

RESEARCH

Open Access



Clinical evaluation of 3D printed splint in the treatment of temporomandibular disorders

Yuanqing Ma¹, Weixu Li¹, Litong Li¹, Meng Cao^{1*} and Chi Zhang²

Abstract

Objective To use a T-scan (Tekscan, Boston, USA) to evaluate the grinding effect of a three-dimensional (3D) printed occlusal splint and provide reference guidelines for adjusting occlusion and alleviating temporomandibular joint symptoms before orthodontic treatment.

Methods Eighteen patients with temporomandibular disorder (TMD) were treated with 3D-printed stable occlusal plates for three months. The occlusal time (OT) of the dentition and the difference percentage of occlusal force between the left and right sides (Asymmetry index of occlusal force, AOF) were observed one week, one, two, and three months after T-scan-guided occlusal splint treatment. Before and after treatment, we investigated joint space, electromyography (EMG), the maxillofacial pain visual analog scale (VAS), and the Chinese version of the jaw function limitation scale (JFLS).

Results Significant reductions in OT and AOF were observed across four time points in TMD patients wearing T-scan-guided occlusal splints ($P < 0.05$). Furthermore, the bilateral masseter muscle (MM) and temporalis anterior (TA) asymmetry index were reduced at the mandibular postural and intercuspal positions. Cone beam computed tomography (CBCT) showed that the anterior space of the articular had decreased, the posterior space had increased, and the VAS and JFLS scores had decreased significantly ($P < 0.05$).

Conclusion T-scan accurately located the abnormal occlusal contact point, guidance enhances occlusal equilibration and may improve TMJ function and symptoms in TMD patients.

Keywords Tekscan T-scan digital occlusal analysis, Temporomandibular disorders, 3D printing stability occlusal splint, BioEMG-III-Electromyography

Background

The pathogenesis of temporomandibular disorder (TMD), predominantly manifesting as orofacial pain and limited mandibular function, is still inconclusive, although potential causes include occlusal factors, psychiatric factors, and immune factors [1, 2]. Despite controversy regarding the relationship between occlusion pattern and TMD, studies have shown that if all teeth are occlusal at the maximum intercuspal position (MIP), the force is distributed to the center of the condylar head, and the direction of force distribution changes when the posterior teeth bite unilaterally or only the anterior teeth

*Correspondence:

Meng Cao
1307753550@qq.com

¹State Key Laboratory of Oral and Maxillofacial Reconstruction and Regeneration, National Clinical Research Center for Oral Diseases, Shaanxi Key Laboratory of Stomatology, Department of Orthodontics, School of Stomatology, The Fourth Military Medical University, No. 145, Chang Le Xi Road, Xi'an 710032, Shaanxi Province, People's Republic of China

²Xi'an Boen Biotechnology Limited Corporation, Xi'an, People's Republic of China



[3]. It is common to aim for the condyle to be in the anterior position of the joint fossa to carry out pre-orthodontic diagnosis, pre-orthodontic adjuvant treatment, and to adjust the occlusal relationship [4]. Previous studies have shown that stable occlusal splints alleviate clinical symptoms by altering the occlusion's contact state and jaw position relationship, thus relieving interference, reducing abnormal muscle activity, and reducing intra-articular pressure [5, 6]. Over recent years, digital technology has been introduced into the design and production of occlusal splints, which can improve the manufacturing quality and long-term stability of occlusal splints [7, 8]. The application of intraoral scanning and digital occlusal splint design saves time when making stable occlusal splints and increases patient comfort during treatment [9].

In a previous study, Kerstein found that the T-Scan is a reliable tool for detecting early contacts and can effectively check occlusal balances [10]. T-Scan is a digital occlusion analysis device that uses a small, flexible, pressure-sensitive bite transducer inserted in a dental arch-shaped recording sensor to record and evaluate tooth contact, force, and timing in real time [11]. Articulating paper markings can be contaminated by the saliva and hence can cause misinterpretation of readings whereas in T-Scan the sensors are synthetic and resistant to salivary wetting of the sensors thus maintaining the accuracy of the recordings [12]. In the present research, we analyzed patients with TMD who were treated with 3D-printed occlusal splints. The T-scan was used to analyze the occlusal of the 3D-printed occlusal splint and to observe whether there were any statistical differences in the occlusal time and the percentage difference between the left and right occlusal forces before and after T-scan-guided occlusion. Changes in the VAS score, JFLS scale, masticatory muscle electromyography, and temporomandibular joint space, were analyzed during follow-up and clinical evaluation.

Methods

Inclusion and exclusion criteria

The inclusion criteria were as follows: (1) patients with clinical symptoms such as unilateral or bilateral maxillo-facial pain, joint snapping, and abnormal jaw movement; (2) the patient's periodontal tissue was healthy, the tooth body and dentition were relatively intact, and there was an absence of poor restoration; (3) there were no apparent organic lesions in the temporomandibular joint area upon imaging examination; (4) the patient met the TMD classification and diagnostic criteria issued by the International Association for Dental Research in 2014 [9]; (5) the patient had not received any treatment for a TMD over the past three months.

The exclusion criteria were as follows: (1) patients aged < 18 or > 45 years; (2) severe restriction of mouth opening; (3) a history of immune disease, rheumatoid arthritis, or trauma to the TMJ; (4) mental illness or the patient was unable to express their subjective opinions in a normal manner.

General information

Between April 2023 and March 2024, we enrolled 18 patients with TMD in the Department of Orthodontics, Hospital of Stomatology, Air Force Medical University Hospital, including 6 males and 12 females, aged 18 to 45 years (mean: 29.0 ± 1.5 years). The study was reviewed and approved by the Biomedical Ethics Committee of the Stomatological Hospital of the Air Force Military Medical University (Reference: IRBREV-2022189). All study subjects were confirmed by the TMD clinical and imaging examinations, and each subject provided informed and signed consent.

Experimental methods

Acquisition and digital transfer of centric relation

Firstly, a certain number of Leaf Gauge measuring pieces of 0.1 mm were placed in the anterior tooth area of the patient. Then, instructed the patient to bite tightly. The posterior teeth were just disengaged after increasing or decreasing the number of measuring pieces, and the maxillo-mandibular relationship at this time was recorded with occlusal recording materials and the intra-oral scanner (TRIOS 3; 3Shape A/S) to obtain a digital model of the patient's dentition with centric relation.

Design and production of a 3D-printed stability occlusal plate

After importing the digital model of the maxillary and mandibular dentition with centric relation (STL format) into the 3shape dental system we accessed the occlusal splint design module (3shape Splint Studio) and configured the virtual occlusion parameters by the established jaw position relationship and specific design requirements for the occlusal splint. (Fig. 1A) The inclination of the condylar guide was set to 30°, with a Bennett angle of 10°. The incision inclination was determined based on the first molar, which could be adjusted by 1 to 2 mm. The contact gap between the occlusal splint and the lower dentition was set to measure zero. The edge was kept 0.5 to 1.0 mm below the highest point of the contour, and the undercut value was controlled between 0.14 and 0.15 mm. The thickness of the tissue surface was 2.0 to 3.0 mm, and the thickness of the buccal and palatal sides was 1.5 mm. In addition, the splint covered one-third of the 13 mesial to 23 mesial to ensure that the upper lip was able to close naturally and allow the tongue to move freely during retention. A virtual



Fig. 1 3shape splint studio. **A.** Digitized model of the virtual average articulator. **B.** Early contact points and interference points in red



Fig. 2 Intraoral image wearing a 3D-printed occlusal splint. **A.** Right bite image. **B.** Frontal bite image. **C.** Left bite image

articulator simulated the centric, forward extension, and lateral movements and the occlusal splint was adjusted based on dynamic mandibular motion data. Early contact points and interference points are indicated in red within the software (Fig. 1B), were eliminated to ensure that the buccal cusps and anterior incisal margins of all posterior mandibular teeth were in uniform contact with the occlusal splint during median movement. The anterior bevel area was uniformly induced during anterior extension movement, and the canine area was induced during lateral movement. Finally, the digital occlusal plate was processed (Formlabs Form3 MA, USA), illuminated, removed from the printed contact support sites, and cleaned with an ultrasonic cleaner (Unimed, Matfors, Sweden). The dental clear resin (Dental LT Clear V2) used in this study passed the requirements for biocompatibility risk (ISO 7405:2018) according to the ISO 10993-1:2018 biological assessment of medical devices, and is a resin material that meets the requirements for clinical use is used in light-curing 3D printers.

Wearing of the 3D printing stability occlusal splint

We ensured that met the following requirements when wearing the stable occlusal: (1) the patient needed to take off the occlusal splint in the correct manner, and all patients needed to wear their splint for 8 h a day; (2) wear the stable occlusal splint on the maxillary dentition, and tissue surface (the medial surface) fitted entirely

with good retention; (3) the occlusal surface was flat, and the edge was smooth to avoid irritating the soft tissues; (4) during central occlusion, the occlusal surface was in point contact with all the functional cusps of the mandibular teeth; (5) when the mandibular protrusion movement, the incisors touched evenly; (6) during lateral movement, only the canines were in contact with the occlusal splint. (Fig. 2)

Grinding method for a 3D-printed stability occlusal splint

When the patient wears the occlusal splint for the first time, use red and blue articulating paper to adjust it. When the occlusion was centric, the occlusal imprint was evenly distributed and consistent in color. When forward extension was moved to the incision, there needed to be no occlusal mark on the posterior teeth. During lateral movement, the working canines or bicusps were in contact, and there was no occlusal mark on the non-working side (Fig. 3). Occlusal recordings were obtained using the T-scan system, before recording, the digital model datas were entered into the T-Scan dental chart to customize the graphical dental arches for improved occlusal arch mapping during recordings, and a 100- μ m thick sensor foil (large / small) was selected to be placed intraoral to measure occlusal parameters according to the patient's arch size. Instructed the subject to occlude into the recording sensor 2–3 times consecutively at maximum bite force if it is a new sensor. This will adjust the



Fig. 3 The red and blue articulating paper grinding stabilization splint

sensor and acclimate the patient to the occlusal sensor by clicking one of the fourteen available sensitivity sliders. Adjust the sensitivity from lowest to highest until 1–3 red contacts are visible. Select to perform 2–3 times maximal intercuspal position (MIP) recordings, these were recorded without removing the sensor from the patient's mouth, and the recordings were repeated to obtain 2–4 occlusal video recordings per participant (Fig. 4A). In this mandibular position, the right and left percentages were averaged for each participant and recorded as %R and %L, respectively. (Fig. 4B)

The OT indicates the time from the first tooth contact (point "A" in the T-Scan III force vs. time graph) to when all teeth are in complete intercuspation (point "B") (Fig. 4C). The OTs were averaged for each occlusal video recording and then averaged for each participant. A shorter OT indicates less time required to contact all

teeth. T-scan combined with articulating paper to adjust the occlusal splint until there were no apparent early contact and occlusion interference points (Fig. 5).

Observation indicators

The dentition and occlusion time of the 3D printed occlusal splint in the centric occlusion and the difference in the percentage of occlusal force between the left and right dental arches were observed at four observation points (one week, and then one, two, and three months) after treatment. We used a BioEMG-III system to record the myoelectric amplitude and masticatory muscle asymmetry index of the temporalis and masseter muscles in the mandibular postural position (MPP) and intercuspal position (ICP) (Fig. 6). Changes in myoelectricity, joint space (Fig. 7), VAS, and JFLS scales of the temporalis and masseter muscles were observed three months later.

Statistical methods

SPSS 24.0 software was used to analyze the data. Measurement data were expressed as mean $\pm$ standard deviation and checked for normality and homogeneity. Paired sample t-tests were used for data that were normally distributed and had a homogeneous variance, and the Wilcoxon rank sum test was used for data that were not normally distributed and were heterogeneous. Data for the same index at different time points were compared by repeated measures analysis of variance (ANOVA), and $P < 0.05$ was considered statistically significant.

Results

The OT values were performed using the Shapiro-Wilk normality test, which did not conform to the normal distribution and were expressed as median and quartile points range (25th – 75th). The Wilcoxon rank-sum test

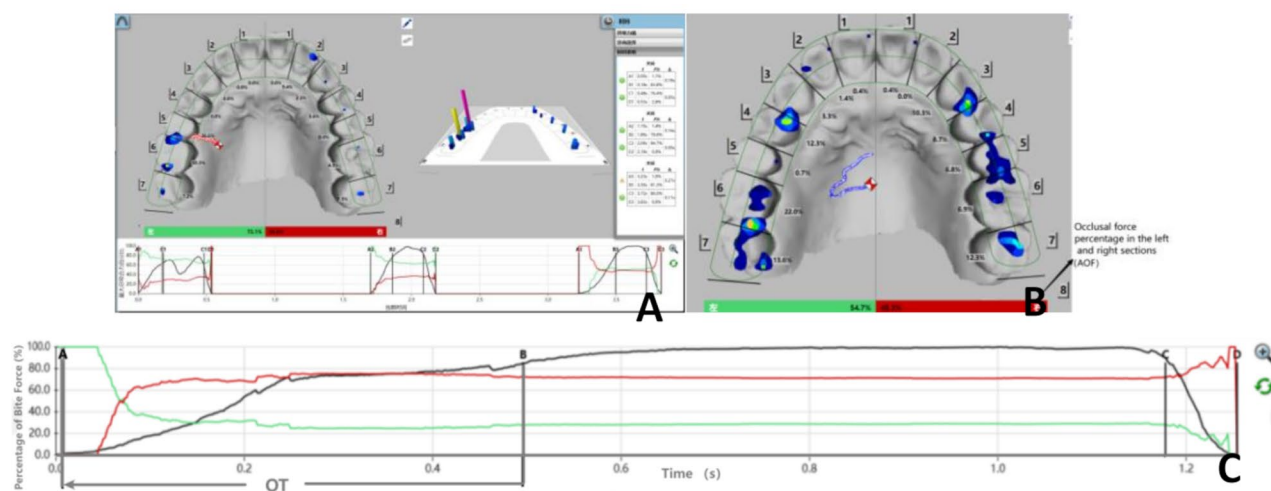


Fig. 4 A. Screenshot showing 2–3 times maximal intercuspal position (MIP) recordings B. The percentage of occlusal force. C. The timing table with the occlusal time (OT) values for multi-bite closures to MIP

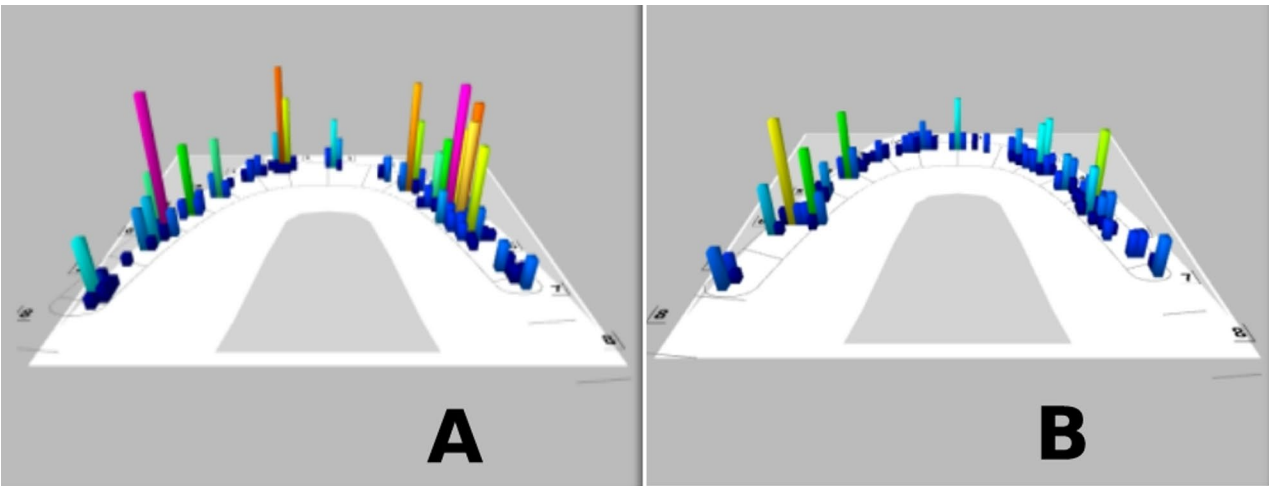


Fig. 5 T-scan combined with articulating paper to adjust the occlusal splint. **A.** Before grinding **B.** After grinding

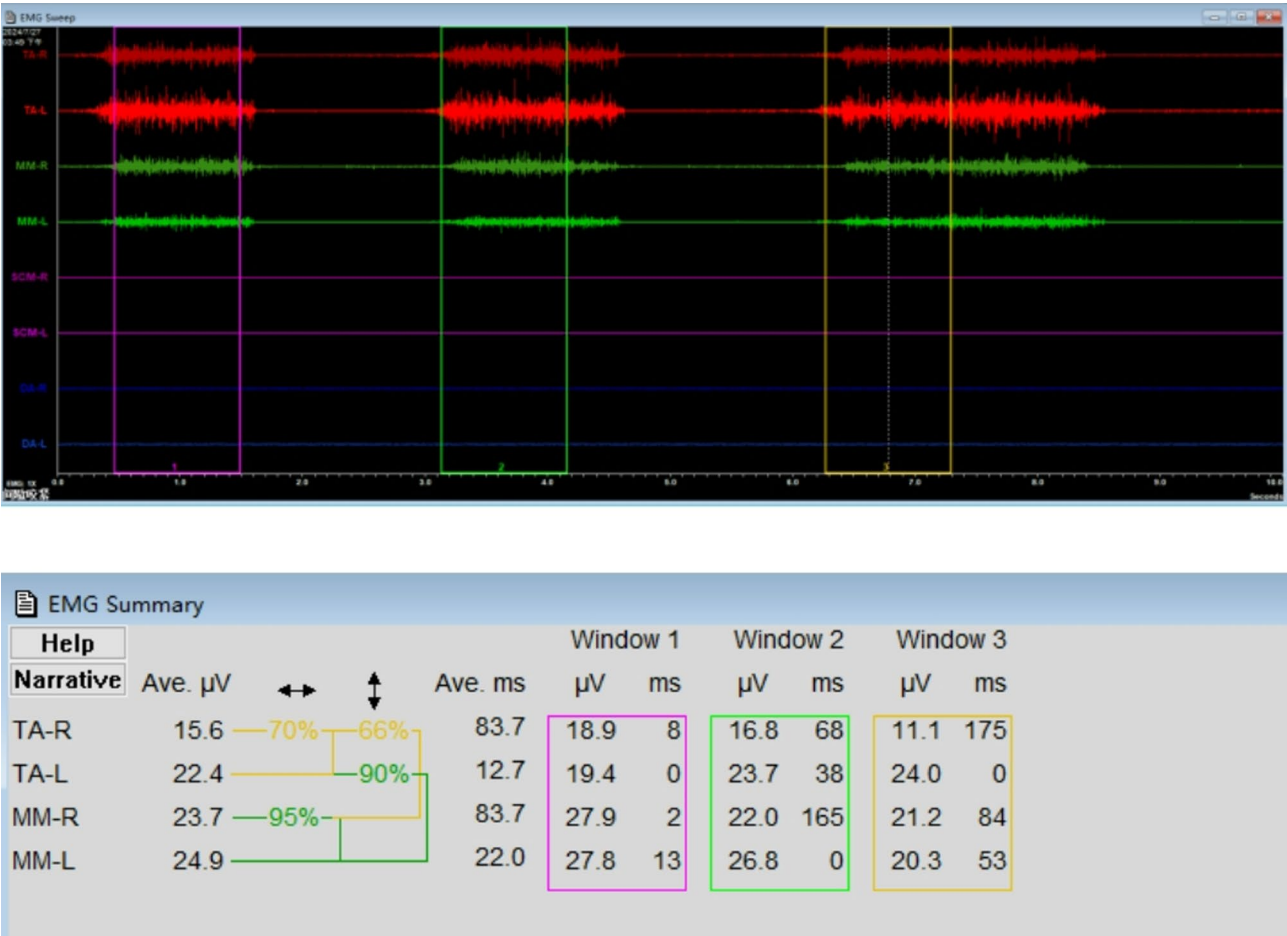


Fig. 6 Temporalis and masseter muscle EMG values were selected from 3 EMG groups and averaged

used the OT values before and after T-scan guidance. When the T-scan was used to detect the grinding effect of the 3D printed stable occlusal plate, the difference in occlusal time at the four observation points of 18 patients were significantly reduced compared with that before T-scan guidance ($P<0.05$). Natural dentition occlusal time was not statistically significant, as data for the same indicator at different time points were compared using

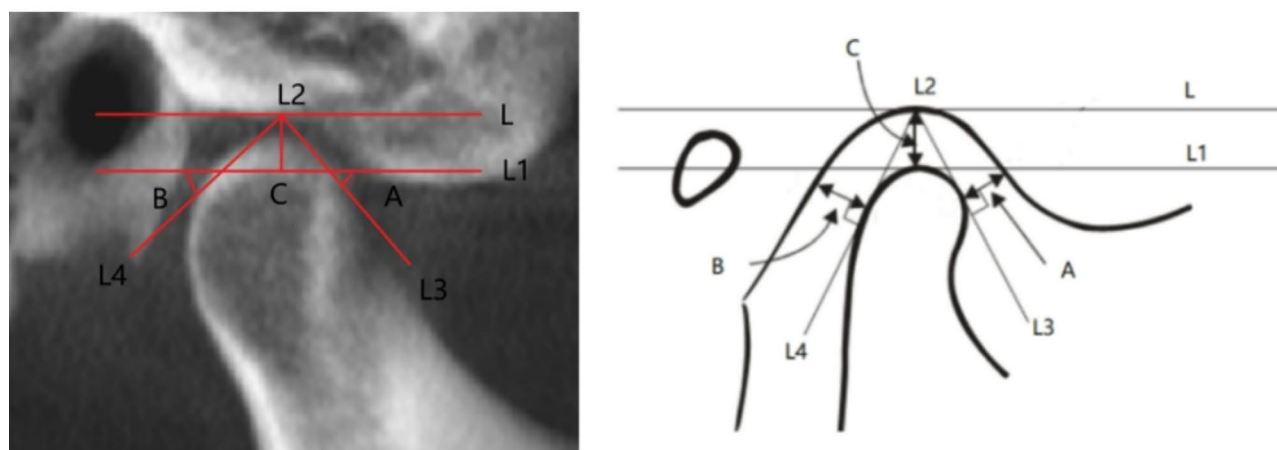


Fig. 7 Mapping of anterior, upper and posterior interspace of TMJ measured by Kamelchuk. Note: A. Anterior articular space. B. Posterior articular space. C. Upper articular space. The horizontal L line and L1 line are parallel to the orbitoauricular plane, and the L line is tangent to the upper edge of the glenoid fossa. L1 was tangential to the superior margin of the condyle. The vertical lines of L3, L4, and L1 passing through the leading and trailing edges of the L-tangent point are marked as L2; The vertical line A of L3 passes through the anterior condyle tangent point

Table 1 The Occlusion time (OT) values of 18 T-scan-guided natural dental arches and occlusal splints before and after grinding. [M(p_{25}, p_{75}), s]

Time	Natural Dentition	Pre-T-scan Guided	Post-T-scan Guided	z-value	p-value
1 week	0.51 (0.31, 0.64)	0.35 (0.22, 0.88)	0.25 (0.15, 0.71)	-3.061	0.002
1 month	0.25 (0.19, 0.55)	0.31 (0.19, 0.58)	0.22 (0.15, 0.40)	-3.059	0.002
2 month	0.21 (0.14, 0.33)	0.23 (0.19, 0.35)	0.18 (0.13, 0.29)	-3.062	0.002
3 month	0.20 (0.13, 0.24)	0.20 (0.15, 0.24)	0.16 (0.14, 0.20)	-2.913	0.004
F-value	2.975	3.573	4.357		
P-value	0.089	0.060	0.037		

Note: Z value and P value are the statistical values of OT before and after t-scan guidance

Table 2 The AOF values of 18 T-scan-guided natural dental arches and occlusal splints before and after grinding. ($\bar{x} \pm s, \%$)

Time	Natural Dentition	Pre-T-scan Guided	Post-T-scan Guided	t-value	p-value
1 week	30.97 ± 18.54	24.03 ± 14.87	11.92 ± 6.47	3.961	0.002
1 month	14.72 ± 10.17	19.85 ± 11.08	9.80 ± 4.59	4.501	0.001
2 month	10.00 ± 6.23	15.17 ± 7.07	8.28 ± 4.83	3.823	0.003
3 month	5.30 ± 2.44	13.38 ± 7.14	6.18 ± 3.05	4.472	0.001
F-value	10.872	5.051	6.503		
P-value	0.002	0.013	0.012		

Note: t value and p value are the statistical values of AOF before and after t-scan guidance. AOF: The difference percentage of occlusal force between the left and right sides

repeated measures analysis of variance (ANOVA). (Table 1).

The AOF values were tested using the Shapiro-Wilk normality test. The AOF values in one week, February and March, conformed to the normal distribution and were expressed by mean ± standard deviation, which guided the AOF values before and after grinding to use the paired samples t-test. The difference in the percentage of bite force between the left and right sides of natural dentition decreased, and the difference was statistically significant ($P < 0.05$). Repeated measures ANOVA showed that the AOF values of natural dentition at the four observation points and before and after wearing

the occlusal splint were statistically significant, $P < 0.05$. (Table 2)

After three months of treatment with the stabilization splint, the anterior joint space was smaller, the posterior joint space was wider, although the upper joint space did not change significantly. Because the VAS values did not follow a normal distribution (Shapiro - Wilks test), data are expressed as medians and percentiles. Data distributions are expressed as medians, range (25th – 75th). Other measurements are expressed as mean ± standard deviations. The VAS and JFLS scores both decreased significantly following treatment ($P < 0.05$). The asymmetry index of the temporalis and masseter muscles decreased

Table 3 Aggregated measurements of pre- and post-treatment indicators in 18 cases

Class	Pre-treatment	Post-treatment	Statistic	p-value
VAS [M(p25, P75), score]	2.50 (1.25, 3.00)	0.50 (0.00, 1.75)	Z=-2.842	0.004
JFLS ($\bar{x} \pm s$, score)	28.92 $\pm$ 21.19	15.83 $\pm$ 11.94	t=3.410	0.006
Anterior Articular Space $n=36$ ($\bar{x} \pm s$, mm)	2.54 $\pm$ 0.59	2.31 $\pm$ 0.56	t=2.781	0.011
Upper Articular Space $n=36$ ($\bar{x} \pm s$, mm)	2.95 $\pm$ 0.90	2.95 $\pm$ 0.58	t=-0.043	0.966
Posterior Articular Space $n=36$ ($\bar{x} \pm s$, mm)	2.11 $\pm$ 0.67	2.36 $\pm$ 0.56	t=-3.671	0.001
Temporal Muscle Asymmetry Index at MPP ($\bar{x} \pm s$, %)	14.81 $\pm$ 9.55	6.99 $\pm$ 3.28	t=3.175	0.011
Masseter Muscle Asymmetry Index at MPP ($\bar{x} \pm s$, %)	11.26 $\pm$ 10.13	8.86 $\pm$ 6.96	t=-0.669	0.520
Anterior Temporalis Asymmetry Index at ICP ($\bar{x} \pm s$, %)	8.17 $\pm$ 5.95	4.89 $\pm$ 3.83	t=1.347	0.211
Masseter Asymmetry Index at ICP ($\bar{x} \pm s$, %)	15.99 $\pm$ 5.87	8.87 $\pm$ 3.16	t=1.063	0.315

Note: Temporal muscle (TA) asymmetry index:| Mean EMG amplitude of right temporal muscle - EMG amplitude of left temporal muscle| / (right temporal muscle mean EMG amplitude + left temporal muscle EMG amplitude) $\times$ 100%. Masseter muscle (MM) asymmetry index:| mean EMG amplitude of right masseter muscle - EMG amplitude of left masseter muscle| / (mean EMG amplitude of right masseter muscle + EMG amplitude of left masseter muscle) $\times$ 100%

when the mandibular postural position and intercuspal positions were interleaving. (Table 3).

Discussion

The relationship between temporomandibular disorder (TMD) and malocclusion is intricate, with evidence indicating that occlusal asymmetry is closely associated with condylar asymmetry [13]. Consequently, TMD have become a primary concern for patients seeking orthodontic treatment. Orthodontic intervention may not be the optimal approach to address TMD, and cannot prevent the onset of TMD [14]. By analyzing the clinical manifestations of different types of malocclusions at the CR and CO positions (the most significant intersection of tooth tips in the past was called central occlusion), the relationship between CR-CO and TMD can provide a reference for further improving and optimizing orthodontic correction strategies for different types of malocclusions. When joint clicking occurs alongside symptoms such as pain, restricted mouth opening, and discomfort, prioritizing TMD management becomes essential.

Changes in occlusal parameters in central occlusion are characteristic of temporomandibular joint disorders [15]. OT is a reflection of occlusal health to a certain extent [16]. When the jaw is closed, the early contact point can easily guide the jaw to deviate from the muscle force closure path, thus resulting in a prolonged OT due to adaptive jaw position [17]. Furthermore, prolonged exercise leads to prolonged muscle activity, thereby promoting the occurrence of TMD [18]. In our current research, we adjusted the early contact point and occlusal interference point of the occlusal plate with the T-scan occlusal dynamometer combined with the occlusal paper; then, we found that the OT of wearing the occlusal plate decreased when compared with that beforehand under the guidance of T-scan. This difference was statistically significant, indicating that the T-scan occlusal dynamometer was able to accurately locate and adjust the abnormal occlusal contact point.

In the temporomandibular joint system, the masticatory muscles regulate mandibular movement and determine the position of the mandibular condyle in the joint. In patients with TMD, the uneven distribution of bite force on both sides of the dental arch determines the symmetry of bilateral masticatory muscle activity, possibly leading to temporomandibular joint disorder [15]. In electromyography studies, the masticatory muscles were more balanced after occlusal balance [19]. In our present research, After occlusal equilibrium, the corresponding asymmetry index of the bilateral TA and MM myogram in the mandibular postural position and the intercuspal position decreased.

After adjusting and sharpening the occlusal splint with the T-scan occlusal analysis system, the bite was improved, and the pain in the temporomandibular joint was reduced. After three months of treatment, the VAS score and JFLS scale values of TMD patients decreased, and the condyle position tended to move forwards and upwards, indicating that 3D-printed stable occlusal splints are an effective means of treating TMD. In this experiment, it can be observed that there is no statistical difference in the OT value of natural dentition at the four observation points, and there is a statistical difference in the AOF value, which is considered to be related to the change of muscle and joint position. In addition, a mandibular motion analysis system will be used to reproduce the dynamic jaw position relationship and mandibular motion trajectory from multiple angles to obtain an accurate and stable occlusal relationship and achieve personalized and comprehensive reconstruction of the patient's mandibular relationship [20, 21] to observe the changes in the occlusal of the natural dentition after wearing the occlusal splint.

Dedem et al. described the digital production of occlusal splints, in which the average-value articulator is often used in the design process [7, 22]. Studies have shown that no statistically significant difference was found in the volume of occlusal adjustment of digital occlusal devices between those designed using an average digital

articulator and the JMA (JMAlyser, Zebris Medical GmbH) [23]. Because the JMA is expensive and may not be widely available, the use of an average articulator represents an appropriate option [24]. The use of a virtual average articulator saves time and allows 3D-printed occlusal splints to be used more commonly in the pre-orthodontic treatment of TMD. In orthodontic decision-making, particularly when diagnosing and treating patients with TMD, it is necessary to carefully analyze the symptoms and severity of TMD. TMD-related scales are recommended to assist in diagnosis [25]. Through the correct pre-treatment diagnosis, aiming at the CR position, the occlusal relationship is improved based on establishing the correct maxillary position to achieve the coordination of bone, muscle, and synthus and avoid the occurrence of TMD after orthodontics.

The digital occlusal splint treatment system has the following advantages: (1) The oral scanning technology can reduce the discomfort of patients in preparing the dentition model and effectively reduce the artificial errors caused during the molding process. (2) Digital files are convenient for long-term storage in computer systems, making it easier to obtain subsequent data and case discussions. (3) During the design stage of the 3D printing stable occlusal splint, the jaw edge movement can be simulated on the virtual mount for precise grinding, reducing the time of occlusal adjustment next to the chair and improving work efficiency. (4) If the patient's bite plate is lost or damaged, the data can be retrieved directly and then remade, reducing the number of follow-up visits of the patient and realizing a repeatable production mechanism.

Conclusion

Significant reductions in OT and AOF were observed in TMD patients wearing T-scan-guided occlusal splints ($P < 0.05$). Furthermore, after treatment, the bilateral masseter muscle (MM) and temporalis anterior (TA) asymmetry index were reduced at the mandibular postural and intercuspal positions. The 3D-printed stabilized occlusal splint of T-scan guided grinding enhances occlusal balance relieves joint pain, and reduces jaw movement restriction.

Abbreviations

3D	Three-dimensiona
AOF	Asymmetry index of occlusal force
CBCT	Cone beam computed tomography
CR	Centric relation position
EMG	Electromyography
ICP	Intercuspal position
JFLS	Jaw function limitation scale
MIP	Maximum intercuspal position
MM	Masseter muscle
MPP	Mandibular postural position
OT	Occlusal time
TA	Temporalis anterior

TMD	Temporomandibular disorder
TMJ	Temporomandibular joint
VAS	Visual analog scale

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12903-025-06622-x>.

Supplementary Material 1

Acknowledgements

We are particularly grateful to all the people who have given us help on our article.

Author contributions

Y-Q M conceived the study, participated in the study's design, and performed the occlusal analysis, writing manuscript preparation, and data collation. W-X L: Investigate and rigorously revise the manuscript. L-T L: Supervise and revise the manuscript strictly. M C: Review Editor, corresponding author. Chi Zhang: Provide technical support. All authors reviewed the manuscript.

Funding

Funded by establishing a digital orthodontic-prosthetic occlusal reconstruction diagnosis and treatment system with functional integration, No. LX2020-105.

Data availability

All data generated or analysed during this study are included in this article. Further enquiries can be directed to the corresponding author.

Declarations

Ethics approval and consent to participate

This study has been approved by the Medical Ethics Committee of the Third Affiliated Hospital of the Air Force Medical University (IRB-REV-2022189). All methods were carried out in accordance with relevant guidelines and regulations. The patients provided their written informed consent to participate in this study.

Consent to publish

Informed consent from all subjects for publication of identifying images in an online open-access publication.

Competing interests

The authors declare no competing interests.

Received: 28 November 2024 / Accepted: 14 July 2025

Published online: 26 July 2025

References

1. Zhao N, Fang B. Research progress on orthodontic treatment and temporomandibular joint disorder. *J Stomatol.* 2024;44:20–3.
2. Klanrit P, Thongprasom K, Rojanawatsirivej S, Theamboonlers A, Poovorawan Y. Hepatitis C virus infection in Thai patients with oral lichen planus. *Oral Dis.* 2010;9:292–7.
3. Chaikla K, Pumklin J, Piyapattamin T. Comparison of occlusal parameters between open bite and nonopen bite patients using the T-scan III system: a pilot study. *Eur J Dentistry.* 2022;16:656–62.
4. Jing D, Shen Y, Yang P, Zhao ZH. Relevance of Chinese relationships and orthodontic treatment. *West China J Stomatol.* 2019;37:6.
5. Pinho JC, Caldas FM, Mora MJ, Santana-Penín, electromyographic activity in patients with temporomandibular disorders. *J Rehabil.* 2010;27:985–90.
6. Zhu Y, Zheng F, Gong Y, Zhu J, Yin D, Liu Y. Effect of occlusal contact on TMJ loading during occlusion: an in silico study. *Comput Biol Med.* 2024;178.
7. Dedem P, Tuorp JC. Digital Michigan splint - from intraoral scanning to plasterless manufacturing. *Int J Comput Dent.* 2016;19:63.

8. Lauren M, McIntyre F. A new computer-assisted method for design and fabrication of occlusal splints. *Am J Orthod Dentofac Orthop*. 2008;133:S130–5.
9. Berntsen C, Kleven M, Heian M, Hjortsjö C. Clinical comparison of conventional and additive manufactured stabilization splints. *Acta Biomater Odontol Scand*. 2018;4:81–9.
10. Kerstein RB. Computerized occlusal analysis technology and cerec case finishing. *Int J Comput Dent*. 2008;11:51–63.
11. Gade JR, Agrawal MJ, Dandekar SGS, Minal NJ. Karan, vingole, anil, digital occlusal analyser T-scan: a review. *J Res Med Dent Sci*. 2021;9:187–93.
12. Agbaje JO, Castele EVD, Salem AS, Anumendem D, Shaheen E, Sun Y, Politis C. Assessment of occlusion with the T-scan system in patients undergoing orthognathic surgery. *Sci Rep*. 2017;7:5356.
13. Wang MQ, He JJ, Chen CS, Widmalm SE. A preliminary anatomical study on the association of condylar and occlusal asymmetry. *Cranio J Craniomandib Pract*. 2011;29:111–6.
14. Coêlho TGdS, Caracas HCPM. Perception of the relationship between TMD and orthodontic treatment among orthodontists. *Dent Press J Orthod*. 2015;20:45–51.
15. Agn D, Gaivil P, Au?Ra BA, Gediminas S. Evaluation of the relationship between the occlusion parameters and symptoms of the temporomandibular joint disorder. *Acta Med Lituanica*. 2017;24:167–75.
16. Baldini A, Nota A, Cozza P. The association between occlusion time and temporomandibular disorders. *J Electromyogr Kinesiol*. 2015;25:151–4.
17. Estelle C, RéJean-Philippe G, Anne P, Anne O, Jean-Daniel. Dental occlusion: proposal for a classification to guide occlusal analysis and optimize research protocols. *J Contemp Dent Pract*. 2021;22:840–9.
18. Kerstein RB, Wright NR. Electromyographic and computer analyses of patients suffering from chronic myofascial pain-dysfunction syndrome: before and after treatment with immediate complete anterior guidance development. *J Prosthet Dent*. 1991;66:0–686.
19. Lin P.T., Jiao Y., Zhao S.J., Wang F., Li L., Yu F., Tian M., Yu H.H., Chen J.H. Occlusion and disocclusion time changes in single unit crowns designed by functional generated path technique: a randomised clinical trial. *Rep*. 2017;7:388.
20. Ahlers MO, Bernhardt O, Jakstat HA, Kordaß B, Türp JC, Schindler HJ, Hugger A. Motion analysis of the mandible: guidelines for standardized analysis of computer-assisted recording of condylar movements. *Int J Comput Dent*. 2015;18:201–23.
21. Reicheneder C, Kardari Z, Proff P, Fanghaenel J, Faltermeyer A, Römer P. Correlation of condylar kinematics in children with gender, facial type and weight. *Annals of Anatomy - Anatomischer Anzeiger*; 2013. <https://doi.org/10.1016/j.aanat.2013.01.012>.
22. Fang SB, Yang GJ, Kang YF, Sun YC, Xie QF. Method and accuracy of determining the jaw position of repositioning splint with the aid of digital technique. *Beijing Da Xue Xue Bao Yi Xue ban = J Peking Univ Health Sci*. 2020;53:76–82.
23. Peng T, Yang Z, Ma T, Zhang M, Ren G. Comparative evaluation of the volume of occlusal adjustment of repositioning occlusal devices designed by using an average value digital articulator and the jaw movement analyzer. *J Prosthet Dent*. 2023. <https://doi.org/10.1016/j.prosdent.2023.06.018>
24. Fang S, Yang G, Kang Y-F, Sun Y-C, Xie Q-F. To explore and evaluate the accuracy of the method of determining the jaw position of repositioning splint with the assistance of digital technology. *Beijing Da Xue Xue Bao Yi Xue Ban*. 2021;53:76–82.
25. Eric S, Look J, Edmond, Truelove R. Ohrbach, diagnostic criteria for temporomandibular disorders (DG/TMD) for clinical and research applications: recommendations of the international RDC/TMD consortium network and orofacial pain special interest group. *J Orofac Pain*. 2014. <https://doi.org/10.11607/jop.1151>

Publisher's note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.