http://dx.doi.org/10.35630/2199-885X/2022/12/2.29

IMPLEMENTATION OF NEUROMUSCULAR DENTISTRY PRINCIPLES IN REHABILITATION OF PATIENTS WITH COMPLETE ADENTIA

Received 30 December 2021;
Received in revised form 26 January 2022;
Accepted 27 January 2022

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ABSTRACT — According to World Health Organization about 15% of the world's adult population suffer from complete adentia, with a steady growth in the number of patients affecting not only the elderly which is accounted for by an increase in life expectancy, yet also among people in their working age. Apart from disturbed chewing and speech functions, complete adentia leads to altered anatomical and topographic proportions of the face and facial skeleton, progressive atrophy and osteoporosis of the jaws, masticatory and mimic muscle atrophy, as well as to dysfunction affecting these muscles and temporomandibular joints. Due to lack of proper nutrition, changed exterior, issues in interaction with others, this group of patients develop a whole set of psychosomatic reactions finally causing social withdrawal. Rehabilitation of patients with complete loss of teeth is an urgent issue. However, the effectiveness of prosthetic treatment depends not only on the denture manufacturing technology, but on the quality of functioning involving the maxillofacial organs in combination with the respective orthopedic appliances. Whereas precise and reliable assessment of the maxillofacial neuromuscular balance enables to predict immediate and long-term outcomes of orthopedic treatment. Employing the principles of neuromuscular dentistry allows us to assess reliably the changes in the reflex mechanisms of muscular apparatus. This was carried out throughout all the stages of prosthetic treatment in patients with complete adentia with intraosseous implants with fixed bridges and conditionally removable dentures.

KEYWORDS — neuromuscular dentistry, complete adentia, masticatory muscles functional activity, electromyography, occlusion computer analysis, dental implants.

INTRODUCTION

Loss of teeth entails serious changes affecting the masticatory system, which involves the bones, mucous membranes and muscles. The alveolar process bone tends to resorb, the development of a new bone slows down, the covering mucosa features a decrease in the number of receptors, thus resulting in reduced afferent pulsation. Sensitive receptors, such as neuromuscular spindles, periodontal and intradental pressure receptors, have a strong effect on the activity of motor neurons, and thereby — on muscle control. Most of the sensitive impulse connections with the motor impulse generated in the central nervous system occur at the level of premotoneurons located in the nucleus reticularis parvocellularis, in the trigeminal nerve medullary nucleus, and in the adjacent nuclei. Many cells in these nuclei have receptor fields in mucous membrane and respond to the pressure experienced by the teeth, as well as to extension of the masticatory muscles [15, 43].

Sensitive impulses in people with adentia undergo change. Patients of this category reveal a reduced chewing cycle amplitude as well as lower effectiveness and chewing muscle contraction strength, if compared to patients with teeth. Besides, the chewing cycle opening and closing rate de-creases, whereas the occlusal pause increases [6, 14, 36].

Rehabilitation of patients with complete adentia is not only an urgent interdisciplinary issue faced by orthopedic and surgical dentistry, yet also a social one. The rehabilitation objectives in this case include the following: restored chewing and speech function; jaw atrophy and osteoporosis prevention; shorter terms of functional adjustment to dentures; developing conditions for effective social adjustment of patients with complete adentia [7–10, 13, 19, 22–26, 30, 38, 42].

The issues above-mentioned can be resolved only taking in view of the pathogenesis of the dental system morphological and functional changes, which are due to complete loss of teeth. The prevention of progressive atrophy, jaw osteoporosis and change affecting the topographic and anatomical maxillofacial proportions in case of complete adentia rely on the preservation of blood supply, microcirculation and recovery of bioelectric activity in the jaw bone tissue [2, 12, 16, 29, 32, 37, 41].

The authors have proven that the mandible resting position in patients with complete adentia changes due to loss of function of proprioceptive receptors located in the periodontium. The factors affecting the mandible resting position include physiological reasons (volitional control over the jaw position, the emotional status, fatigue, parafunctions of the masticatory muscles) and pathological conditions of the maxillofacial area organs (diseases of muscles, joints, nervous regulation disorders) [1, 34].

Currently, the treatment of patients with complete adentia relies on prosthetic treatment with completely removable dentures, as well as on combined treatment, which involves surgical approaches for correcting topographic and anatomical conditions for removable prosthetics and endoprosthetics (implantation) for removable and non-removable prosthetics [4, 11, 20, 31, 40].

Intraosseous implants used to fix dentures adds to the stability of orthopedic structures, promotes improvement of the temporomandibular function, activates metabolism in the surrounding tissues, ensures uniform load distribution on the prosthetic bed tissues and multiple occlusal contacts of artificial teeth in case of a complicated jaw ratio, thus allowing arriving at high functional and aesthetic results [3, 18, 27, 33, 39]. The main advantage of dental implantation is the maximum preservation of the alveolar bone. The stress and tension on the bone tissue lead to an increase in the bone trabeculation, which enhances its density, so there is no pronounced atrophy of the jaw bone tissue. The authors claim that, from the stance of recovering the lost functions, prevention of jaw atrophy and osteoporosis, as well as in view of social well-being, implantation can be considered one of the most acceptable rehabilitation ways for patients with complete adentia [5, 17, 21, 28, 35].

Despite the available research data on changes affecting masticatory muscle function in case of complete adentia, the data concerning the status of the motor and tonic activity in the masticatory muscles in case of employing various rehabilitation methods when dealing with patients featuring complete loss of teeth, remains incomplete and lacks systematic arrangement.

Aim of study:

to evaluate the effectiveness of fixed and conditionally removable prosthetics based on the analysis of the functional activity in the masticatory muscles and the occlusion balance in patients with complete adentia.

MATERIALS AND METHODS

The study involved 11 patients (4 males, 7 females; median age — 56.2±4.3) with complete adentia, whose orthopedic rehabilitation relied on bridge-shaped metal-ceramic prostheses with cement fixation (Group 1; n = 2) and conditionally removable prostheses with beam fixation (Group 2; n = 9). The exclusion criteria were hemorheological, mental, oncological diseases, as well as general somatic diseases in their decompensation stage. The patients had titanium screw implants installed: Touareg (ADIN Dental implant systems Ltd, Israel) — 3 patients, 30 implants; SPI (Alpha-Bio.Tec. Ltd, Israel) — 8 patients, 70 implants. The installation of intraosseous dental implants was performed subject to the traditional two-stage technique with delayed loading. In the first week following the surgery, a provision structure was made. 3–6 months after the surgery and the end of implant engraftment, there were abutments attached to them. After the gum contour was shaped, with full-fledged osteointegration (objective stability of implants following the Periodest method — 3.7 ± 1.6) and upon checking the correctness of the central point's location and the axes of implants, patients with complete adentia underwent clinical and laboratory stages required to manufacture dental prosthetic structures. The final load, therefore, was applied 3–6 months after the plantation.

Two patients of Group 1 had bridge-shaped metal-ceramic prostheses made for them with cement fixation supported by 8 implants for the upper jaw, and 6 implants — for the lower jaw (Fig. 1).

The 9 patients of Group 2, following the All-on-4 implantation surgical protocol (Palo Malo), had four implants installed in the following positions: two implants were installed in the bulk of the available bone tissue in the frontal part of the jaw, with another two implants installed more distally at an angle of up to 45°, not affecting the maxillary sinus inner wall in the upper jaw, the mandibular canal and the mental opening in the lower jaw (sinus lifting and lateralization of the mandibular nerve are excluded). The primary stabilization of the implants through the surgery was 30–35 N/cm^2, which allowed having direct loading on the implants. Subject to the All-on-4 implantation protocol, the sutures were removed on the 10th day following the surgery. The beams were made by milling by CAD/CAM (Fig. 2).

The study of the masticatory muscles functional status was carried out through the bioelectric activity of the proper masticatory muscles and the anterior part of the temporal ones were recorded simultaneously on both sides during the functional state of rest of the lower jaw as well as during a chewing test (0.8g of almonds). The electromyograms were evaluated by the shape, amplitude and duration of the bioelectric activity phases corresponding to muscle contraction. The analysis of the bioelectric activity and bioelec-

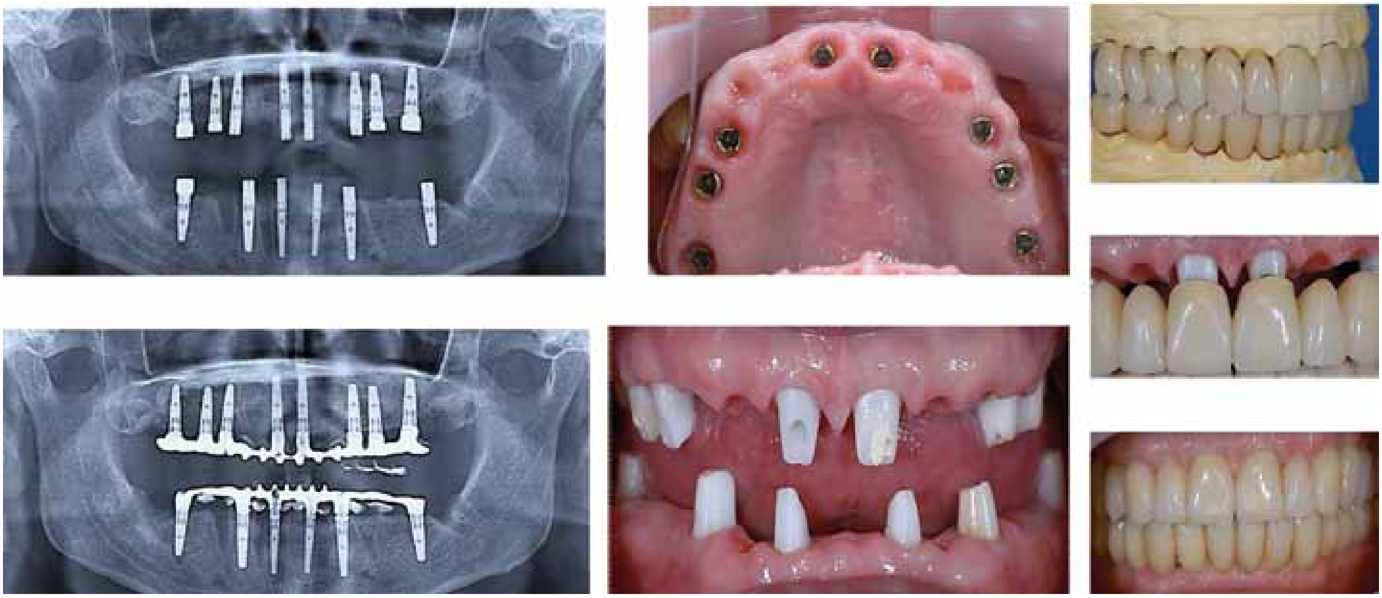

Fig. 1. Installed (a) and osteointegrated (b, c) dental implants on the upper and lower jaws; individual full-ceramic Procera abutments on dental implants (d); metal-ceramic structures in the articulator (e) and in the oral cavity (f, g)

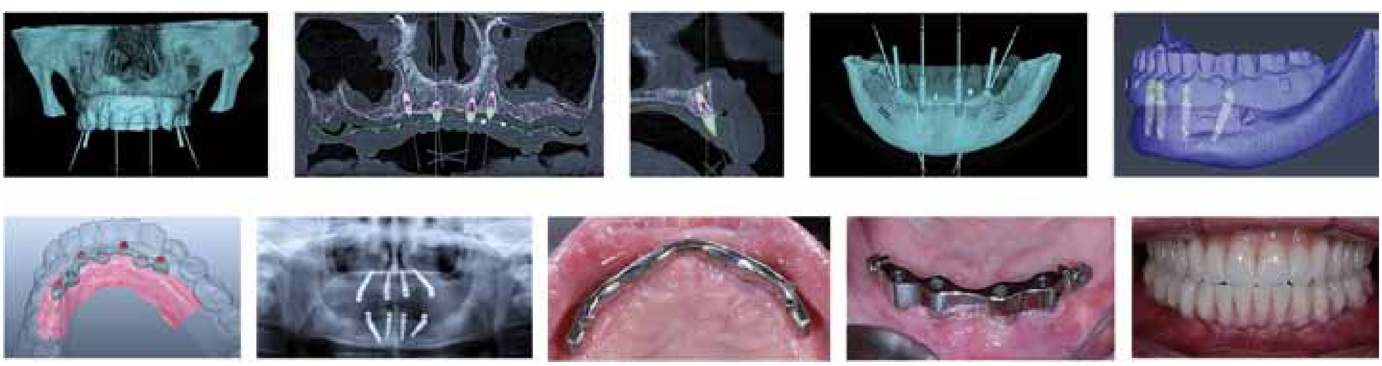

Fig. 2. Planning of dental implantation in the frontal part of the upper and lower jaw (a–f); osteointegrated (g) dental implants on the upper and lower jaws; installed beam structures on dental implants on the upper (h) and lower (i) jaws; conditionally removable dentures in the oral cavity (k)

tric rest duration offers an idea of the excitation and torsion process, as well as of the muscle endurance. Matching of electromyograms of the muscles on the right and left sides allows identifying the side of chewing, its type, and the coordination of the muscles of both sides. When processing electromyograms, the following was detected: A_{ch} — the average amplitude of biopotentials in the phase of bioelectric activity of the muscles through chewing the nuts (microvolts); A_{avch} — the average amplitude of biopotentials in the phase of bioelectric activity of the muscles during the maximal jaw compression (microvolts); T_a — the time of bioelectric activity of the muscles during excitation through the phase of one chewing movement (sec); T_r — the time of bioelectric muscle activity during rest in the phase of one chewing movement (sec); coefficient K ($K = T_a/T_r$); the time of one chewing movement ($T_a + T_r$) (sec).

Occlusion analysis was done employing the T-scan III system, which real-time-recorded the sequence of occlusal contacts, their localization, time, the portion of each tooth and the resulting strength of the total occlusal load. In each record, there was detection made for the period of the first occlusal contact occurrence and its location, the presence or lack of contacts between all teeth, as well as the percentage distribution of the balance of forces between the left and right sides at the time of multiple occlusion.

To study the tone of the masticatory muscles (that of proper masticatory and temporal ones), a SZIRMA myotometer (METRIMPEX, Hungary) was used. The device is equipped with a scale calibrated in grams, and a probe with a contact pad. When immersing the probe in the motor point (the most convex part of the muscle), the moment the restrictive area touched the skin, the readings on the scale were taken using light indication. The measurements were taken both at resting (T_r) and at stressed (T_s) condition of the masticatory muscles. Myofunctional studies and T-scan studies were carried out on the day the fixation was applied, one month and six months following the installation of permanent prosthetic structures. The statistical analysis of the study outcomes was done with the Statistica 12.0 software (StatSoft Inc., USA).

RESULTS AND DISCUSSION

The results obtained through the electromyographic (EMG) studies of M. masseter and M. temporalis in Group 1 on the right (dexter, D) and on the left (sinister, S) featured no statistically meaningful differences, which allowed them to be combined (Table 1, 2).

The difference in electromyographic (EMG) studies of M. masseter and M. temporalis in Group 2 patients on the right (dexter, D) and on the left (sinister, S) featured no statistical differences, which allowed them to be combined (Table 3, 4).

Examining the results of the magnitude of the biopotentials average amplitude with the maximum reduction of M. masseter (D), M. masseter (S) and M. temporalis (D), M. temporalis (S) in the two groups, revealed that the values were most optimal one month after the introduction of dental prosthetic structures: Group 1 — 418.5 ± 35.1 µV and 377.4 ± 33.8 µV, respectively; Group 2 – 314.7 ± 26.8 µV and 284.4 ± 23.1 µV, respectively.

The maximum values of the biopotentials average amplitude of M. masseter (D), M. masseter (S), M. temporalis (D), and M. temporalis (S) during functional loading (0.8 g of nut chewing) in patients of both groups were observed six months after the application of prosthetic structures, namely, Group 1 – 363.3 ± 28.1 µV and 345.7 ± 24.8 µV, respectively; Group 2 – 279.4 ± 18.7 µV and 263.9 ± 17.8 µV, respectively.

The examination of the *excitation time* indicator in patients of both groups shows that the

Table 1. *Functional characteristics of M. masseter (D) and M. masseter (S), Group 1, (p>0.05)*

EMG indicators	Terms of examination		
	On the application day	1 month	6 months
Chewing amplitude, µV	209.2 ± 18.9	351.8 ± 27.6	363.3 ± 28.1
Maximum compression amplitude, µV	256.4 ± 21.3	418.5 ± 35.1	421.6 ± 34.7
Rest time Tr, sec	0.43 ± 0.02	0.37 ± 0.03	0.36 ± 0.02
Excitation time Ta, sec	0.48 ± 0.02	0.41 ± 0.03	0.39 ± 0.03
K =Ta/Tr	1.12 ± 0.03	1.11 ± 0.02	1.08 ± 0.02
Time of one chewing movement Ta + Tr, sec	0.91 ± 0.02	0.78 ± 0.03	0.75 ± 0.02

Table 2. *Functional characteristics of M. temporalis (D) and M. temporalis (S), Group 1, (p>0.05)*

EMG indicators	Terms of examination		
	On the application day	1 month	6 months
Chewing amplitude, µV	191.7 ± 17.6	339.2 ± 25.9	345.7 ± 24.8
Maximum compression amplitude, µV	239.1 ± 20.2	377.4 ± 33.8	375.8 ± 32.3
Rest time T_r, sec	0.35 ± 0.03	0.31 ± 0.02	0.29 ± 0.02
Excitation time T_a, sec	0.42 ± 0.03	0.35 ± 0.02	0.32 ± 0.03
$K = T_a/T_r$	1.20 ± 0.02	1.13 ± 0.03	1.10 ± 0.02
Time of one chewing movement $T_a + T_r$, sec	0.77 ± 0.03	0.66 ± 0.02	0.61 ± 0.02

***Table 3.** Functional characteristics of M. masseter (D) and M. masseter (S), Group 2, (p>0.05)*

EMG indicators	Terms of examination		
	On the application day	1 month	6 months
Chewing amplitude, µV	157.8 ± 17.4	268.3 ± 19.1	279.4 ± 18.7
Maximum compression amplitude, µV	194.1 ± 21.3	314.7 ± 26.8	318.8 ± 25.6
Rest time Tr, sec	0.49 ± 0.04	0.45 ± 0.02	0.43 ± 0.03
Excitation time Ta, sec	0.54 ± 0.03	0.46 ± 0.04	0.45 ± 0.02
K =Ta/Tr	1.10 ± 0.02	1.02 ± 0.03	1.05 ± 0.02
Time of one chewing movement Ta + Tr, sec	1.03 ± 0.03	0.91 ± 0.02	0.88 ± 0.03

***Table 4.** Functional characteristics of M. temporalis (D) and M. temporalis (S), Group 2, (p>0.05)*

EMG indicators	Terms of examination		
	On the application day	1 month	6 months
Chewing amplitude, µV	146.2 ± 16.3	257.9 ± 18.4	263.9 ± 17.8
Maximum compression amplitude, µV	181.6 ± 20.4	284.4 ± 23.1	282.5 ± 22.7
Rest time Tr, sec	0.43 ± 0.03	0.42 ± 0.02	0.38 ± 0.03
Excitation time Ta, sec	0.51 ± 0.02	0.43 ± 0.03	0.42 ± 0.02
K =Ta/Tr	1.19 ± 0.03	1.02 ± 0.02	1.11 ± 0.03
Time of one chewing movement Ta + Tr, sec	0.94 ± 0.02	0.85 ± 0.03	0.80 ± 0.02

maximum values were obtained on the day the dental structures were applied (Group 1 — 0.48 ± 0.02 sec and 0.42 ± 0.03 sec, respectively; Group 2 — 0.54 ± 0.03 sec and 0.51 ± 0.02 sec, respectively). The minimum parameters of the active period through one chewing movement the phase were identified six months following the introduction of the prostheses (Group 1 — 0.39 ± 0.03 sec and 0.32 ± 0.03 sec respectively; Group 2 — 0.45 ± 0.02 sec and 0.42 ± 0.02 sec, respectively).

Studying the *rest time* indicator allows stating that in both groups the maximum values were obtained on the day of applying the prosthetic structures (Group 1 — 0.43 ± 0.02 sec and 0.35 ± 0.03 sec, respectively; Group 2 — 0.49 ± 0.04 sec and 0.43 ± 0.03 sec, respectively). The lowest values of the passive period in one chewing movement phase were to be observed six months after the application of the prostheses (Group 1 — 0.36 ± 0.02 sec and 0.29 ± 0.02 sec, respectively; Group 2 patients — 0.43 ± 0.03 sec and 0.38 ± 0.03 sec, respectively), which points at a gradual proper recovery of the tone and bio-electrical activity in the muscle fibers after loading.

An analysis of the *K* coefficient revealed that on the day the dental structures were installed (Group 1 — 1.12 ± 0.03 and 1.20 ± 0.02, respectively; Group 2 — 1.10 ± 0.02 and 1.19 ± 0.03, respectively), its value was maximum, which is to be accounted for by a significant predominance of the bioelectric activity time over the bioelectric rest time and the initial phases of adjustment to the dental structures. Further on, the K coefficient value decreased following six months the installation of the dentures, reaching 1.08 ± 0.02 and 1.10 ± 0.02, respectively, in Group 1, and 1.05 ± 0.02 and 1.11 ± 0.03, respectively, in Group 2. The nearly full balance between the bioelectric excitation time and the bioelectric rest time six months after the prosthetic structures were installed, combined with a reduction in the one chewing movement time in both groups, means the completion of adjustment to new occlusal relationships after applying the prosthesis and the restructuring the masticatory muscles coordination ratios.

Qualitative assessment of the obtained electromyograms showed that in both groups, after the prosthetic structures were installed, the vibration amplification assumes some typical Spindle-shaped appearance, with clarity appearing in the rotation between biopotential impulses and rest periods, as well as there was some synchronicity and symmetry identified in the function of the examined muscles, with no chaotic bursts in biopotentials (Fig. 3).

Occlusiogram analysis in Groups 1 and 2 following the installation of the prosthetic structures showed that all cases featured occlusion issues: uneven distribution of occlusal load between the left and the

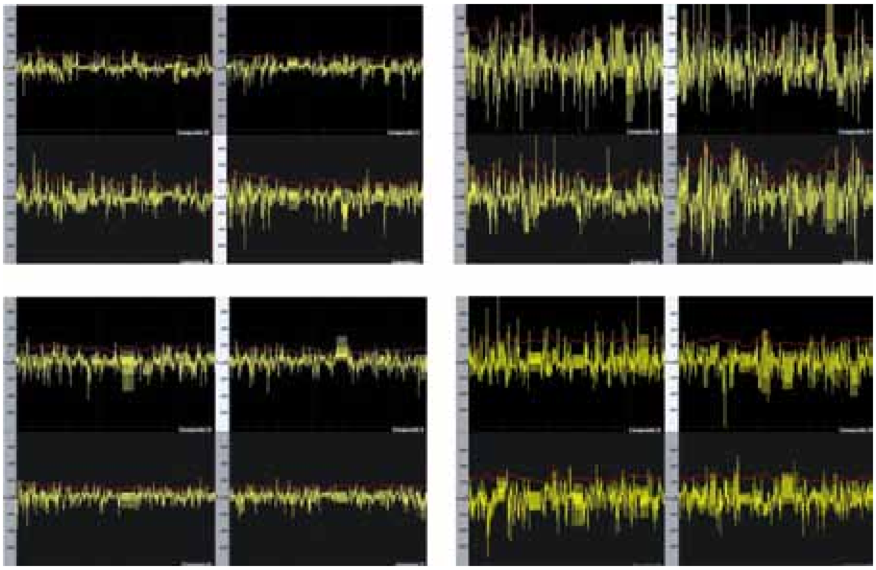

Fig. 3. Electromyograms of the biopotential dynamics in the M. temporalis and M. masseter performance at the stages of adjustment: on the day of the dentures were applied (a — Group 1, b — Group 2); 6 months after the dentures were applied (c — Group 1, d — Group 2)

right dentition sides; an increase in the time required to arrive at the maximum inter-tubercular contact (in Group 1 — up to 2.7 sec; in Group 2 — up to 4.3 sec); displaced total vector. As computer occlusiography (T-Scan device) showed, all patients (100%) of both groups were found to have: occlusive issues manifesting as premature contacts; supercontacts; displaced total vector of occlusive load; disturbed occlusion balance between the left and the right sides; unequal distribution of contacts over the area. We believe that the similarity of signs for the occlusion issues in the two groups developed due to lengthy lack of teeth and adaptive-compensatory restructuring of the maxillary system (Fig. 4).

6 months following the installation of dentures in Group 1, there was a more effective recovery of occlusive balance observed (50/50 balance was observed in 100% of patients), whereas in Group 2, a 50/50 balance was to be seen in 67% of cases (n=6). The time required to arrive at the maximum inter-tubercular contact decreased, reaching 0.23±0.01 sec in Group 1, and 1.02±0.01 sec — in Group 2. A recovered trajectory of the relative straightness of the occlusal load total vector was found in all the patients of Group1 and in 88% of the patients (n=8) in Group 2 (Fig. 5).

The dynamics of changes in the M. masseter (D, S) and M. temporalis (D, S) tone in Groups 1 and 2 can be seen in Table 5, 6.

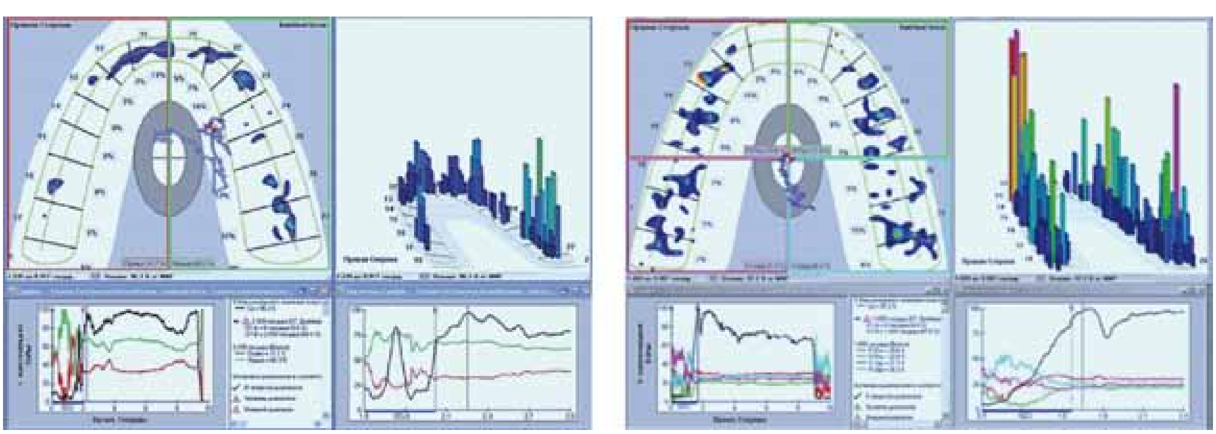

Fig. 4. Computer analysis of the occlusion following the fixation of dentures at maximum closure. Imbalanced occlusal load between the left and the right sides of the dentition (a — Group 1, b — Group 2)

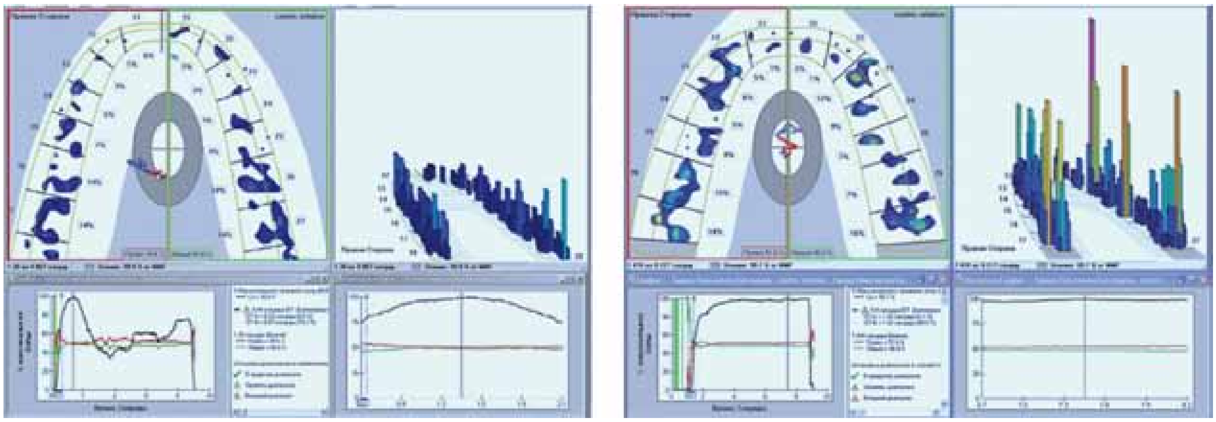

Fig. 5. *Computer analysis of occlusion following 6 months from the date the dentures were applied at maximum closure (a – Group 1, b – Group 2)*

Table 5. *Tone indicators for M. masseter (D, S) and M. temporalis (D, S), Group 1, (g), (p>0.05)*

Tone indicators	Terms of examination		
	On the application day	1 month	6 months
M. masseter (D, S)			
Resting tone, Tr	27.9 ± 7.4	47.8 ± 5.1	49.3 ± 5.6
Stress tone, Ts	81.6 ± 14.2	162.7 ± 10.6	167.3 ± 9.2
M. temporalis (D, S)			
Resting tone, Tr	30.4 ± 6.8	45.4 ± 5.9	48.1 ± 8.1
Stress tone, Ts	89.1 ± 8.4	150.2 ± 9.3	156.9 ± 9.7

Table 6. *Tone indicators for M. masseter (D, S) and M. temporalis (D, S), Group 2, (g), (p>0.05)*

Tone indicators	Terms of examination		
	On the application day	1 month	6 months
M. masseter (D, S)			
Resting tone, Tr	22.1 ± 7.7	37.2 ± 6.3	38.5 ± 5.1
Stress tone, Ts	64.2 ± 11.9	126.9 ± 8.8	129.4 ± 7.8
M. temporalis (D, S)			
Resting tone, Tr	24.5 ± 6.9	35.0 ± 6.6	36.9 ± 7.5
Stress tone, Ts	69.7 ± 7.2	114.9 ± 7.6	117.4 ± 9.1

The resting tone indicators for M. temporalis in patients of the groups exceeded the similar parameters of M. masseter, on average by 3.1 ± 0.6 grams, while the stress tine indicators of M. temporalis exceeded similar values of M. masseter, on average by 8.6 ± 4.7 grams through all the stages of functional status recovery in the chewing muscles in case of using prosthetics to treat patients with complete adentia.

The growth rates of masticatory muscle tone indicators by month 6 following the installation of prosthetic structures in Group 1 (M. masseter: resting tone — 76.7±5.4%, stress tone — 105.0±8.7%; M. temporalis: resting tone — 58.2±4.7%, stress tone — 76.1±7.3%) exceeded the increase dynamics in functional indicators of Group 2 (M. masseter: resting tone — 74.2±4.6%, tension tone — 101.6±7.9%; M. temporalis: resting tone — 50.6± 4.1%, tension tone — 68.4±5.9%).

The above shows that in almost all patients, within 3–6 months following the installation of fixed and conditionally removable dentures relying on intra-osseous implants, there was proper recovery observed in the masticatory and phonetic function. Besides, prevention of jaw atrophy and osteoporosis, improved functional adjustment to the dentures, all this should contribute to the patient's better overall health status and higher quality of life.

CONCLUSIONS

1. The results of our functional studies show that employing fixed and conditionally removable prosthetics relying on intraosseous implants in patients with complete adentia leads by the 6th month after installation of prosthetic structures to improved position of the lower jaw and optimal spatial ratio of TMJ elements. We also observed an improved functional status of the masticatory muscles due to improved bioelectric activity, elimination of occlusal imbalance, restored coordination between M. masseter (D, S) and M. temporalis (D, S).

2. Electromyography data, 6 months after the installation of the prostheses revealed symmetric involvement of the temporal and masticatory muscles observed in the jaws closing, which basically matched the conventional values typical of the normal indicators. The balance between the bioelectric excitation time and the bioelectric rest time in combination with a reduction in the one chewing movement time, as well as a significant decrease in the spontaneous activity of M. masseter (D, S) and M. temporalis (D, S) in both groups down to the upper limits of the normal values could be attributed to the emergence of uniform occlusive contacts in the position of central occlusion on the teeth of the right and left sides after prosthetic treatment. This is a tendency towards completion of the adjustment process and compensatory restructuring of the dental system in view of the new occlusive balance.

3. As computer occlusiograms and electromyograms show, higher indicators of the clinical and functional effectiveness of orthopedic treatment offered to patients with complete adentia, using fixed bridges relying on intraosseous implants, in contrast to prosthetics with conditionally removable dentures, are due to reduced time of the occlusal balance improvement (50/50); reduced time required to achieve maximum inter-tubercular contact (below 0.3 seconds); recovered trajectory of relative straightness of the occlusal load total vector; basically complete balance between the bioelectric excitation time and the bioelectric rest time after six months from the moment the prosthetic structures were installed, combined with a reduction in the one chewing movement time in both groups.

4. Electromyography, as a basic method for functional research, allows studying the coordination of the antagonist and synergist muscles operation prior to, and through, surgical treatment, while comparative electromyography helps identify the degree and the type of chewing in a particular clinical case. Electromyography results can serve as an objective indicator pointing at the masticatory muscles functional status, as well as at the effectiveness of orthopedic treatment.

5. Interdisciplinary studies should be part of the entire set of comprehensive diagnostics and examination administered to patients with complete adentia and seeking a complete reconstruction of the dentition. Such examination should include assessment of the musculoskeletal condition, neurological and psychological status, the patient's quality of life, as well as consultations of respective specialists.

6. The tone in the masticatory muscles does not increase in strict proportion to the developed force of masticatory contractions. The interdependence between the tone of the masticatory muscles and the compression force is subject to individual fluctuations, with no direct relationship between the increase rate in the masticatory muscle tone and the compression force.

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