.019 μV and 0.061 μV respectively after the completion of splint treatment, which was closer to the EMG of normal people without TMD (1.3 μV and 1.2 μV) [35], thus better confirming our hypothesis.

In the research, when patients were in the maximum voluntary clench, the EMG of bilateral AT and MM are 66.290 μV, 76.774 μV, 83.097 μV, 82.968 μV respectively before the treatment. Tartaglia et al. [39] found that the average EMG of the masseter muscle and temporal muscle of the healthy subjects during MVC was 131.7μV, which was significantly higher than the mean value in our study, the reason may be the decrease of the activity of the corresponding masticatory muscle, due to the pain of TMD patients, which leads to the weakening of masticatory function, of course, the influence of occlusal factors on the masticatory muscle is also not excluded here.

After the treatment, the EMG of bilateral AT tended to decrease and bilateral MM tended to increase during MVC. Pinho et al. [37] also measured the EMG of patients with and without TMD during MVC, and the average EMG of the group without TMD during MVC was 110.30 ± 82.97 μV, and that of the group with TMD was 66.77 ± 35.22 μV. The conclusion of Tartaglia et al. [39] was also consistent with the conclusion above, they measured the EMG of MM and AT during MVC in TMD patients and healthy subjects, and they found that the mean EMG of MM and AT during MVC was significantly higher in the control group (131.7μV) than in the group with TMD (88.7-117.6μV). In other words, the EMG of MM and AT in the patients without TMD was higher than that in the patients with TMD during MVC. In our research, the decease of AT was not consistent with the early research, however, Ferrario et al. [40] found that under the same occlusal loading, when the EMG activity of bilateral AT was greater than that of MM, it might cause more loads on TMJ, thus causing discomfort and even TMD. Interestingly, in our research, the decreasing trend of bilateral AT and the increasing trend of MM may release the load on the TMJ, accounting for relieving the symptoms and signs of TMD patients.

As for the limitations of this study, the further sublimation needs a long-term evaluation and a large number of randomized controlled trials to comprehensively evaluate the curative effect by combining the methods of MRI, spiral CT, Cadiax (computer aided diagnosis axiogragh), mandibular movement trace, joint noise record, T-scan and 3D photography.

Conclusion

IMS stabilization splint is a therapeutic reversible treatment for TMD, especially for pain and mandibular movement disorder; it produces effects of forward and outward condylar movement and elimination of the masticatory muscles antagonism.

Abbreviations

TMD	Temporomandibular Disorders
IMS	Individual musculoskeletally stable
MSP	Musculoskeletally stable position
CR	Centric Relation
CBCT	Cone-Beam Computed Tomography
sEMG	Surface Electromyogram
AT	Anterior temporalis
MM	Masseter muscles
MPP	Mandibular postural position
MVC	Maximum voluntary clench
MRI	Magnetic resonance imaging

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Author contributions

ZZ, XLi, BS and LT were involved in the conception of the study and designed the study. ZZ and XL are responsible for data collection. Then ZZ analyzed data. ZZ and XL drafted the primary manuscript, XLi, BS and LT revised and approved the final manuscript. Finally, all authors have read and approved the manuscript.

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Data availability

The data presented in this study are available on reasonable request from the corresponding author.

Declarations

Ethics approval and consent to participate

The volunteer provided written informed consent and agreed to use their data for research and journal publication. This study was approved by the Ethics Committee of West China Hospital of Stomatology Institutional Review Board of Sichuan University (reference number WCHSIRB-D-2016-073) and performed in accordance with the relevant guidelines and regulations.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Yap AU, Zhang MJ, Cao Y, Lei J, Fu KY. Comparison of psychological states and oral health-related quality of life of patients with differing severity of temporomandibular disorders. J Oral Rehabil. 2022;49(2):177–85.
2. Dworkin SF, LeResche L. Research diagnostic criteria for temporomandibular disorders: review, criteria, examinations and specifications, critique. J Craniomandib Disord. 1992;6(4):301–55.
3. De Boever JA, Carlsson GE, Klineberg IJ. Need for occlusal therapy and prosthodontic treatment in the management of temporomandibular disorders. Part I. Occlusal interferences and occlusal adjustment. J Oral Rehabil. 2000;27(5):367–79.
4. Michelotti A, Iodice G. The role of orthodontics in temporomandibular disorders. J Oral Rehabil. 2010;37(6):411–29.
5. Roth RH, Rolfs DA. Functional occlusion for the orthodontist. Part II. J Clin Orthod. 1981;15(2):100–23.
6. Roth RH. Occlusion and condylar position. Am J Orthod Dentofac Orthop. 1995;107(3):315–8.
7. Okeson JP. Management of temporomandibular disorders and occlusion. 7th ed. St. Louis: Elsevier Medicine; 2013.
8. Khan MT, Verma SK, Maheshwari S, Zahid SN, Chaudhary PK. Neuromuscular dentistry: occlusal diseases and posture. J Oral Biol Craniofac Res. 2013;3(3):146–50.
9. Corte-Real A, Abreu J, Figueiredo JP, Nunes T. Temporomandibular trauma and reflections on personal evaluation. Forensic Sci Med Pathol 2023.
10. Dawson PE. Functional Occulsion from TMJ to smile design. J Oral Health J 2007.
11. Fricton JR, Schiffman EL. Reliability of a craniomandibular index. J Dent Res. 1986;65(11):1359–64.
12. Derogatis L. SCL-90-R: Administration, scoring and procedures manual for the Revised version.; 1977.
13. Fricton JR, Schiffman EL. The craniomandibular index: validity. J Prosthet Dent. 1987;58(2):222–8.
14. Kamelchuk LS, Grace MG, Major PW. Post-imaging temporomandibular joint space analysis. Cranio. 1996;14(1):23–9.
15. Ikeda K, Kawamura A, Ikeda R. Assessment of optimal condylar position in the coronal and axial planes with limited cone-beam computed tomography. J Prosthodont. 2011;20(6):432–8.
16. Zhang P, Ge Y, Zhang J, Xu W. Orthodontic treatment improves magnetic resonance imaging features and quality of life in adult patients with temporomandibular disorders. Am J Transl Res. 2023;15(5):3723–30.
17. Kuttila M, Le Bell Y, Savolainen-Niemi E, Kuttila S, Alanen P. Efficiency of occlusal appliance therapy in secondary otalgia and temporomandibular disorders. Acta Odontol Scand. 2002;60(4):248–54.
18. Gavish A, Winocur E, Ventura YS, Halachmi M, Gazit E. Effect of stabilization splint therapy on pain during chewing in patients suffering from myofascial pain. J Oral Rehabil. 2002;29(12):1181–6.
19. Leite WB, Oliveira ML, Ferreira IC, Anjos CF, Barbosa MA, Barbosa AC. Effects of 4-Week Diacutaneous Fibrolysis on Myalgia, Mouth opening, and Level of Functional Severity in Women with Temporomandibular disorders: a Randomized Controlled Trial. J Manipulative Physiol Ther. 2020;43(8):806–15.
20. Brooks SL, Brand JW, Gibbs SJ, Hollender L, Lurie AG, Omnell KA, Westesson PL, White SC. Imaging of the temporomandibular joint: a position paper of the American Academy of Oral and maxillofacial Radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1997;83(5):609–18.
21. Weinberg LA. Role of condylar position in TMJ dysfunction-pain syndrome. J Prosthet Dent. 1979;41(6):636–43.
22. Major PW, Kinniburgh RD, Nebbe B, Prasad NG, Glover KE. Tomographic assessment of temporomandibular joint osseous articular surface contour and spatial relationships associated with disc displacement and disc length. Am J Orthod Dentofac Orthop. 2002;121(2):152–61.

23. Zhang ZL, Cheng JG, Li G, Zhang JZ, Zhang ZY, Ma XC. Measurement accuracy of temporomandibular joint space in Promax 3-dimensional cone-beam computerized tomography images. Oral Surg Oral Med Oral Pathol Oral Radiol. 2012;114(1):112–7.
24. Mongini F. Abnormalities in condylar and positions.in:Silberg,Clark GT,editers.Abnormal jaw mechanics,diagnosis and treatment. In: Chicago:Quintessence,. vol. 30; 1980.
25. Westesson PL, Kurita K, Eriksson L, Katzberg RW. Cryosectional observations of functional anatomy of the temporomandibular joint. Oral Surg Oral Med Oral Pathol. 1989;68(3):247–51.
26. Sahler LG, Morris TW, Katzberg RW, Tallents RH. Microangiography of the rabbit temporomandibular joint in the open and closed jaw positions. J Oral Maxillofac Surg. 1990;48(8):831–4.
27. Hasegawa Y, Kakimoto N, Tomita S, Honda K, Tanaka Y, Yagi K, Kondo J, Nagashima T, Ono T, Maeda Y. Movement of the mandibular condyle and articular disc on placement of an occlusal splint. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2011;112(5):640–7.
28. Ramachandran A, Jose R, Tunkiwala A, Varma RB, A MS, Nair PK, Kumar KS, Sam LM. Effect of deprogramming splint and occlusal equilibration on condylar position of TMD patients - a CBCT assessment. Cranio. 2021;39(4):294–302.
29. Alhammadi MS, Almashraqi AA, Thawaba AA, Fayed MMS, Aboalnaga AA. Dimensional and positional temporomandibular joint osseous characteristics in normodivergent facial patterns with and without temporomandibular disorders. Clin Oral Investig. 2023;27(9):5011–20.
30. Musa M, Zhang Q, Awad R, Wang W, Ahmed MMS, Zhao Y, Almashraqi AA, Chen X, Alhammadi MS. Quantitative and qualitative condylar changes following stabilization splint therapy in patients with temporomandibular joint disorders. Clin Oral Investig. 2023;27(5):2299–310.
31. Ahmed MMS, Shi D, Al-Somairi MAA, Alhashimi N, Almashraqi AA, Musa M, Li N, Chen X, Alhammadi MS. Three dimensional evaluation of the skeletal and temporomandibular joint changes following stabilization splint therapy in patients with temporomandibular joint disorders and mandibular deviation: a retrospective study. BMC Oral Health. 2023;23(1):18.
32. Witkowska A. An outline of the history of electromyography. The significance of surface electromyography in neurophysiological diagnosis. Nowiny Lekarskie. 2008;77(3):227–30.
33. Wozniak K, Piatkowska D, Lipski M, Mehr K. Surface electromyography in orthodontics - a literature review. Med Sci Monit. 2013;19:416–23.
34. Visser A, McCarroll RS, Naeije M. Masticatory muscle activity in different jaw relations during submaximal clenching efforts. J Dent Res. 1992;71(2):372–9.
35. Scopel V, Alves da Costa GS, Urias D. An electromyographic study of masseter and anterior temporalis muscles in extra-articular myogenous TMJ pain patients compared to an asymptomatic and normal population. Cranio. 2005;23(3):194–203.
36. He S, Wang S, Song F, Wu S, Chen J, Chen S. Effect of the use of stabilization splint on masticatory muscle activities in TMD patients with centric relation-maximum intercuspation discrepancy and absence of anterior/lateral guidance. Cranio. 2021;39(5):424–32.
37. Pinho JC, Caldas FM, Mora MJ, Santana-Penin U. Electromyographic activity in patients with temporomandibular disorders. J Oral Rehabil. 2000;27(11):985–90.
38. Lei Q, Lin D, Liu Y, Lin K, Huang W, Wu D. Neuromuscular and occlusion analysis to evaluate the efficacy of three splints on patients with bruxism. BMC Oral Health. 2023;23(1):325.
39. Tartaglia GM, Moreira Rodrigues da, Silva MA, Bottini S, Sforza C, Ferrario VF. Masticatory muscle activity during maximum voluntary clench in different research diagnostic criteria for temporomandibular disorders (RDC/TMD) groups. Man Ther 2008, 13(5):434–440.
40. Ferrario VF, Sforza C. Biomechanical model of the human mandible in unilateral clench: distribution of temporomandibular joint reaction forces between working and balancing sides. J Prosthet Dent. 1994;72(2):169–76.

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