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Effects of magnetostimulation on muscle activity and pain in edentulous adults with temporomandibular disorders

RAFAŁ RÓJ[1]*, GRZEGORZ CHLADEK[2], MAGDALENA WYSZYŃSKA[1],
TADEUSZ MORAWIEC[3], JACEK KASPERSKI[1]

[1] Department of Prosthetic Dentistry, School of Medicine with the Division of Dentistry in Zabrze,
Medical University of Silesia in Katowice, Bytom, Poland.
[2] Silesian University of Technology, Faculty of Mechanical Engineering,
Institute of Engineering Materials and Biomaterials, Gliwice, Poland.
[3] Department of Oral Surgery, School of Medicine with the Division of Dentistry in Zabrze,
Medical University of Silesia in Katowice, Bytom, Poland.

Introduction: Multifactorial aetiologies of painful temporomandibular disorders (TMD) have an impact on correct diagnosis and consequently prevent proper treatment. *Aim of the study*: The aim of the study was to evaluate the effect of magnetic stimulation on electromyographic activity in temporal muscles and masseters in patients using occlusal splints. *Materials and methods*: The examined group consisted of 40 edentulous patients with TMD. The patients were examined based on Helkimo Index. Next, electromyographic activity of the temporal muscle and masseter were investigated using 8-channel surface electromyography. All patients received acrylic occlusal splints for 12 weeks. The group qualified for the study included 20 randomized patients, whose therapy was additionally carried out by extremely low-frequency magnetic fields for a period of 21 days. Following examinations were conducted after 3, 6 and 12 weeks with surface electromyography recording of the examined muscles. Patients received occlusal splint corrections using the T-Scan III system. The clinical evaluation of TMD was analysed using Helkimo index and VAS scale before and after the treatment. All the data were analysed using Statistica 12.5 PL. *Results*: Patients with combination therapy had lower asymmetry of temporal muscle activity. *Conclusions*: Combination therapy using magnetic stimulation reduced intensity of pain in patients with TMD and decreased values of the Helkimo indices.

Key words: *temporomandibular disorders, electromyography, magnetic fields therapy*

1. Introduction

Temporomandibular disorders (TMD) are a group of conditions related to the muscles of mastication, temporomandibular joints and adjacent structures [4], which occur in 60–70% of the population. However, only 25% of persons with a TMD are aware of its presence and report for treatment due to various symptoms [10], [14], [28]. Possible aetiological factors are parafunctional habits and occlusal factors. Patients with TMD suffer from muscle tenderness, joint clicking, limited mandibular movement, orofacial pain, pain in TMJ, headache. Murphy et al. [16] reported that 3–12% of the population with symptoms originating from the muscles of mastication or temporomandibular joints experience painful ailments connected with TMD. Such disorders occur in all age groups [18], [20]. Hence, together with dental caries and periodontal diseases, TMDs are one of the major issues encountered in dentistry. Civilizational changes and increasing number of stress factors may promote the emergence or worsening of painful TMD [10], [20]. Painful conditions may also be a consequence of

* Corresponding author: Rafał Rój, Department of Prosthetic Dentistry, School of Medicine with the Division of Dentistry in Zabrze, Medical University of Silesia in Katowice, pl. Akademicki 17, 41-902 Bytom, Poland. Phone: +48 32 282-79-17, e-mail: rafstoma@gmail.com
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factors related to impaired coordination and incorrect relations in the structures of a temporomandibular joint [25] as well as uncontrolled contractions and asymmetry in certain masticatory muscles, particularly the masseters [22]. Improper occlusal contacts resulting from displacement and loss of teeth in edentulous patients and patients with partial dentition cause changes in the relations within the temporomandibular joints, adversely affecting the functioning of the stomatognathic system [25]. Electromyography is a complementary element of the diagnostics, which allows for an objective recording of muscle electrical activity and the level of asymmetry between the right and left sides of homonymous muscles. This technique enables also the assessment of the changes in muscle activity in the course of treatment, e.g., with use of occlusal splints made of various materials [25], physiotherapy and/or pharmacotherapy [4], [5], [26]. Additional therapies of TMD include: thermotherapy, cryotherapy, electrotherapy, laser therapy, magnetic stimulation, sonotherapy, hydrotherapy, manual therapy, ionophoresis and acupuncture [5], [10]. The aim of physiotherapeutic procedures employed in TMD is to improve the blood flow in overloaded muscles and to relax them, as well as to relieve pain and improve metabolism. Magnetic stimulation is still one of the less widespread methods of TMD treatment. Alternating magnetic field therapy used in medicine and dentistry can be divided into two types of treatment: magnotherapy and magnetic stimulation [12]. Magnotherapy is characterised by induction values between 0.1 and 20 mT and frequency lower than 100 Hz. Magnetic field used in magnetic stimulation usually employs higher frequency (up to 3000 Hz), while magnetic induction ranges from 1 pT to 100 μT [9], [12]. Previous studies indicate a positive impact of magnetic stimulation in acute pulpitis and complications of endodontic treatment [12], after tooth replantation [12], in bone tissue regeneration [12], surgical procedures, complications following anaesthesia [9], orthodontic and prosthetic treatment and in arthropathies of the temporomandibular joint [12]. There are, however, no studies on the assessment of outcome of a combination therapy using occlusal splints and extremely low frequency magnetic fields, nor on the effect of such therapies on masticatory muscles tension and pain symptoms. In view of the above, the aim of this study was to investigate the effects of extremely low-frequency magnetic field therapy on potentials and asymmetry of temporal and masseter muscles as well as pain symptoms in patients with painful TMD. The hypothesis was that the employment of extremely low-frequency magnetic field in the treatment of painful TMD promotes the reduction of potential in muscles of the masticatory system, restoration of asymmetry of temporal and masseter muscles as well as relieves pain symptoms. The aim of physiotherapeutic procedures employed in TMD is restoration of proper metabolism, improvement of blood flow in overloaded muscles, their relaxation and combating pain. Still, magnetic stimulation is not a very common method supporting TMD treatment. Compared to magnetic therapy, it employs higher frequency (up to 3000 Hz) and lower values of magnetic induction (from 1 pT to 100 μT) [9], [11], [12]. Previous studies indicate a positive impact of magnetic stimulation in acute pulpitis and complications of endodontic treatment [12], after tooth replantation [12], in bone tissue regeneration [12], surgical procedures and complications following anaesthesia [9], orthodontic and prosthetic treatment and in arthropathies of the temporomandibular joint [12]. There are, however, no studies on the assessment of the outcome of a combination therapy using occlusal splints and extremely low-frequency magnetic fields, nor on the effect of such therapies on masticatory muscles activity and pain experienced by patients. The aim of this study was to investigate the effects of supportive therapy with extremely low-frequency magnetic field in patients with painful TMD on activity and asymmetry of temporal muscles and masseters, pain experienced and indices describing the intensity of masticatory system dysfunctions. The hypothesis was that the employment of extremely low frequency magnetic field in the treatment of painful TMD promotes treatment efficiency through reduction of pain intensity and muscle asymmetry index as well as through improvement of indices describing the intensity of masticatory system dysfunctions.

2. Material

Out of 412 patients who reported for replacement or control of their complete dentures 40 edentulous patients (38 women, 2 men) aged 43–79 and with painful TMD were selected. All subjects were examined clinically by the same trained dentist and qualification for the study was based on Helkimo Index. The study was initiated after the subjects had signed informed consent forms, and the research program had been approved by the Ethical Committee of the Medical University of Silesia in Katowice – *KNW/0022/KB1/56/12*.

Inclusion criteria were as follows: patient's written consent, no diagnosed oral inflammations, age between 45–85, missing teeth in maxilla and mandible, painful acute or chronic TMD of muscular and/or articular origin diagnosed on the basis of Helkimo Index and VAS scale, intensity of pain min. 3 points in the VAS scale, use of full dentures for more than 5 years.

Exclusion criteria were as follows: lack of written consent, oral inflammations, pregnancy, active cancer, active pulmonary tuberculosis, gastrointestinal bleedings, severe viral, bacterial and fungal infections, presence of electronic implants (e.g., artificial pacemakers) and conditions after organ transplants. The group of 40 edentulous patients was randomly divided into study and control groups of 20 patients each.

3. Method

All the study participants underwent a surface electromyography recording with 8-channel electromyograph (BioEMG III) – BioPAK Measurement System (BioResearch, Inc. Milwaukee, USA). 4 EMG signals were received from 8 channels. The system can register electrical activity from 8 muscles simultaneously. Microvolt signals were amplified with a minimum noise up to 5000 times stronger than their original level. The noise was suppressed to 170 dB with use of NoiseBuster digital filter in the BioPAK programme, which automatically deletes 99% of the remaining noise with frequency higher than 50/60 Hz from the data registered during the analysis. Increased CMRR (noise rejection) from 120 dB to 130 dB at 60 Hz. Resolution of A/D converter was 0.03 microvolt (16 bits). All patients were examined between 8 a.m. and 12 p.m. They were instructed to sit up straight on a chair, without supporting the head, looking forward, with both feet on the floor and hands placed loosely on the knees. Skin around the temples and masseters was wiped a few times with 95% alcohol solution to reduce skin-electrode impedance, recording was performed using bipolar surface electrodes (BioFLEX, Bioresearch Associates INC., Brown Deer, USA). BioFlex Ag/AgCl electrodes have two conductive-adhesive polyester RG-63X hydrogel contacts (100 mm^2) with 19 mm center-to-centerinterelectrode spacing. Electrodes were placed symmetrically on the previously prepared skin. For the frontal part of temporal muscles the placing was vertical to the frontal edge of the muscle approximately over coronal sutures. For masseters the electrode was placed parallel to muscle fibres according to Ferrairo [7]. The grounding electrode was placed on the shoulder. After setting up the device, muscle activity at rest was measured in postural position, the patient had full upper and lower dentures (on the first visit. In subsequent control examinations, the measurements were made with full upper denture and lower occlusal splint). To examine muscle activity during clenching, patients were asked to clench 3 times for 3 seconds with 3-second intervals (similarly, patients had full upper and lower dentures during the first visit, while subsequent control examinations included full upper dentures and lower occlusal splints). Based on the data obtained, the Asymmetry Index (AI), which is used to assess the differences in homonymous muscle activity, was used. The possible values range from 0 to 100%, where 0% is total symmetry and 100% is total asymmetry of muscles. The index was calculated for each pair of homonymous muscles of the right and left sides according to the formula [7]:

$$As_{\text{index}} = \frac{\sum_{i=1}^{N}(R_i - L_i)}{\sum_{i=1}^{N}(R_i + L_i)} \cdot 100\%$$

$$= \frac{\left(\sum_{i=1}^{N} R_i + \sum_{i=1}^{N} L_i\right)}{\left(\sum_{i=1}^{N} R_i - \sum_{i=1}^{N} L_i\right)} \cdot \left(\frac{N}{N}\right) \cdot 100,$$

where: R – value of homonymous muscle activity on the right side, L – value of homonymous muscle activity on the left side. Subsequently, an alginate impression was taken (Kromopan, LASCOD, Italy) in order to produce a lower wax rim. Lower acrylic occlusal splints were made using the open-tray method based on centric occlusion verified with an X-ray directed at temporomandibular joints, in order to determine the centralisation of articular heads as the position of reference [27], [28]. All patients were asked to use the occlusal splints for 12 weeks. Apart from the occlusal splint therapy, the ELF magnetic field therapy with use of the Viofor JPS Delux device (Med & Life, Komorów, Poland) was also employed in the study group. Procedures were performed for three weeks, excluding Saturdays and Sundays (15 procedures in each patient of the study group). The following parameters of the magnetic field were used: basic impulse frequency ranging from 180 to 195 Hz, impulse package frequency ranging from 12.5 to 29 Hz, frequency of impulse package groups ranging from 2.8 to 7.6 Hz and impulse series frequency ranging from

0.08 to 0.3 Hz, while the target effective induction was over 15 mT [13]. The following tests were performed in study and control group patients after 3, 6 and 12 weeks of use of the splint: functional examination and follow-up tension measurements of the above-mentioned muscles. Occlusal contacts were also adjusted, controlled by the T-scan III device employed as an electronic tracer (Tecscan, Boston, Massachusetts) and balancing occlusal contacts on the right and left sides. The software enables displaying both maximum occlusal contact and its distribution on both sides, in relation to the median line. Based on the information obtained during examination, the severity of masticatory system dysfunction was evaluated on the basis of Helkimo indices [28]. The first of them, Anamnestic Index (Ai), is based on subjective data from the interview. It enables classification of the dysfunction as one of the following groups: symptom-free (Ai0), mild (Ai1) and severe (Ai2). The second one, Dysfunction Index (Di), is based on clinical examination. It is a sum of the grading of signs, such as: range of mandibular motion, joint activity, muscle pain, pain in TMJ, pain on mandible movements. Specific assessment criteria of the signs, the way of assessing and classifying them as one of the three dysfunction groups, from mild signs to severe (DiI, DiII, DiIII) [28]. The assessment of pain intensity was performed with the Visual Analog Scale (VAS) in the form of a ruler divided into 10 equal sections. The examined person marked the intensity of pain on the scale from 0 to 10, where 0 set as no pain and 10 was the most severe conceivable pain. Each patient was interviewed about pain symptoms on each control visit and pain intensity was assessed on the basis of the VAS [26]. The results were subjected to statistical analysis with the use Statistica 12.5 software. The distribution of data was tested with the Shapiro–Wilk test and the equality of variances was tested with Levene's test. If the distribution of data was not normal and/or the variances were not equal, the non-parametric Mann–Whitney U ($\alpha = 0.05$) test or the Kruskal–Wallis test ($\alpha = 0.05$) with multiple comparisons of mean ranks for all groups post-hoc test ($\alpha = 0.05$) were used.

4. Results

40 patients aged 43–79 (64.6 ± 6.8) participated in the study, including 38 females (95%) and 2 males (5%). The study group consisted of 20 patients aged 54–76 (66.6 ± 5.4), whereas the control group consisted of 20 patients aged 43–79 (62.6 ± 7.5), including 19 females.

The results of muscle activity measurements in temporal muscles at rest are presented in Fig. 1. No statistically significant reduction of muscle activity in temporal muscles at rest on the left side (Fig. 1a) and on the right side (Fig. 1b) was observed in study and control groups during the treatment. Statistically significant differences at particular stages of the treatment between the values of muscle activity in the study and control groups were also not demonstrated. No statistically significant reduction of muscle activity in temporal muscles during clenching on the left side (Fig. 2a) and on the right side (Fig. 2b) was ob-

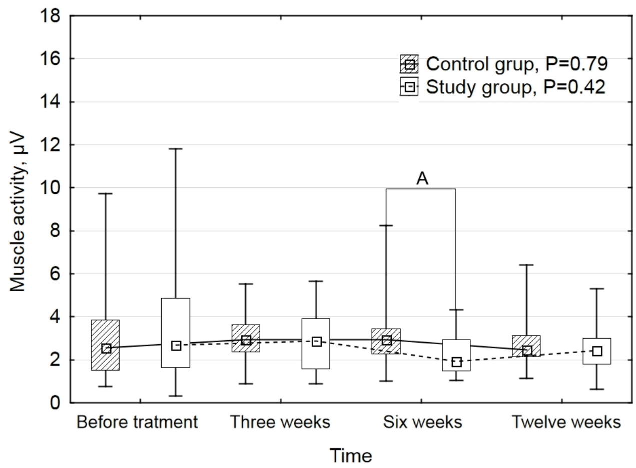

Fig. 1a. Medians, interquartile ranges, minimum and maximum values of the temporal muscles activity while during resting at the left side with Kruskal–Wallis test results; the letter indicate significantly different study and control groups in Mann–Whitney U test at the $p < 0.05$ level

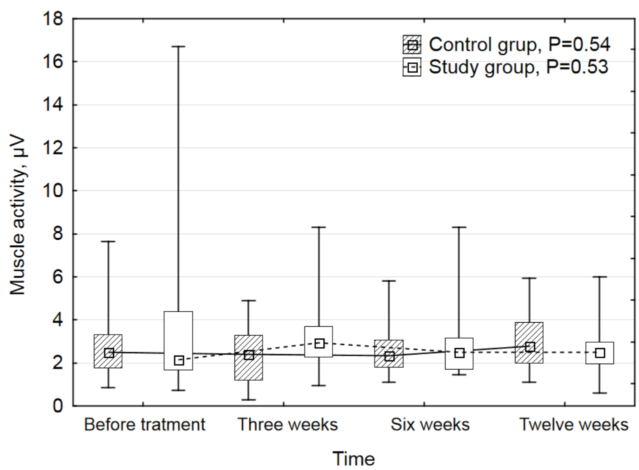

Fig. 1b. Medians, interquartile ranges, minimum and maximum values of the temporal muscles activity while during resting at the right side with Kruskal–Wallis tests results; the letter indicate significantly different study and control groups in Mann–Whitney U test at the $p < 0.05$ level

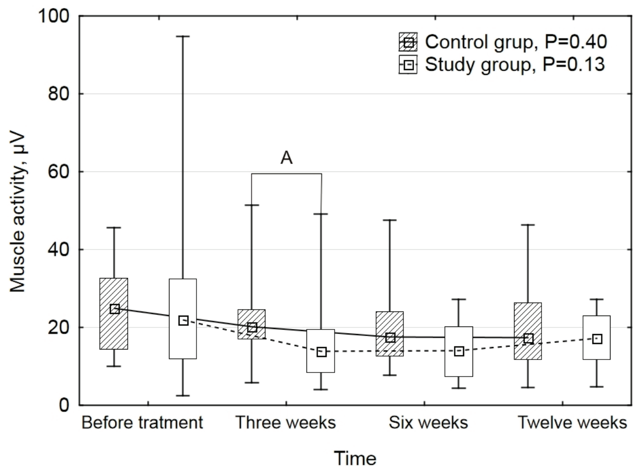

Fig. 2a. Medians, interquartile ranges, minimum and maximum values of the temporal muscles activity during clenching at the left side with Kruskal–Wallis test results; the letters indicate significantly different study and control groups in Mann–Whitney U test for particular times at the $p < 0.05$ level

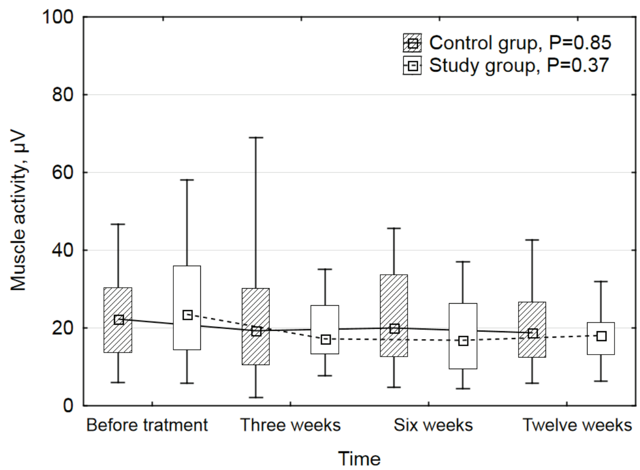

Fig. 2b. Medians, interquartile ranges, minimum and maximum values of the temporal muscles activity during clenching at the right side with Kruskal–Wallis test results; the letters indicate significantly different study and control groups in Mann–Whitney U test for particular times at the $p < 0.05$ level

served in study and control groups during the treatment. Medians of the values of muscle activity in the study group were lower than in the control group, yet, only in the third week from the beginning of the treatment were the differences statistically significant. No statistically significant influence of the treatment on the reduction of masseter muscle activity at rest (Fig. 3) and during clenching (Fig. 4) was observed for both groups. Statistically significant difference was only observed in masseter muscle activity during clenching on the left side between the groups before the beginning of the treatment (Fig. 4a). In later control periods, however, no statistically significant differences were demonstrated. Statistically significant reduction of the Asymmetry Index of temporal muscles at rest was not observed in the study and control groups (Fig. 5a). Statistically significant reduction of the Asymmetry Index of temporal muscles during clenching was observed both in the study and control groups (Fig. 5b), whereas in the case of the control group the value $P = 0.04$ was only slightly above the significance level and post hoc tests did not confirm the occurrence of statistically significant differences at particular stages of the treatment. In the case of the study group, the *post hoc* test confirmed statistically significant differences between medians of the Asymmetry Index during the whole period of treatment (Fig. 5b). It should be noted that during clenching

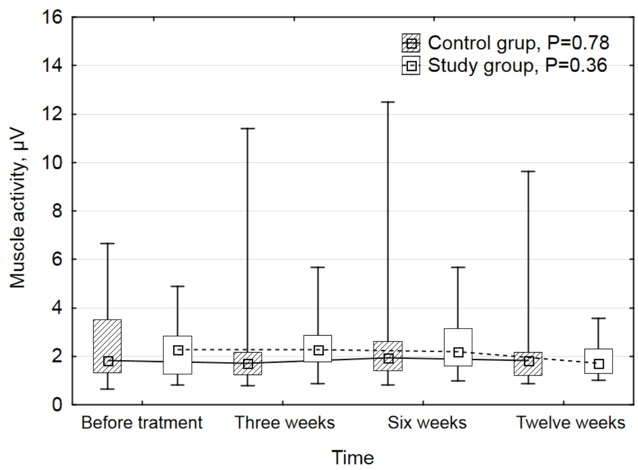

Fig. 3a. Medians, interquartile ranges, minimum and maximum values of the masseter muscles activity during resting at the left side with Kruskal–Wallis test results; the letters indicate significantly different study and control groups in Mann–Whitney U test for particular times at the $p < 0.05$ level

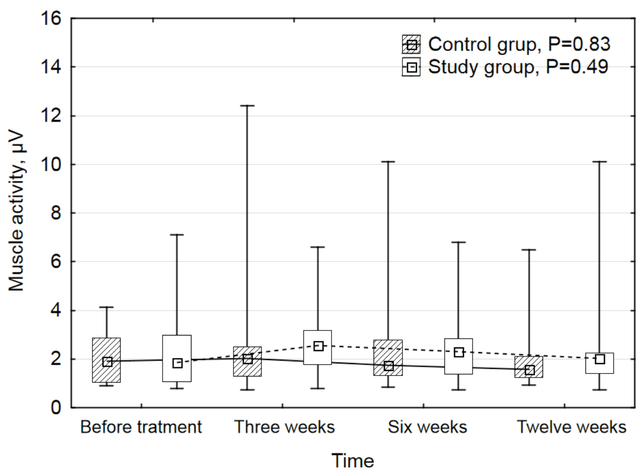

Fig. 3b. Medians, interquartile ranges, minimum and maximum values of the masseter muscles activity during resting at the right side with Kruskal–Wallis test results; the letters indicate significantly different study and control groups in Mann–Whitney U test for particular times at the $p < 0.05$ level

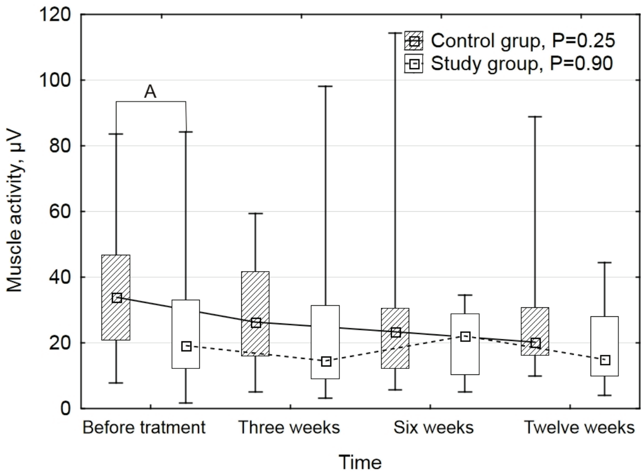

Fig. 4a. Medians, interquartile ranges, minimum and maximum values of the masseter muscles activity during clenching at the left side with Kruskal–Wallis test results; the letters indicate significantly different study and control groups in Mann–Whitney U test for particular times at the $p < 0.05$ level

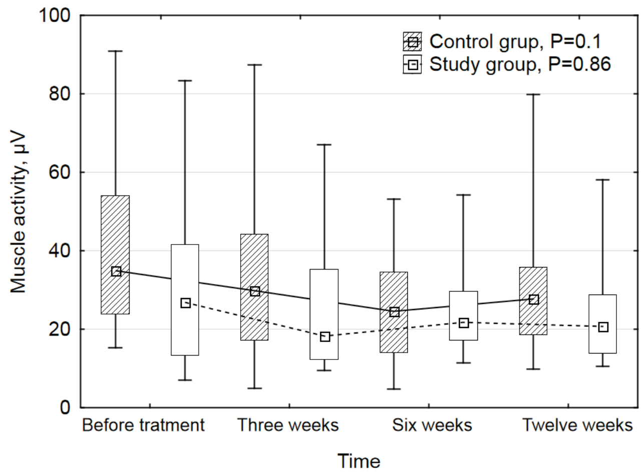

Fig. 4b. Medians, interquartile ranges, minimum and maximum values of the masseter muscles activity during clenching at the right side with Kruskal–Wallis test results; the letters indicate significantly different study and control groups in Mann–Whitney test for particular times at the $p < 0.05$ level

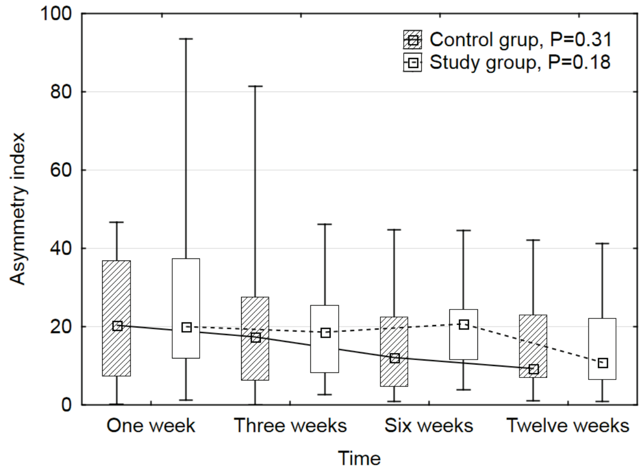

Fig. 5a. Medians, interquartile ranges, minimum and maximum values of the asymmetry index of temporal muscles at resting with Kruskal–Wallis test results; symbols indicate significantly different medians at different times for control or study group in a *post-hoc* test at the $p < 0.05$ level, the letters indicate significantly different study and control groups in Mann–Whitney U test for particular times at the $p < 0.05$ level

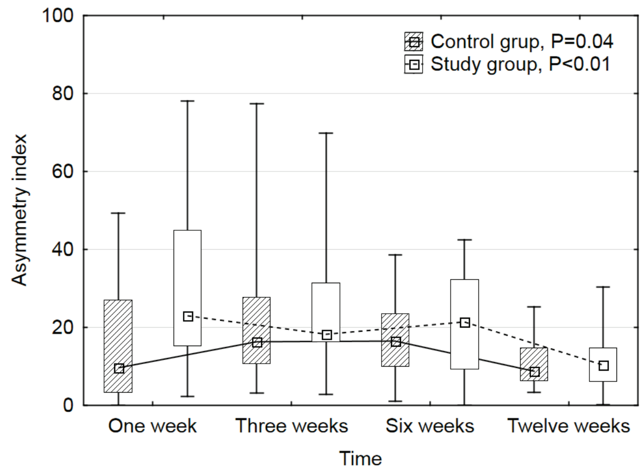

Fig. 5b. Medians, interquartile ranges, minimum and maximum values of the asymmetry index of temporal muscles during clenching with Kruskal–Wallis test results; symbols indicate significantly different medians at different times for control or study group in a *post-hoc* test at the $p < 0.05$ level, the letters indicate significantly different study and control groups in Mann–Whitney U test for particular times at the $p < 0.05$ level

before the beginning of the treatment the median of the Asymmetry Index was larger in the study group than in the control group. Statistically significant reduction of the Asymmetry Index of masseter muscles at rest was observed neither in the study nor control groups (Fig. 6a). Statistically significant reduction of the Asymmetry Index of masseter muscles during clenching was observed in the study group and the *post hoc* test confirmed the differences in medians of the Asymmetry Index before and after the treatment (Fig. 6b). Tables 1–4 show medians of muscle tension after the division into the dominant and non-dominant sides. No statistically significant change of muscle tension during the therapy was demonstrated. Nevertheless, a reduction in medians of the tension of examined muscles during clenching on the dominant side was observed during the therapy (Tables 2 and 3). Statistically significant influence of the treatment on patients' pain symptoms was reported in the control and study groups (Fig. 7). Statistically significant reduction of pain measured in the VAS scale was achieved after three weeks of treatment in the study

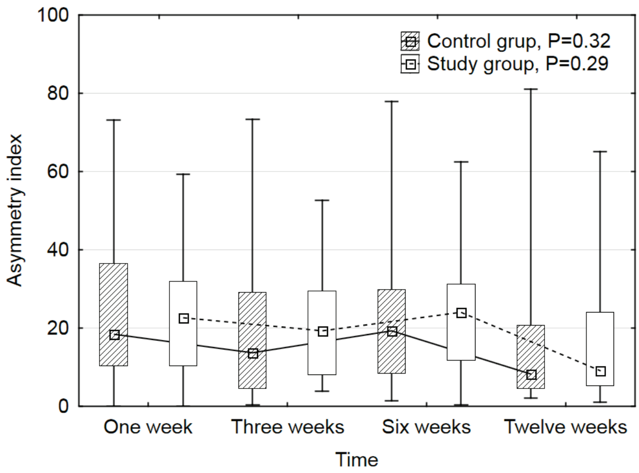

Fig. 6a. Medians, interquartile ranges, minimum and maximum values of the asymmetry index of master muscles at resting with Kruskal–Wallis test results; symbol indicate significantly different medians at different times for study group in a *post-hoc* test at the $p < 0.05$ level

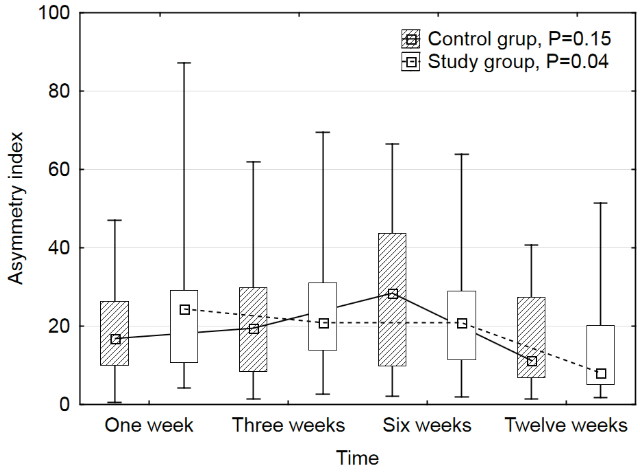

Fig. 6b. Medians, interquartile ranges, minimum and maximum values of the asymmetry index of master muscles during clenching with Kruskal–Wallis test results; symbol indicate significantly different medians at different times for study group in a *post-hoc* test at the $p < 0.05$ level

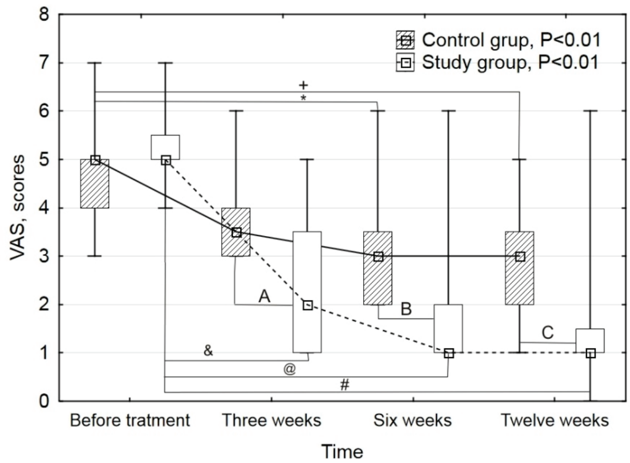

Fig. 7. Medians, interquartile ranges, minimum and maximum of scores in VAS scale with Kruskal–Wallis test results; symbol indicate significantly different medians at different times in study or control group in a *post-hoc* test at the $p < 0.05$ level; the letters indicate significantly different study and control groups with Mann–Whitney U test for particular times at the $p < 0.05$ level

Table 1. Medians, interquartile ranges, minimum and maximum values for temporal muscle activity during resting for dominant and non-dominant side with Kruskal–Wallis test ($\alpha = 0.05$) results

Site		Temporal muscle activity during resting, µV							
		Study group ($P = 0.09$)				Control group ($P = 0.97$)			
		T0	T3	T6	T12	T0	T3	T6	T12
DS	MED (MIN÷MAX)	3.0 (0.7÷16,7)	3.2 (0.9÷8.3)	1.9 (1.1÷8.3)	2.5 (0.6÷6.0)	2.9 (0.9÷9.7)	3.0 (0.9÷5.5)	3.0 (1.1÷8.3)	3.2 (1.2÷6.4)
	IR	8.5	6.2	4.8	4.9	6.9	6.4	6.2	6.6
N-DS		Study group ($P = 0.14$)				Control group ($P = 0.69$)			
		T0	T3	T6	T12	T0	T3	T6	T12
	MED (MIN÷MAX)	1.8 (0.3÷11.8)	2.9 (0.9÷5.7)	2.2 (1.4÷4.7)	2.4 (0.6÷5.3)	1.9 (0.8÷5.7)	2.2 (0.3÷3.8)	2.2 (1.0÷4.9)	2.3 (1.1÷5.1)
	IR	3.9	5.6	4.5	4.8	4.2	4.5	4.8	4.5

DS – dominant site, N-DS – non-dominant site

group and only after six weeks in the control group. Moreover, at particular stages of the treatment, pain sensations in patients of the study group were at a statistically lower level than in the control group. Median of the clinical dysfunction index was reduced in a statistically significant way in study and control groups after the treatment (Table 5). Moreover, statistically lower values of the anamnestic dysfunction index were reported in the study group than in the control group after 12 weeks of treatment, which is visualised in Table 6. Anamnestic dysfunction index was statistically significantly lowered only in the case of the study group (Table 7).

Table 2. Medians, interquartile ranges, minimum and maximum values for temporal muscle activity for dominant and non-dominant side during clenching,with Kruskal–Wallis test ($\alpha = 0.05$) results

Site		Temporal muscle activity during clenching, µV							
		Study group ($P = 0.07$)				Control group ($P = 0.44$)			
		T0	T3	T6	T12	T0	T3	T6	T12
DS	MED (MIN÷MAX)	27.0 (10.0÷94.7)	19.7 (10.2÷49.1)	18.2 (10.0÷94.7)	19.6 (6.3÷31.9)	25.5 (13.1÷46.7)	23.8 (5.8÷69.0)	21.2 (7.8÷47.6)	20.6 (7.7÷46.4)
DS	IR	63.0	40.5	37.3	38.3	51.8	47.6	49.3	43.4
N-DS		Study group ($P = 0.24$)				Control group ($P = 0.71$)			
		T0	T3	T6	T12	T0	T3	T6	T12
	MED (MIN÷MAX)	17.0 (2.5÷39.4)	13.8 (4.1÷32.1)	11.6 (4.4÷27.3)	16.7 (4.8÷27.2)	17.1 (5.9÷41.2)	17.0 (2.2÷43.0)	14.4 (4.7÷43.0)	16.3 (4.6÷42.6)
N-DS	IR	36.6	24.0	24.7	31.0	40.7	30.6	33.6	35.8
DS – dominant site, N-DS – non-dominant site									

Table 3. Medians, interquartile ranges, minimum and maximum values for masseter muscle activity during resting for dominant and non-dominant side with Kruskal–Wallis test ($\alpha = 0.05$) results

Site		Masseter muscle activity during resting, µV							
		Study group ($P = 0.21$)				Control group ($P = 0.56$)			
		T0	T3	T6	T12	T0	T3	T6	T12
DS	MED (MIN÷MAX)	2.6 (0.9÷94.7)	3.0 (0.9÷6.6)	3.0 (1.0÷6.8)	2.2 (1.0÷10.1)	2.9 (1.0÷6.7)	2.1 (0.8÷12.4)	2.2 (1.0÷12.5)	2.0 (1.0÷9.6)
DS	IR	5.3	6.2	5.4	4.5	5.4	5.2	5.1	3.9
N-DS		Study group ($P = 0.53$)				Control group ($P = 0.99$)			
		T0	T3	T6	T12	T0	T3	T6	T12
	MED (MIN÷MAX)	1.5 (0.8÷4.5)	1.9 (0.8÷3.0)	1.8 (0.7÷3.0)	1.6 (0.7÷2.8)	1.6 (0.6÷3.3)	1.4 (0.7÷2.8)	1.5 (0.8÷5.6)	1.5 (0.9÷4.7)
N-DS	IR	3.3	3.9	3.8	3.4	3.0	3.1	3.0	3.0
DS – dominant site, N-DS – non-dominant site									

Table 4. Medians, interquartile ranges, minimum and maximum values for masseter muscle activity for dominant and non-dominant side during clenching, with Kruskal–Wallis test ($\alpha = 0.05$) results

Site		Masseter muscle activity during clenching, µV							
		Study group ($P = 0.59$)				Control group ($P = 0.11$)			
		T0	T3	T6	T12	T0	T3	T6	T12
DS	MED (MIN÷MAX)	33.2 (7.0÷84.3)	21.2 (10.1÷98.1)	25.8 (15.4÷54.3)	23.6 (11.9÷58.1)	39.5 (19.7÷90.9)	33.2 (7.5÷87.3)	31.3 (11.7÷114.3)	29.2 (15.2÷88.8)
DS	IR	63.6	52.7	52.6	50.5	86.5	66.9	59.4	58.1
N-DS		Study group ($P = 0.98$)				Control group ($P = 0.11$)			
		T0	T3	T6	T12	T0	T3	T6	T12
	MED (MIN÷MAX)	16.5 (1.8÷54.7)	12.1 (3.1÷44.6)	16.3 (5.1÷ 30.5)	12.8 (4.1÷36.4)	31.5 (7.7÷82.5)	21.3 (4.9÷56.4)	16.0 (4.8÷53.1)	17.7 (9.9÷79.8)
N-DS	IR	32.3	40.0	33.6	33.1	55.2	44.8	35.8	44.2
DS – dominant site, N-DS – non-dominant site									

Table 5. Medians, interquartile ranges, minimum and maximum values for masseter muscle activity for dominant and non-dominant side during clenching, with Kruskal–Wallis test ($\alpha = 0.05$) results

Site		Masseter muscle activity during clenching, μV							
		Study group ($P = 0.59$)				Control group ($P = 0.11$)			
		T0	T3	T6	T12	T0	T3	T6	T12
DS	MED (MIN÷MAX)	33.2 (7.0÷84.3)	21.2 (10.1÷98.1)	25.8 (15.4÷54.3)	23.6 (11.9÷58.1)	39.5 (19.7÷90.9)	33.2 (7.5÷87.3)	31.3 (11.7÷114.3)	29.2 (15.2÷88.8)
	IR	63.6	52.7	52.6	50.5	86.5	66.9	59.4	58.1
N-DS		Study group ($P = 0.98$)				Control group ($P = 0.11$)			
		T0	T3	T6	T12	T0	T3	T6	T12
	MED (MIN÷MAX)	16.5 (1.8÷54.7)	12.1 (3.1÷44.6)	16.3 (5.1÷ 30.5)	12.8 (4.1÷36.4)	31.5 (7.7÷82.5)	21.3 (4.9÷56.4)	16.0 (4.8÷53.1)	17.7 (9.9÷79.8)
	IR	32.3	40.0	33.6	33.1	55.2	44.8	35.8	44.2
DS – dominant site, N-DS – non-dominant site									

Table 6. Medians, minimum and maximum values and sums for Helkimo clinical dysfunction index

	Before treatment			Twelve weeks		
	Median	Min/Max	Sum	Median	Min/Max	Sum
Study group	$2^{A, a}$	2/3	45	$1^{B, a}$	1/3	24
Control group	$2^{A, a}$	2/3	45	$1^{B, b}$	1/3	32
Notes: * Groups with the same uppercase superscript letters, (A–B) for each row and lowercase superscript letters, (a–b) for each column are not significantly different at the $p < 0.05$ level						

Table 7. Medians, minimum and maximum values and sums for Helkimo anamnestic index

	Before treatment			Twelve weeks		
	Median	Min/Max	Sum	Median	Min/Max	Sum
Study group	$1^{A, a}$	1/2	25	$0^{B, a}$	0/1	8
Control group	$1^{A, a}$	1/2	22	$1^{A, b}$	0/1	19
Notes: * Groups with the same uppercase superscript letters, (A–B) for each row and lowercase superscript letters, (a–b) for each column are not significantly different at the $p < 0.05$ level						

5. Disscusion

The basic therapeutic method in, patients with painful temporomandibular disorders are occlusal splints [20]. KuzmanovicPficer et al. [10] demonstrated on the basis of a meta-analysis of 33 randomized controlled trials that the use of occlusal splints in patients with TMD brings short-term improvement. However, in order to maintain this therapeutic effect for a longer time, other supportive treatment methods should be used. A significant factor observed in this analysis is pain reduction ($p = 0.01$), pain intensity ($p = 0.02$), decrease of muscle tenderness ($p = 0{,}03$), improvement of mouth opening ($p = 0.04$). Advantages of the use of occlusal splints are also emphasised by Wiens [27], who stresses the reversibility of the process. However, other therapies and occlusal appliances may be beneficial when used for a specific TMD diagnostic protocol. Additionally, symptomatic therapy with use of physiotherapy is recommended, possibly combined with pharmacological therapy. Wieckiewicz et al. [26] assessed, based on 66 articles, that supportive treatment should be considered a first choice for TMD pain because of the low risk of side effects and that it is a valid alternative to pharmacological treatment. The study included the following types of supportive treatment: massage, manual therapy and taping, warming/cooling, light and laser therapy. Physiotherapy is used in the TMD treatment because of its analgesic, anti-inflammatory, stimulating and myorelaxing effects [26], [28]. The myorelaxing effect can be examined by palpation (bilateral palpation and muscle exam) or on the basis of the electromyography test [8], [20]. Electromyographic analysis of the muscles of mastication can also provide information on disorders in muscle physiology (high of low muscle activity, symmetry of EMG activity) in the stomatognathic system of patients with TMD and treatment outcomes [1], [8], [24]. Despite numerous publications [1] assessing the change of muscle tension using various methods, there are no studies concerning the influence of extremely low frequency magnetic field therapy on masticatory muscles tension and other effects connected with treatment of painful temporomandibular disorders. The above-mentioned methods of physical therapy are used in the treatment of TMD because of their analgesic, anti-inflammatory, stimulatory and myorelaxing activity [26], [28]. The myorelaxing effect can be examined by palpation or on the basis of an electromyography test [10], [20]. Electromyographic analysis of the muscles of mastication can also provide information on disorders in muscle work (increase or decrease of tension, tension symmetry between the right and left sides) in the stomatognathic system of persons with TMD in order to explain the relation between electrical and mechanical activity [8], [27]. Despite numerous publications [8], [23], [24] assessing the change of muscle tension with the use of various methods, there are no studies concerning the influence of extremely low frequency magnetic field therapy on masticatory muscles tension and other effects connected with treatment of painful masticatory system dysfunction. No statistically significant change in the value of tension of masseters and temporal muscles both at rest and during clenching was observed in the course of the study. At the same time, the observed tension values were on a similar level to those reported by Rilo et al. [19]. Some researchers indicate that employment of physiotherapeutic procedures may influence the reduction of mandibular muscles tension, e.g., by transcutaneous electrical nerve stimulation [4], [15]. Nevertheless, other studies [3] have not demonstrated analogous effects except for reduction of pain. These results indicate the possibility of obtaining different effects with use of various supportive procedures or treatment protocols. However, it must be noted that the presented results concern the signal in μV. Results presented in this form are useful from the clinical point of view, yet the foundations are characterised by considerable variability due to large variability of the signal and various interfering factors, e.g., on second placing of electrodes at successive time points. In this regard, the demonstrated lack of statistically significant differences is not surprising. Normalised values can be compared between examined patients, muscles, undesired interactions in a test conducted on the same person. In order to improve the quality of the analyses, the study employed the Asymmetry Index, which enables a certain normalisation of the results [22]. The correct value of asymmetry of homonymous muscles in the masticatory system is accepted to be approx. 15 at maximum contraction [6] and it is a value similar to those observed during clenching after the treatment. The results indicate that the employment of supportive therapy contributed to the improvement of Asymmetry Index value for temporal and masseter muscles during clenching in the study group. The cause of the reduction of Asymmetry Index value may be the observed reduction of muscle tension on the dominant side. Despite the reduction of muscle tension medians on the dominant side not being statistically significant, the analysis of values seems to confirm the above hypothesis to a certain extent and provides a justification to conduct additional studies in this field in the future. It would be reasonable to refine the protocol for muscle tension measurements, since considerable interquartile ranges and differences between minimum and maximum values of muscle tension can be observed, which results in altered results of statistical tests. Previous studies have indicated ambiguous results of treatment with occlusal splints. Daif [5] demonstrated that this form of therapy may promote both the elimination and the increase of symptoms of painful and painless masticatory system dysfunction, yet it influences the reduction of tension in examined muscles. Vieira e Silva et al. [25] suggest the possibility of asymmetry reduction in examined muscles and reduction of pain intensity as an effect of occlusal splint therapy. Results of the tests presented in the current study indicate that only combination therapy contributed to the reduction of Asymmetry Index value, which may in turn indicate the beneficial impact of magnetic stimulation. The employed therapy contributed to gradual reduction of pain sensations both in the study and control groups. However, reduction of pain experienced by patients was more effective in the group which used supportive therapy with magnetic stimulation. These results are consistent with the expectations of László et al. [11], who obtained positive results in extremely low frequency magnetic field treatment of pain in the stomatognathic system, whereas positive effect in treating pain with occlusal splints was demonstrated by, inter alia, Alajbeg et al. [2] and Rampello et al. [17]. Therefore, it must be concluded that the results obtained clearly indicate the purposefulness of combination therapy, which is consistent with conclusions drawn from the studies of Maia et al. [14] and Salmos-Brito et al. [21]. Positive effects of the employed therapy are also indicated by the obtained values of Helkimo indices. Significant reduction of the values of clinical and anamnestic dysfunction indices was observed in this research both in the study and in the control group. Moreover, statistically significantly lower values of both indices were obtained after the treatment in the study group, which proves the efficiency of the employed supportive therapy. The reported discrepancy between the clinical and anamnestic Helkimo indices, in favour of the latter, may suggest the presence of a psychogenic component in the aetiology of functional disorders [13].

6. Conclusions

The conducted study of the influence of combination therapy on the values of muscle activity, Asymmetry Index, pain sensations and Helkimo indices allowed to formulate the following conclusions:

1. The use of extremely low frequency magnetic fields in order to support the treatment of painful TMD allowed to significantly reduce pain sensations and the clinical and anamnestic dysfunction indices in the study group, compared to the control group, which confirms the purposefulness of this method in clinical conditions.
2. The reported reduction of Asymmetry Index value in patients undergoing combination therapy may be associated with the reported reduction of muscle activity on the dominant side, although the reduction was not statistically significant. However, further studies in this field are necessary and should be conducted after refining the test protocol and making it more specific in order to obtain repeatable results of muscle activity tests.

Conflicts of Interest

The authors declare no conflict of interest.

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References

[1] AGGARWAL A., KELUSKAR V., *Physiotherapy as an adjuvant therapy for treatment of TMJ disorders*, Gen. Dent., 2012, 60, 119–22.

[2] ALAJBEG I.Z., GIKIĆ M., VALENTIĆ-PERUZOVIĆ M., *Changes in pain intensity and oral health-related quality of life in patients with temporomandibular disorders during stabilization splint therapy – a pilot study*, Acta Clin. Croat., 2014, 53, 1, 7–16.

[3] BAZZOTTI L., *Electromyography tension and frequency spectrum analysis at rest of some masticatory muscles, before and after TENS*, Electromyogr. Clin. Neurophysiol., 1997, 37, 365–78.

[4] CHIPAILA N., SGOLASTRA F., SPADARO A., PIETROPAOLI D., MASCI C., CATTANEO R., MONACO A., *The effects of ULF-TENS stimulation on gnathology: the state of the art.*, Cranio, 2014, 32,2, 118–130. Review.

[5] DAIF E.T., *Correlation of splint therapy outcome with the electromyography of masticatory muscles in temporomandibular disorder with myofascial pain*, Acta Odontol. Scand., 2012, 70, 1, 72–77.

[6] DALEWSKI B., SEREWA J., FRĄCZAK B., *Electromyography of bruxism – case* descriptions, Magazyn Stomatologiczny, 2011, 5, 64–68, (in Polish).

[7] FERRARIO V.F., SFORZA C., COLOMBO A., CIUSA V., *An electromyographic investigation of masticatory muscles symmetry in normo-occlusion subjects*, J. Oral. Rehabil., 2000, 27, 33–40.

[8] HUGGER S., SCHINDLER H.J., KORDASS B., HUGGER A., *Clinical relevance of surface EMG of the masticatory muscles. (Part 1): Resting activity, maximal and submaximal voluntary contraction, symmetry of EMG activity*, Int. J. Comput. Dent., 2012, 15(4), 297–314, Review.

[9] KASPERSKI J., ROSAK P., RÓJ R., CZELAKOWSKA A., SIEROŃ-STOŁTNY K., PASEK J., SIEROŃ A., *The influence of low-frequency variable magnetic fields in reducing pain experience after dental implant treatment*, Acta Bioeng. Biomech., 2015, 17, 4, 97–105.

[10] KUZMANOVICPFICER J., DODIC S., LAZIC V., TRAJKOVIC G., MILIC N., MILIC B., *Occlusal stabilization splint for patients with temporomandibular disorders: Meta-analysis of short and long term effects*, PLoS One.2017, 6, 12, (2), Article ID 0171296, DOI: 10.1371/journal.pone.0171296, eCollection 2017.

[11] LÁSZLÓ J.F., FARKAS P., REICZIGEL J., VÁGÓ P., *Effect of local exposure to inhomogeneous static magnetic field on stomatological pain sensation – a double-blind, randomized, placebo-controlled study*, Int. J. Radiat. Biol., 2012, 88, 5, 430–438.

[12] ŁOPUCH P., PIHUT M., BACZYK-ŁOPUCH O., *The use of extremely low frequency magnetic fields and in dentistry – a review of literature*, Implantoprotetyka, 2010, 2–3(39–40), 46–49, (in Polish).

[13] LOSTER J., WIECZOREK A., MAJEWSKI S., *Co-existence of dysfunction of the stomatognathic system and incidences of depressive conditions based on examination of patients at the University Dental Clinic in Cracow*, J. Stoma., 2011, 64, 12, 1017–1025.

[14] MAIA M.L., BONJARDIM L.R., QUINTANSJDE S., RIBEIRO M.A., MAIA L.G., CONTI P.C., *Effect of low-level laser therapy on pain levels in patients with temporomandibular disorders: a systematic review*, J. Appl. Oral. Sci., 2012, 20, 6, 594–602, Review.

[15] MONACO A., SGOLASTRA F., PIETROPAOLI D., GIANNONI M., CATTANEO R., *Comparison between sensory and motor transcutaneous electrical nervous stimulation on electromyographic and kinesiographic activity of patients with temporomandibular disorder: a controlled clinical trial*, BMC Musculoskelet. Disord., 2013, 15, 14, 168.

[16] MURPHY M.K., MACBARB R.F., WONG M.E., ATHANASIOU K.A., *Temporomandibular disorders: a review of etiology, clinical management, and tissue engineering strategies*, Int. J. Oral. Maxillofac. Implants, 2013, 28(6), 393–414.

[17] RAMPELLO A., SACCUCCI M., FALISI G., PANTI F., POLIMENI A., DI PAOLO C., *A new aid in temporomandibular joint disorders' therapy: the universal neuromuscular immediate relaxing appliance*, J. Biol. Regul. Homeost. Agents, 2013, 27, 4, 1011–1019.

[18] RIBEIRO J.A., DE RESENDE C.M., LOPES A.L., FARIAS-NETO A., CARREIRO A.F., *Association between prosthetic factors and temporomandibular disorders in complete denture wearers*, Gerodontology, 2014, 31(4), 308–313.

[19] RILO B., SANTANA U., MORA M.J., CADARSO C.M., *Myoelectrical activity of clinical rest position and jaw muscle activity in young adults*, J. Oral. Rehabil., 1997, 24, 10, 735–740.

[20] ROLDÁN-BARRAZA C., JANKO S., VILLANUEVA J., ARAYA I., LAUER H.C., *A systematic review and meta-analysis of usual treatment versus psychosocial interventions in the treatment of myofascial temporomandibular disorder pain*, J. Oral. Facial. Pain Headache, 2014, 28(3), 205–222, DOI: 10.11607/ofph.1241, Review.

[21] SALMOS BRITO J.A., DE MENEZES R.F., TEIXEIRA C.E., GONZAGA R.K., RODRIGUES B.H., BRAZ R., BESSA-NOGUEIRA R.V., GERBI M.E., *Evaluation of low-level laser therapy in patients with acute and chronic temporomandibular disorders*, Lasers Med. Sci., 2013, 28, 1, 57–64.

[22] SCOPEL V., ALVES DA COSTA G.S., 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.

[23] SUVINEN T.I., KEMPPAINEN P., *Review of clinical EMG studies related to muscle and occlusal factors in healthy and TMD subjects*, J. Oral. Rehabil., 2007, 34(9), 631–44, Review.

[24] SZYSZKOWSKA A., HAMWI R., KOLIŃSKI P., *Physiotherapy procedures used in dental therapy*, Implantoprotetyka, 2011, XII, 1–2, 42–43, (in Polish).

[25] VIEIRA E. SILVA C.A., DA SILVA M.A., MELCHIOR-MDE O., DE FELICIO C.M., SFORZA C., TARTAGLIA G.M., *Treatment for TMD with occlusal splint and electromyographic control: application of the FARC protocol in a Brazilian population*, Cranio, 2012, 30, 3, 218–226.

[26] WIĘCKIEWICZ M., BOENING K., WILAND P., SHIAU Y.Y., PARADOWSKA-STOLARZ A., *Reported concepts for the treatment modalities and pain management of temporomandibular disorders*, J. Headache Pain, 2015, 16, 106.

[27] WIENS J.P., *A progressive approach for the use of occlusal devices in the management of temporomandibular disorders*, Gen. Dent., 2016, 64(6), 29–36. Review.

[28] WITULSKI S., VOGL T.J., REHART S., OTTL P., *Evaluation of the TMJ by means of Clinical TMD Examination and MRI Diagnostics in Patients with Rheumatoid Arthritis*, Biomed. Res. Int., 2014, Article ID 328560.