Research letter

Use of occlusal digital splint for treating the patients with temporomandibular joint dysfunction and planning orthopedic treatment

Mikhail A. Postnikov [1], Dmitry A. Trunin [1], Aleksandr M. Nesterov [1], Mukatdes I. Sadykov [1], Vladimir P. Potapov [1], Rustem R. Gabdrafikov [1], Natalya V. Pankratova [2]

[1] Samara State Medical University, Samara, Russia
[2] Moscow State University of Medicine and Dentistry, Moscow, Russia

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Abstract: *Objective* of the study: to develop and assess the occlusal digital splint for treating patients with temporomandibular joint dysfunction (TMJD).
Material and Methods — 17 patients between the ages of 30 and 49 diagnosed with TMJD were admitted for treatment. To normalize mandibular position, an occlusal digital splint for all patients was manufactured in accordance with our original method. An intensity of pain sensations in all patients prior to, and after, the treatment was assessed by a visual analogue scale, along with the changes in the mandibular movements' amplitude, and the signs of splint wear and stability of occlusal contacts.
Results — Patients have adapted themselves well to the splint and found it convenient in use. The study results showed that it was sufficiently effective in treatment of TMJD. Reduction in pain intensity and restoration of mandibular movements' amplitude were detected with certainty. Only in 2 (11.7%) cases, the signs of wear on the splint were found, as evidenced by the changes in pre-treatment occlusal contacts. In all other cases throughout the study, a stable occlusal contact has been encountered.
Conclusion — Our results indicated that proposed occlusal digital splint may be considered as a treatment option for the patients with TMJ disorders.

Keywords: occlusal splint, temporomandibular joint dysfunction, splint therapy, orthopedic treatment, dentistry, orthodontics.

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Correspondence to Mikhail A. Postnikov. Address: 89 Chapayevskaya St., Samara, 443099, Russia. Phone: +7-960-830-0006.
E-mail: postnikovortho@yandex.ru.

Introduction

Contemporary dentistry pays considerable attention to diagnostics and treatment of the patients with temporomandibular joint dysfunction (TMJD), mostly due to the fact that this pathology is very common and difficult to treat [1-5].

All proposed methods for oral rehabilitation of the patients with TMJD incorporate the use of occlusal splints. The splints enable solutions for multiple problems by means of simultaneous acting on masticatory muscles, TMJ, and dental arches. In addition, they allow planning further orthopedic treatment and demonstrating the future sizes and aesthetics (shape, texture, colour, proportions) of dental arches to a patient [6-9].

Splint therapy is often used for treatment of the patients with TMJ disorders. Splint therapy does not always provide the required precision for repositioning of the mandible. As an alternative to TMJD treatment, this method often involves no dynamic diagnostics, but rather relies on statistical CT data and, at best, neurostimulation. Splint is defined as a rigid or flexible material used to protect, immobilize, or restrict motion [10, 11].

To date, plastic splints of various designs were used as temporary dentures and manufacture of occlusal splints by original methods, most common of which are Michigan, Sveda, Ramfierd, etc. Along with advantages, the above-mentioned splints had some shortcomings as well: the shape of the future splint is modeled by lab technician in dental prosthetic laboratory on plaster models, using wax (a labor-intensive and time-consuming work with a high risk of inaccuracies). Splints are held in the mouth on the teeth by retention elements (dental clasps, peyotes). Splints do not follow the shape of the teeth: wearing those causes discomfort in patients due to unaesthetic appearance that develops inferiority complex in patients, which, in turn, forces them to remove a splint when communicating, or eating, thus reducing the effectiveness of disclusion treatment. Splints are made from dental plastic for denture bases, not intended for long-term occlusal loads. They are not abrasion-resistant in the course of antagonistic teeth contacts, which, accordingly, lead to a loss of achieved therapeutic intermaxillary separation [12-15].

Hence, despite multiple diagnostic and treatment appliances utilized in the treatment procedures of the patients with TMJ disorders, many of those had flaws providing motivation for seeking new and effective methods of manufacturing occlusal splints.

The modern development of digital dental technology set new criteria for the quality of diagnostic and treatment of the patients with various pathologies of maxillofacial system, which affected all its structures, including those related too TMJ. Present day patients, applying for dental care, would like to know the forecasted result, and also to get it as quickly as possible, and in comfortable conditions of recovery stages.

The objective of our study was to develop and evaluate the digital occlusal splint of a new design for treatment of the patients with TMJD.

Material and Methods

Patients

Two groups were formed from the patients. Group 1 patients were diagnosed with restoration of mandibular position by traditional occlusal splints, while Group 2 patients' restoration of mandibular position was performed by the digital occlusal splint proposed by the authors. To control the quality of diagnosis and repositioning parameters of the mandible and TMJ elements, all patients underwent repeated computed tomography of maxillofacial system with occlusal splints in a new therapeutic position after 14 days.

Study design

All patients with TMJD in our study were diagnosed, and we received anthropometric data according to a single protocol based on clinical studies (status localis) and additional parameters (photos, impressions of the upper and lower dentitions, registration of the original habitual occlusion and computed tomography of dentoalveolar system with TMJ in this position, conducting optical digital axiography). After receiving a diagnosis on the CAR equipment of the Freecorder® BlueFox diagnostic complex, the therapeutic position of the lower dentition was determined by the change in the position of the TMJ condyles, compared with their usual state. Assessment of pain intensity from visual analogue scale (VAS) was carried out as follows: on a segment of a straight line 10 cm long, a patient marked pain intensity. The beginning of the line on the left corresponded to the absence of pain (0 points), while the end of the segment on the right corresponded to intolerable pain (10 points). Further, the patient independently noted pain intensity on the straight line section.

Methods in Group 1

Group 1 included 17 patients from 25-49 YO with complaints of pain, clicks, and crepitus in TMJ. Diagnostics was carried out in full, and Sved occlusal splints and Michigan splints were manufactured using traditional technology. Positive dynamics in the form of improving the amplitude and trajectories of mandibular movements, along with decrease in intensity of symptoms during treatment were observed in patients in the first month of treatment. The period of functional restoration to the maximum with disappearance of pain symptoms and occasional clicks with amplitude movements, averaged 5.2 months in the group.

Patients noted an improvement in overall health with a disciplined splint wearing schedule, and a sharp manifestation of pathological signs during the period when patients did not wear splints for a number of reasons. Situations were identified, in which our patients did not use splints: while communicating with colleagues at work, while eating, and single patients communicating with friends.

The main factors when our patients removed occlusal splints made using traditional technology were the unaesthetic appearance of a dentition with a splint and inability to eat with a splint on their teeth. Patients were called to the clinic for the check-up every month, and almost all complaints revealed another drawback of traditional technology. After 4-5 months, patients were undergoing through the lack of a positive dynamics, and in some, the treatment caused negative dynamics. During this period, the analysis of occlusal splints, manufactured by the traditional method, showed that some correction of the manufactured splint elements was required in connection with the wear of the splint material – stomatological acrylic plastic.

Our goal was to restore the lost TMJ function up to the planned parameters, using a brand new splint, which had to meet the following novel requirements: to match the functionality of an occlusal splint; to be as aesthetically pleasing and close to the shape of the teeth as possible; to be made of the material allowing safe food intake and being resistant to occlusal loads and wear; to apply manufacturing techniques that exclude the risk of the human factor.

Methods in Group 2

Group 2 was formed to accomplish the stated objective, 17 patients between the ages of 30 and 49 diagnosed with TMJD were examined and admitted for treatment. Patients complained about pain of various intensity in TMJ area and masticatory muscles, and limitations in the amplitude of mandibular movements. In this group, the pathological process in all examined patients lasted under a year. To normalize the mandibular position, occlusal digital splints for all patients were made from poly(methyl methacrylate) (PMMA) in accordance with the technique proposed by the authors (RF patent for invention No.2692994 'Method to produce occlusal splint').

The process of manufacturing occlusal digital splint (ODS) included the following stages. At the first stage, we examined the patients to diagnose functioning and articulation (mandibular movements), with recording of the movements' trajectories over a distance with respect to mandibular axis and displacement angles of mandibular condyles, when making movements on Freecorder® BlueFox equipment (digital optical diagnostic test) (*Figure* 1).

Digital optical method of recording implied fixation of two arches on the patient's head, on the end of which QR-targets were placed for high-speed recording cameras, incorporated into C-arch over the head of patient to the right, to the left, and from above to make recording in three coordinate axes. One arch was fixed rigidly along the Frankfurt plane with fastening in the external auditory canals and on the nasal bridge rest. The second arch was fixed along the border of alveolar ridge and dental arch, with a fastening arch, custom-made by bending to match the shape of a mandibular dental arch ridge and fixed on fast-hardening high-strength occlusal silicone (80 by Shore scale). When the lower jaw moves, C-arch cameras record displacement of the targets on a movable arch, fixed on the lower jaw with respect to the targets of an arch, statically fixed on the upper jaw with 0.01mm accuracy. Recordings of obtained trajectories are transferred in a digital form *via* computer program as linear graphs to the marked plane

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with 1x1mm mesh size for convenience of analysis. The program is supposed to recalculate automatically produced graphs into linear parameters in millimetres or degrees. The resulting graphs of mandibular movements were further analyzed, excluding the segments of pathological trajectories of joint movement, when its compensatory displacement occurs in TMJ capsule. We conducted the analysis in the digital analytical program of Freecorder® BlueFox equipment (with accuracy of 0.1^0 or 0.01 mm) (*Figure* 2).

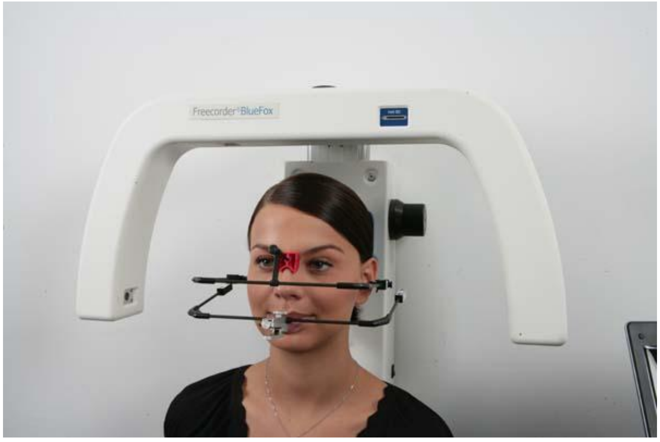

Figure 1. TMJ diagnostics with Freecorder® BlueFox axiograph.

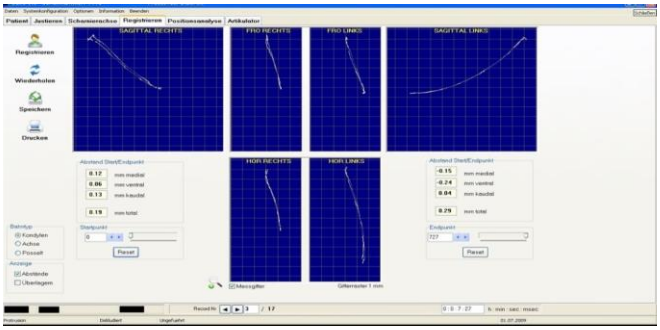

Figure 2. Recording mandibular movements on Freecorder® BlueFox axiograph.

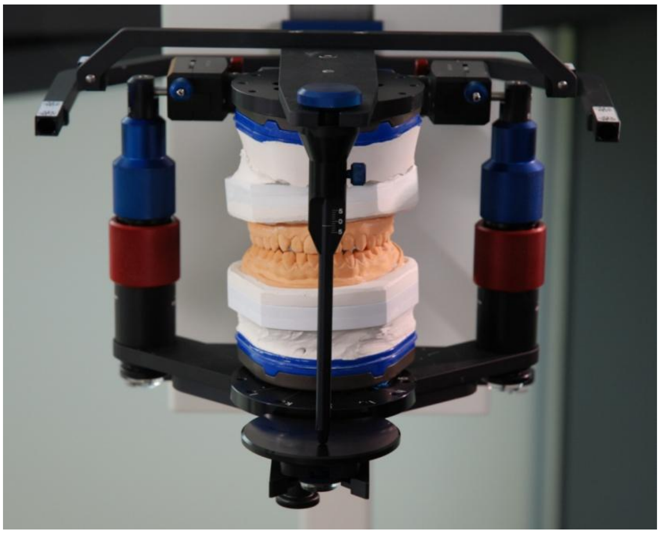

Figure 3. Finding disclusion position in model jaws in CAR Freecorder® BlueFox system

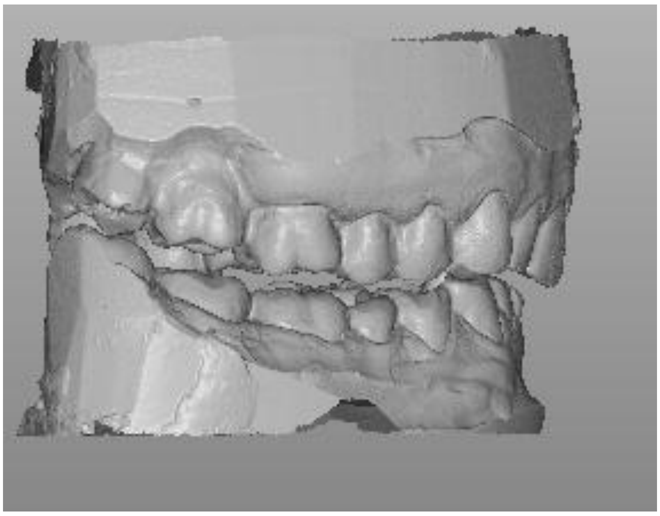

Figure 4. Models of the lower and upper jaws in a separated state in STL format.

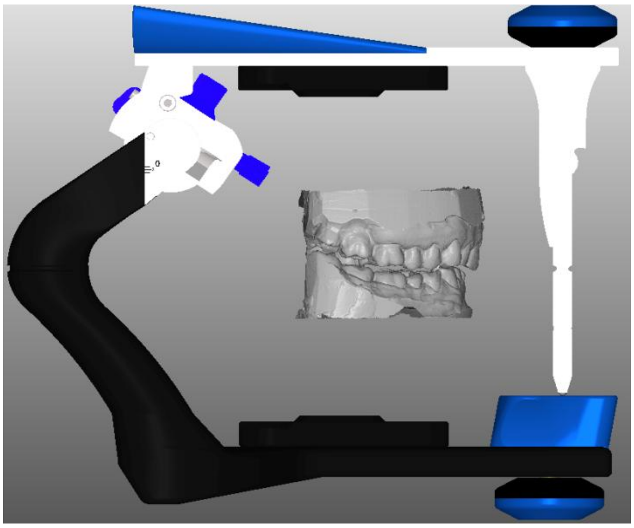

Figure 5. Maxilla and mandible models in a separated state in STL format in a virtual articulator.

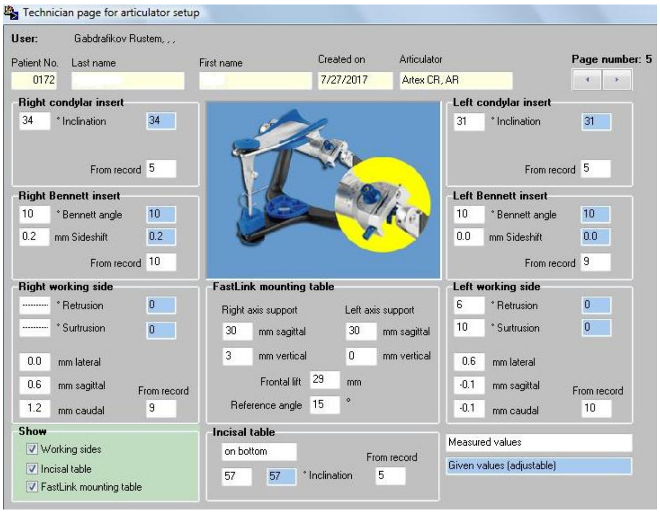

Figure 6. Customized data sheet of Amann Girrbach articulator.

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Figure 7. Occlusal digital model splint of maxilla in STL format.

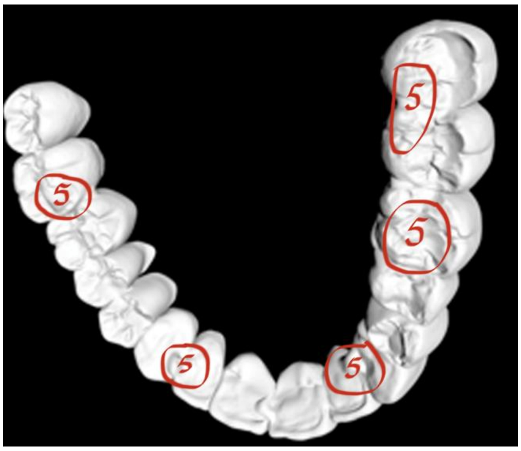

Figure 8. Occlusal splint: occlusal surface view. Pos. 5: contact surfaces for developing balanced occlusion.


Figure 9. Occlusal splint of a maxilla manufactured by milling using a plaster model.

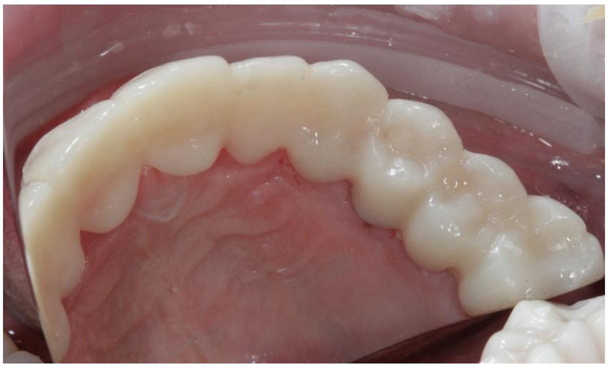
Figure 10. Occlusal splint of a maxilla after fixation on maxillary dental arch (palatal view).


Figure 11. Maxillary occlusal splint of the upper jaw after fixation on maxillary dental arch (labial view)

Then, CAR (computer-assisted repositioning) included in the diagnostic equipment set Freecorder® BlueFox, was used to determine physiological rest position of condyles in TMJ, followed by transferring the positions of model jaws into articulation system (Amann Girrbach) and fixing them in this state (*Figure* 3).

A computer program of Freecorder® BlueFox equipment enabled producing the data sheet for setting a fully adjustable medical articulator in order to customize individual mandibular movements in the instruction manual for Freecorder® BlueFox. We then placed the obtained plaster casts for a patient into an articulator in the normal physiological TMJ rest position (*Figure* 4).

Afterwards, plaster casts were digitalized in STL format, using Zirkonzahn scanner (*Figure 5*). Then we uploaded resulting images (in STL format) of the models and positions of jaws with respect to each other into a virtual articulator Amann Girrbach. The latter was set to replicate motion trajectories in accordance with obtained data sheet for settings of the Amann Girrbach medical articulator from the program of Freecorder® BlueFox equipment (*Figure* 6). An occlusal digital splint has been further created in the program for processing images and generating 3D viewing of Zirkonzahn equipment prosthetic dentures (*Figure* 7-8). Afterwards, the occlusal splint was manufactured from PMMA by milling, tried on, and fixed in a patient's mouth (*Figure* 9-11).

Data analysis

Treatment effectiveness of the patients under study was evaluated based on analyzing questionnaire and clinical examination data. An intensity of pain symptoms was assessed using a visual analogue scale from 0 to10, where 0 meant no pain, while 10 meant the most intense pain ever experienced by the patient. Furthermore, limited opening of the mouth, diverted mandibular movement in transversal and sagittal planes, along with splint wear and steadiness of occlusal contacts have also been analyzed. Treatment results have been considered positive, if no complaints were received from the patient, and the results of clinical examination were within normal range. After installation of occlusal splints, the patients were under medical supervision for a year, with weekly appointments during the first month and monthly follow-up visits in subsequent months.

Table 1. Upper teeth sizes

№		18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
									Group 1								
Pre-treatment	M		6.79	7.01	7.10	8.32	9.31	8.48	9.07	9.39	8.79	9.39	8.19	7.23	6.61	6.09	
	± SD		1.05	1.21	1.29	1.11	1.20	1.07	0.93	1.20	1.21	1.65	1.55	1.35	1.22	1.31	
After prosthetics	M		7.46	8.61	9.21	9.58	10.85	9.83	11.27	11.21	10.07	10.84	9.56	8.88	8.77	7.93	
	±SD		1.83	1.61	0.85	1.27	1.40	1.32	0.89	0.89	0.89	0.93	1.53	1.71	1.52	1.16	
									Group 2								
Pre-treatment	M		6.87	6.93	6.22	7.01	9.01	8.49	9.28	9.40	8.65	9.21	7.57	7.18	6.79	5.88	
	±SD		0.67	0.63	0.80	0.90	1.2	1.2	1.2	1.1	1.1	0.77	0.88	1.09	0.98	1.04	
After prosthetics	M		8.28	8.35	8.57	9.07	10.48	10.03	11.35	11.38	9.99	10.59	8.84	8.70	8.04	7.69	
	±SD		0.79	0.73	0.89	0.90	1.11	1.24	0.91	0.91	1.35	0.67	1.07	0.71	0.66	1.09	
P level (Pre-treatment)			0.793	0.811	0.023	0.001	0.471	0.979	0.572	0.980	0.727	0.686	0.161	0.906	0.639	0.608	
P level (After prosthetics)			0.010	0.549	0.040	0.186	0.499	0.652	0.797	0.408	0.840	0.375	0.122	0.691	0.079	0.539	

P levels are presented to demonstrate statistical significance of differences between the same indicators among the groups.

Table 2. Lower teeth sizes

№		48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
									Group 1								
Pre-treatment	M		6.45	7.25	7.68	8.26	9.15	8.09	7.72	7.65	8.01	9.09	8.31	7.17	6.73	5.62	
	± SD		1.64	1.56	1.61	1.48	1.77	0.66	0.95	1.31	0.88	1.03	1.51	1.98	1.71	1.26	
After prosthetics	M		7.58	8.71	9.24	9.70	10.61	9.62	9.58	9.53	9.60	10.75	9.67	8.67	8.43	6.70	
	±SD		1.37	1.17	1.29	1.50	1.22	0.91	0.68	0.68	1.06	0.83	0.69	0.87	1.20	1.06	
									Group 2								
Pre-treatment	M		4.80	6.12	6.50	7.28	8.52	7.53	7.24	6.99	7.43	7.85	7.55	7.14	5.88	5.70	
	±SD		0.93	1.36	1.57	1.44	1.0	0.81	1.23	0.97	0.61	1.1	1.15	1.06	1.5	1.41	
After prosthetics	M		6.47	7.30	7.97	8.69	9.78	8.90	8.20	8.84	8.96	9.85	8.78	8.28	7.73	7.15	
	±SD		1.22	1.10	1.47	1.19	1.15	0.91	1.21	1.20	0.91	1.07	1.34	1.42	1.29	1.26	
P level (Pre-treatment)			0.001	0.031	0.038	0.059	0.211	0.034	0.212	0.105	0.033	0.002	0.109	0.956	0.133	0.863	
P level (After prosthetics)			0.018	0.001	0.012	0.008	0.050	0.028	<0.001	0.047	0.068	0.010	0.021	0.342	0.111	0.268	

P levels are presented to demonstrate statistical significance of differences between the same indicators among the groups.

Table 3. Pre- and post-treatment values of pain intensity in TMJ and masticatory muscles based on a visual analogue scale in the groups 1 and 2

Sampling times for the study	*Group 1*	*Group 2*	*P* -level*
Prior to the treatment	5.1±1.9	4.9±1.8	0.755
1 month after	2.7±1.5	3.4±1.6	0.198
6 months after	0.9±0.4	1.2±0.6	0.096
P1 level	<0.001	0.015	
P2 level	<0.001	<0.001	

P1 and P6. Statistical significance of differences between pain intensity values after 1 and 6 months, respectively, and pre-treatment value in each group. P* shows differences between the groups.

Statistical analysis

For continuous variables, descriptive statistics was reported as a mean (M) with standard deviation (SD) for normal distribution. We applied the Shapiro-Wilk test to check whether the data were approaching normal distribution. The *t*-test was used to compare the continuous variables between the groups. Computed estimations were considered statistically significant if $P<0.05$.

Results and Discussion

The results of our study confirmed that, in the course of the treatment patients, of both groups experienced significant abrasion of all teeth. Use of occlusal splints in the patients of both groups led to restructuring of myotatic reflex in all patients, which enabled permanent prosthetics. Teeth heights before and after prosthetics in the patients of both groups are presented in *Tables* 1 and 2.

Table 1 implies tha maxillary teeth crown heights increased by 14.9% (tooth 23) all the way up to 37.8% (tooth 15) in the course of orthopedic treatment with a high degree of certainty ($P<0.001$).

As can be seen from Table 2, mandibular teeth crown heights after the treatment increased by 13.5% (tooth 41) up to 34.8% (tooth 47) but with lower statistical significance.

Based on obtained results of assessing recovery of TMJ function and effectiveness of provided treatment, the authors discovered the trend towards reducing the pain intensity in the TMJ area and masticatory muscles in both groups. These findings are presented in *Table* 3.

We also conducted the studies on changing the amplitude of mandibular movements in three directions. Our results confirmed the effectiveness of provided treatment. The values of mandibular movements amplitude prior to, and 6 months after, the installation of occlusal splints in patients are shown in *Table* 4.

Using proposed splint provided normalization of the amplitude of mandibular movements in various directions (*Table* 4). In particular, when opening the mouth to the maximum, 9.6% changes occurred, while 20.6% and 23.3% of changes took place at the lateral mandibular motion to the right and to the left, respectively. Protrusive mandibular movement accounted for 20.2% of the changes. The obtained result was retained throughout the entire observation period.

Patients adapted themselves to the splint well and found it convenient to use. In the course of treatment, only 2 patients (11.7%) have reported some changes in occlusion. On examination, we found in these patients that occlusal contacts, installed in the beginning of treatment, changed due to a splint wear. No wear, deformity, defects of occlusal contacts were observed in remaining 15 patients throughout the treatment. Instead, a stable occlusal contact has been seen.

Table 4. Amplitude of mandibular movements prior to, and 6 months after, the treatment in both groups combined (n=34)

	Maximum mouth opening (mm)	*Right lateral movement of the lower jaw (mm)*	*Left lateral movement of the lower jaw (mm)*	*Protrusive movement of the lower jaw (mm)*
Prior to treatment (n=34)	44.5±5.5	7.3±1.5	6.9±1.3	5.9±2.1
6 months after (n=34)	49.2±7.5	9.2±1.8	9±1.5	7.4±1.7
P-level	0.004	<0.001	<0.001	0.002

Conclusion

The effectiveness of the proposed splint was achieved by its manufacturing from PMMA by milling technique, and by the fact that it covered the entire dental arch, following its shape, and contained an occlusal surface, fully matching the surface of the opposite dental arch. Here, the anatomy has been replicated: heights and angles of dental tubercle slopes, depth and width of dental fissures, area of occlusal contacts of the teeth. The curve of Spee and curve of Wilson were specified; there was a commissural plane parallel alignment with no deformities in bones of the facial skeleton. Furthermore, retention trajectories for fixing the splint on the surface of the upper and lower jaw dental arches were made. Those trajectories went between the equator and cervical lines, and along the cervical line of teeth, when they were largely destroyed (more than 0.5 of the clinical crown length). All of the above-mentioned advantages enabled obtaining positive treatment results in 17 patients with TMJD.

Ethical approval

This article does not cover any studies involving human participants or animals performed by any of the authors.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Authors:
Mikhail A. Postnikov – MD, Associate Professor, Department of Dentistry, Institute for Professional Education, Samara State Medical University, Samara, Russia. http://orcid.org/0000-0002-2232-8870.
Dmitry A. Trunin – MD, Professor, Head of the Department of Dentistry of the Institute for Professional Education, Samara State Medical University, Samara, Russia. http://orcid.org/0000-0002-7221-7976.
Aleksandr M. Nesterov – MD, Associate Professo, Department of Dental Orthopedics, Samara State Medical University, Samara, Russia. http://orcid.org/0000-0002-4187-4375.
Mukatdes I. Sadykov – MD, Professor, Department of Dental Orthopedics, Samara State Medical University, Samara, Russia. http://orcid.org/0000-0003-1986-8996.
Vladimir P. Potapov – MD, Associate Professor, Department of Dental Orthopedics, Samara State Medical University, Samara, Russia. http://orcid.org/0000-0002-3365-8365.
Rustem R. Gabdrafikov – Resident, Department of Dentistry, Institute for Professional Education, Samara State Medical University, Samara, Russia. http://orcid.org/0000-0002-6057-0107.

Natalya V. Pankratova – Candidate of Medicine, Assistant Professor, Department of Orthodontics, Moscow State University of Medicine and Dentistry, Moscow, Russia. http://orcid.org/0000-0002-0672-1381.