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ORIGINAL ARTICLE

Adaptation to new complete dentures—is the neuromuscular system outcome-oriented or effort-oriented?

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Abstract

Objective The aim of this study was to observe the adaptation strategy of the stomatognathic system during the adaptation of complete dentures, comprising masticatory parameters and subjective measures. Our hypothesis was that with new dentures, masticatory performance would increase while the effort of the system is kept constant.

Material and methods Thirty-two patients received standardized new complete dentures. Masticatory performance tests were conducted with old dentures (T1), immediately after incorporation of new dentures (T2) and after an adaptation period of 3 months (T3). Patients habitually chewed the silicone-based artificial test food Optocal. The comminuted test food was analyzed and mean particle sizes (x_{50}) were calculated. Simultaneously, surface EMGs of the anterior temporalis and masseter muscles were recorded. Specific (SMW) and total muscle work (TMW) were determined. Patients filled in the OHIP-49 questionnaire. Test conditions were compared using repeated-measures ANOVA with SPSS 22 (SPSS Inc.)

Results Masticatory performance increased ($P = 0.016$) between old ($x_{50} = 4.99 \pm 0.28$) and adapted new dentures ($x_{50} = 4.80 \pm 0.33$). TMW deteriorated ($P = 0.004$) at T2 (from $TMW_1 = 119.77 \pm 56.49$ to $TMW_2 = 92.12$ 46.27), and increased again ($P = 0.028$) at T3 ($TMW_3 = 107.66 \pm 44.65$). OHIP scores decreased significantly in all subscales ($P < 0.001 \ldots P = 0.046$); the total score was reduced ($P < 0.001$) from 56.24 ± 29.05 (T1) to 34.66 ± 24.74 (T3).

Conclusion In complete denture wearers, masticatory performance improves over an adaptation period. Muscle work initially decreased before reaching its original level again after adaptation. Subjective parameters overestimated the functional improvements.

Clinical significance The subjective evaluation does not adequately reflect functional improvements. The assessment of function requires an adaptation period.

Keywords Complete denture · Adaptation · Masticatory performance · EMG · Masseter · OHIP

Introduction

Masticatory function has been thoroughly studied for several decades among different groups of patients, the main focus being on complete dentures. Although attention has shifted toward implant-supported overdentures as a therapeutic option for edentulous patients [1], functional aspects of complete dentures remain unresolved. Investigations on treatment options of the edentulous patient may be biased concerning two major aspects.

Firstly, many studies comparing prosthodontic rehabilitations refer to patient-based subjective variables as the oral health impact profile (OHIP) [2], although it is known that self-assessment does not correspond well with denture quality [3–5] and most patients with complete dentures are satisfied with their oral and masticatory function [6–8]. Studies on objective functional variables, for example, masticatory performance, masticatory efficiency, and electromyographic data, lead to a different conclusion: a substantial reduction of maximum bite force [9–12] and masticatory performance [13, 14] compared to dentate patients. Masticatory efficiency

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decreased sevenfold in complete denture wearers as opposed to dentate individuals [13]. Renewal of complete dentures did not necessarily have an immediate effect on masticatory function [15–17].

Secondly, emphasis should be placed on the effect of an adaptation period, whereas some authors have observed substantial improvement of masticatory performance with new complete dentures after periods of 1 month [16], 3 months [3], or up to a year [18, 19]; others observed no change at all [20] or even deterioration [10]. With respect to the testing methodology, the adaptation seemed to affect masticatory performance to a greater degree than masticatory efficiency. This may reflect a physiological mechanism. As chewing frequency is regulated by a central pattern generator [21], deterioration of masticatory performance could be compensated by prolonged chewing time [22, 23]—however, studies show that it is usually compensated by swallowing larger particles [9, 24], as long as a cohesive bolus can be formed [25].

Other measures like electromyographic (EMG) data from jaw-closing muscles may complement our understanding of the adaptation mechanisms. Most studies focused on either EMG [3, 12, 26] or masticatory performance, but did not combine both. Consequently, functional benefits of a denture in reducing muscle effort may be overlooked when masticatory performance remains constant or, more worrying, insufficient fragmentation of food is masked by constant muscle activity. As alteration of food choice in edentulism may lead to a severe lack of nutrients and predispose to adverse conditions as deficiencies in wound healing, cardiac diseases, arthritis, diabetes, etc. [27, 28], the need for appropriate measures of functional outcomes is emphasized.

We argue that both the choice of several objectives in addition to subjective functional parameters as well as the consideration of an adaptation period is crucial for the clinical decision-making of the dental practitioner in optimizing the treatment of edentulous patients. As systematic studies integrating both these factors are lacking, the aim of our investigation was to describe masticatory performance, EMG parameters, and subjective parameters during the adaptation period of complete dentures. The reaction of the stomatognathic system to experimental impairments of the occlusal surface in dentate patients consists in diminished masticatory performance, while total muscle work remained unchanged, suggests that effort is kept constant at the expense of masticatory performance [29, 30].

The primary purpose of this study was to test whether similar observations hold for complete denture wearers. Our hypothesis was that during adaptation to new complete dentures, muscle work will largely be kept constant, while masticatory performance increases. In addition, we wanted to reveal, whether the self-reported improvement of the treatment corresponds with the investigated functional parameters.

Material and methods

Subjects

Thirty-two edentulous patients dissatisfied with mandibular complete dentures at least 2 years old and seeking implant treatment of the lower jaw participated in a randomized clinical trial [31] in the Department of Prosthodontics of the Heidelberg University Clinic.

Inclusion criteria were an edentulous mandible with a positive ridge and informed consent to participation. Exclusion criteria were drug or alcohol abuse, inadequate vertical or horizontal bone dimensions, and intravenous bisphosphonates in the last 10 years.

All patients were informed about the treatment and the experimental study protocol and signed a consent document. The study was approved by the ethics committee of the Medical Faculty of the University of Heidelberg (S-208/2010).

Study protocol

Each patient was examined three times for the purpose of this study: (1) at baseline, wearing their old dentures (T1); (2) immediately after incorporation of a newly fabricated pair of complete dentures and removal of pressure points (T2); (3) after an adaptation period of 3 months (T3). The examination comprised assessment of masticatory performance and simultaneous bilateral surface EMG recording of the masseter and anterior temporalis muscles.

Fabrication of new dentures

To achieve maximum standardization, clinical procedures during denture treatment were conducted by two specialized prosthodontists. All dentures were manufactured by two designated dental technicians in the same dental laboratory. Centric jaw relation was determined by the dentists, and bilateral balanced occlusion was established. The occlusal profile was full anatomic tooth shape (Premium 8 Posteriors; Heraeus Kulzer GmbH, Hanau, Germany).

Masticatory performance

Masticatory performance was measured by use of a validated procedure reported elsewhere [32]. Patients were seated in a dental chair in an upright position and were instructed to comminute a portion of standardized artificial test food as if they were habitually chewing.

The artificial test food Optocal Plus [33] was used in portions of 17 cubes with an edge length of 5.6 mm (~3.5 g). Patients performed 15 chewing strokes in their habitual manner with the investigator silently counting the frequency adopted and abruptly stopping the chewing at the predefined chewing stroke. The chewed particles were collected in a labeled coffee filter (1 × 4; Melitta Bentz GmbH & Co. KG, Minden, Germany). The patients rinsed their mouth with approximately 100 ml water and spat the remaining particles into the filter. After the masticatory performance test, patients were asked which side they had just preferred during chewing (right, left, or none). The air-dried samples were disinfected with absolute alcohol on the same filter and then processed by use of an optical scanning method. The method [32] yields a particle size distribution which is equivalent to that obtained by use of the stacked-sieve method (10 sieves) and reports median particle size, x_{50}. Median particle sizes were determined for every chewed sample.

Electromyography

For EMG recording, Ag/AgCl bipolar surface electrodes (conducting surface diameter 14 mm, distance from center to center of the two electrodes 20 mm; Noraxon Dual Electrodes; Noraxon, Scottsdale, USA) were applied to the masseter and anterior temporalis muscles. The center of the muscle bulk was located by palpation and the electrodes were placed parallel to the longitudinal axis of the muscle. The skin had previously been carefully cleaned with 70% ethanol. A single surface electrode placed over the seventh vertebra served as the common electrode. The EMG signals were differentially amplified, recorded at a sampling rate of 900 Hz, saved, and analyzed on a personal computer with appropriate software (WinJaw Software; Zebris, Isny, Germany). EMG was recorded during maximum voluntary clench (MVC) on cotton rolls and during chewing. The raw EMG data obtained from the four muscles were rectified by use of the root mean square (RMS) algorithm, and MVC on cotton rolls was used as reference for normalization of the RMS. The individual masticatory cycles were identified by use of semiautomatic software developed in-house [34] which also computed the area under the curve (integral) for each muscle as a measure of specific muscle work (SMW). Total muscle work (TMW) was summed over all the muscles investigated.

Subjective data

Oral health-related quality of life was assessed by use of the Oral Health Impact Profile (OHIP-49), which was completed at T1 and T3. The German Version contains four additional questions not included in the English original. It furnishes, on a five-point Likert scale (0–4), the sum of items representing the extent of impairment. Seven subscales cover different areas of perceived oral health.

Statistics

The variables x_{50}, SMW, and TMW were tested for normality by use of the Kolmogorov–Smirnov test, then compared among the different test conditions by one-way repeated-measures analysis of variance (RM ANOVA) with the level of significance set at $P \leq 0.5$. Post-hoc comparisons were performed by use of paired t tests with the Bonferroni adjustment for multiple comparisons. Differences between SMW for the homonymous muscles under the three test conditions were analyzed by two-way repeated-measures ANOVA and post-hoc pairwise comparisons (Bonferroni). All procedures were conducted with SPSS 18.0 (SPSS Inc., Chicago, USA). Differences between OHIP scores were determined by use of paired t tests.

Results

Patients

Patients were between 53 and 93 years old (mean: 74.63 ± 6.33 years).

Masticatory performance

Median particle size was 4.99 mm at baseline and decreased to 4.88 mm on insertion of the new complete dentures and to 4.80 mm after an adaptation period of 3 months. There was a statistically significant difference between particle sizes for old dentures (T1) and adapted new dentures (T3; $P = 0.016$), but not between T1 and T2 ($P = 0.739$) or T2 and T3 ($P = 1.0$). The results are summarized in Table 1 and Fig. 1.

The gain of masticatory performance after 3 months of adaptation to the new complete dentures was greater for patients with initially worse masticatory performance (Fig. 2).

EMG

The normalized RMS during chewing decreased after insertion of new dentures but returned to the original level after adaptation. Changes were not statistically significant (Table 1).

Similarly, total muscle work decreased immediately on insertion of new dentures, and after the adaptation period increased again. Both these changes were statistically significant ($P < 0.05$) (Table 1, Fig. 3). The pattern of the specific muscle work of all the masticatory muscles was similar; this was significant for the left masseter muscle and the left anterior temporalis muscle only (Table 1, Fig. 3).

Table 1 Descriptive statistics differences, with statistical significance (*P* value), for the three test sessions T1 (mastication with old complete dentures), T2 (mastication with new complete dentures immediately after insertion), and T3 (mastication with new complete dentures after 3-month adaptation period)

	T1		T2		T3		T1–T2		T2–T3		T1–T3	
	Mean	SD	Mean	SD	Mean	Δ*x*	*P* value	Δ*x*	*P* value	Δ*x*	*P* value	SD
x_{50} [mm]	4.99	0.28	4.88	0.53	4.80	0.11	0.739	0.085	1.0	0.19	0.016*	0.33
MVC RTA [%]	0.64	0.13	0.59	0.17	0.65	0.05	0.554	− 0.06	0.294	− 0.01	1.0	0.12
MVC LTA [%]	0.62	0.19	0.56	0.19	0.65	0.06	0.150	− 0.09	0.106	− 0.03	1.0	0.14
MVC RMAS [%]	0.63	0.13	0.62	0.15	0.64	0.01	1.0	− 0.02	1.0	− 0.01	1.0	0.12
MCV LMAS [%]	0.63	0.12	0.60	0.14	0.65	0.03	0.400	− 0.05	0.280	− 0.02	1.0	0.12
SMW RTA [μV]	30.64	16.84	24.87	17.54	28.19	5.76	0.202	− 3.32	0.901	2.44	1.0	15.23
SMW LTA [μV]	26.40	12.30	19.58	9.89	24.58	6.82	0.003*	− 5.0	0.193	1.82	1.0	13.18
SMW RMAS [μV]	32.79	19.19	26.85	17.54	26.72	5.93	0.043	0.13	1.0	6.07	0.18	14.55
SMW LMAS [μV]	29.95	19.24	20.81	12.46	28.16	9.14	0.018*	− 7.35	0.009*	1.78	1.0	15.07
TMW [μV]	119.77	56.49	92.12	46.27	107.66	27.65	0.004*	− 15.54	0.028*	12.11	0.47	44.65

Mean values and standard deviation (SD) of median particle size (x_{50}) and the EMG results specific muscle work (SMW) of the right/left temporalis anterior (RTA/LTA) and right/left masseter (RMAS/LMAS) muscles, and total muscle work (TMW)

*Significant at $P \leq 0.05$

Combined effects

While masticatory performance is initially (T2) not significantly changed, TMW drops to ~ 80% of the original value with old dentures. After adaptation (T3), x_{50} is significantly reduced (masticatory performance increased) and TMW increases to ~ 90% of the original value. This signifies pre-adaptation constant performance with less muscular effort and post-adaptation increased performance with slightly less than the effort before denture renewal.

There was a trend toward changing of the preferred chewing side from the right with old dentures to the left after adaptation of the new dentures. These changes were not statistically significant.

Subjective data

Perceived oral health-related quality of life was significantly improved in all domains of the OHIP for adapted new complete dentures in comparison with old complete dentures (Table 2).

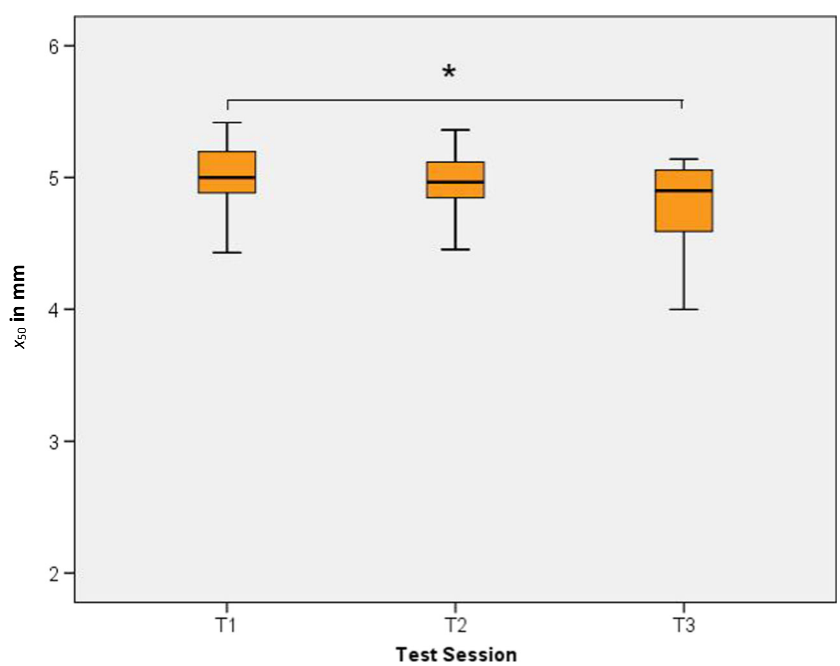

Fig. 1 Median particle size x_{50} over the three test sessions T1 (mastication with old complete dentures), T2 (mastication with new complete dentures immediately after insertion), and T3 (mastication with new complete dentures after 3-month adaptation period)

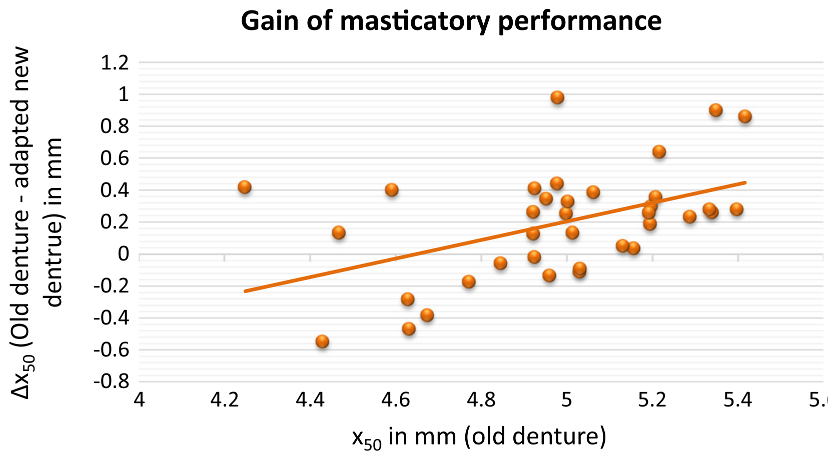

Fig. 2 Intra-individual difference between median particle size during mastication with old complete dentures and mastication with adapted new complete dentures, relative to masticatory performance before denture renewal. Δx_{50} = difference between the x_{50} values described

Discussion

The results of this study confirm the initially stated hypothesis only partially. After installation of new dentures, masticatory muscle activity reaches approximately the original level (at T1) after an adaptation period of 3 months (at T3), but masticatory performance increases by a small amount. In contrast, muscle activity decreases immediately after incorporation (at T2), whereas the performance is kept largely constant. It is obvious that the improvement of performance is only shown after the period of adaptation has passed. In agreement with previous studies, it has also been shown that self-reported therapeutic improvement does not correspond with the functional performance. However, the correlation between objective and subjective parameters was not statistically analyzed in our study.

The median particle sizes measured in this study are within the ranges reported by other authors for edentulous patients with complete dentures (CD) (5.3 ± 0.7 mm [35], 4.63 ± 0.67 mm [36], and 4.5–5.5 mm [9]). Differences between median particle size at the different times (T1, T2, and T3) are small and of unknown clinical relevance, regarding their nutritional meaning. They do, however, give insight into the motor behavior of the masticatory system during the period of

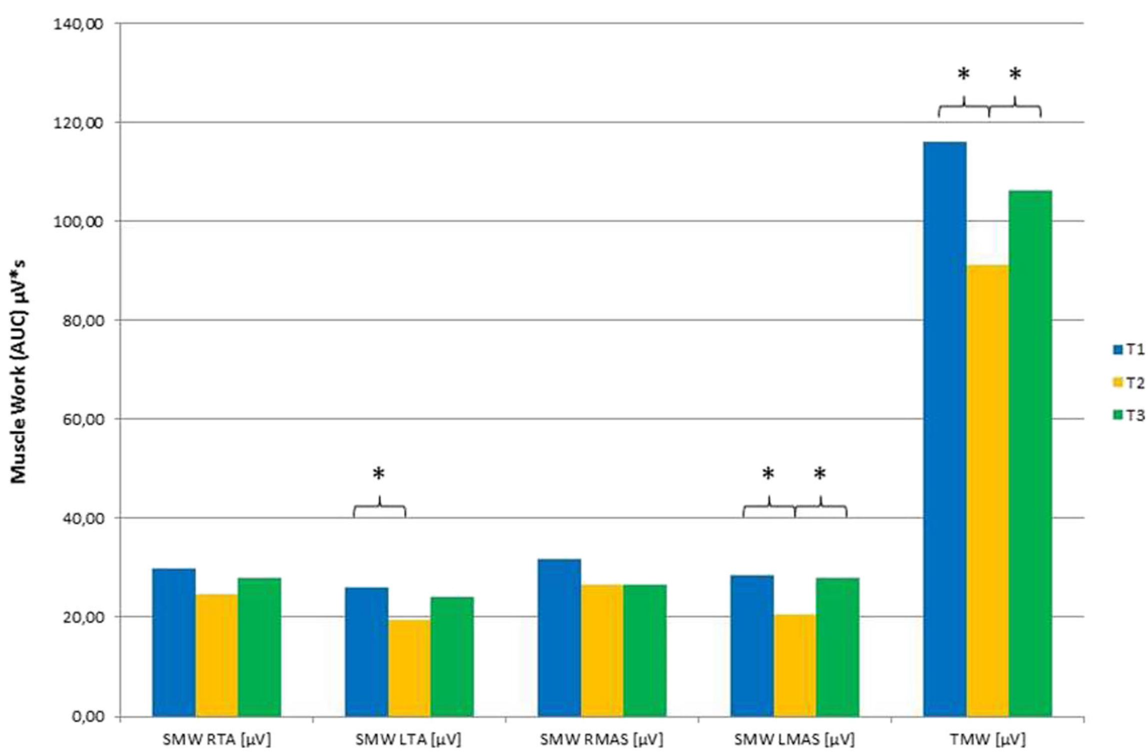

Fig. 3 Specific muscle work [µV × s] of the right and left anterior temporalis and masseter muscles over the three test sessions T1 (mastication with old complete dentures), T2 (mastication with new complete dentures immediately after insertion), and T3 (mastication with new complete dentures after 3-month adaptation period)

Table 2 Subscale scores and total score of the oral health impact profile (OHIP) for old dentures (T1) and after adaptation to new dentures (T3)

	T1		T3		*P*
	Mean	SD	Mean	SD	
Functional limitation	11.86	4.41	7.17	4.30	< 0.001*
Physical pain	11.14	5.87	7.34	5.03	< 0.001*
Psychological discomfort	6.45	5.46	2.90	3.27	< 0.001*
Physical disability	10.79	6.25	7.31	6.26	0.005*
Psychological disability	5.21	4.37	3.07	3.59	0.011*
Social disability	2.90	2.83	1.86	2.50	0.046*
Handicap	3.72	3.46	2.03	2.60	0.018*
Additional items**	4.17	3.03	2.97	2.34	0.051
OHIP total score	56.24	29.05	34.66	24.74	< 0.001*

*Significant at $P \leq 0.05$

**Four items included in the German version of the OHIP but not in the English original

adaptation to new dentures. The underlying mechanisms of these adaptation effects may be both re-programming of the neuromuscular system and the increased quality of the new dentures, in particular, better occlusal profile, absence of balancing interferences [37], increased stability [38], and denture comfort.

Similar immediate responses to occlusal modification have been observed for fully dentate individuals [29, 30]. There are indications that the reaction of the stomatognathic system of CD patients to the new stimulus may differ from that of patients receiving fixed dental prostheses, because the neuroplasticity patterns made visible in an fMRI study varied substantially [39]. Studies on adaptation to total dentures based on objective data are scarce. It has been reported that the regularity and frequency of masticatory strokes, as assessed by use of EMG data, increased on insertion of new complete dentures, an effect that became obvious after 1 week and was even more pronounced after up to 59 days of adaptation [40]. Another study [20] on complete denture adaptation over a period of 6 months seems to contradict our results, because it revealed a generally negligible improvement of masticatory performance. This work was not comparable with ours, however, because it studied a heterogeneous group of subjects, including patients with natural dentition which was replaced with complete dentures. Masticatory performance was, moreover, assessed by a single-sieve method, which is not appropriate for detecting small differences and is, rather, best regarded as a screening method [41]. Remarkably, patients with an initially bad masticatory performance seemed to profit most from renewal of complete dentures, although there was much variance. The fact that all patients in our study were seeking implant treatment because of perceived functional deficits may present a bias toward a greater gain of performance. A previous study, which also used the one-sieve-method, suggested that the difference between poor and superior performers was connected with lower maximum bite forces and poorer retention of the mandibular denture [42]. Given our small sample size, subgroup analysis of good and bad performers would not have been appropriate. A weakness of our study is the lack of bite force measurements and no systematic determination of denture quality (retention, relief, and contact area).

The quality of the dentures may contribute to the observed effects on at least two levels. It has been shown for dentate subjects [30] and for complete denture wearers [43] that tooth relief has an effect on masticatory performance. The evidence is not very strong, however, because it was obtained by use of a subjective criterion [44] or a very small number of individuals [43]. The dentures in our study were manufactured by the same dental technician, using the same type of denture teeth in bilateral balanced occlusion. Nevertheless, small variations are possible, which is a limitation of our study. Comparison of the occlusal relief of old and new dentures was not objectively studied to correct for this potential confounder.

Likewise, the denture base seems to have a positive effect on masticatory performance, as has been demonstrated by denture relining [45]. This pilot study revealed positive effects on masticatory performance, maximum bite force, and chewing time of relining a complete mandibular denture with a soft liner. Similar denture design in our study was ensured by standardized fabrication by a single dental technician.

In addition to these considerations, our study shows that adaptation time [3] is of crucial importance in attempts to detect differences between masticatory performances. This is especially relevant when designing studies to show the effectiveness of a new treatment option, for instance different kinds of implant-supported overdenture. Many studies do not specify whether the complete dentures were already fully adapted when masticatory performance tests were conducted [9, 10, 46]; this might lead to misinterpretation of the long-term functional benefit of implants for denture stabilization.

Mean EMG activity during our chewing test was in the same range as that observed by other authors [18, 47]. The findings of our study that muscle activity was reduced after initial incorporation of new complete dentures are in agreement with other work [3, 48, 49]. Piancino et al. observed a similar effect, although they did not normalize EMG activity and did not consider muscle work [48]. Maximum bite force can be expected to decrease upon insertion of new complete dentures according to a pilot study by Müller et al. [49], this trend being more pronounced in individuals with severe alveolar ridge resorption. After an adaptation phase of 1 month, the bite force recovers in dependence of bone resorption [49]. These observations confirm the pattern of EMG activity in our study, muscle activity being considered a surrogate measure for bite force within certain limitations [50]. Study of the changes in the electromyographic activity of the masticatory muscles enables more complete understanding of the adaptation mechanism. Total muscle work obviously decreases substantially on insertion of new dentures, whereas masticatory performance remains approximately the same as with the old dentures. This apparent increase in efficiency at T2 might be explained by patients' conscious awareness of the new oral condition, which triggered rather a simple biting behavior than a chewing cycle. It is well known that biting and chewing with comparable force vectors evoke less electric muscle activity during biting [50].

The improvement of subjective oral health-related quality of life is confirmed by other studies, which reveal significant differences after one [51], three [52, 53], or 6 months [54, 55]. Relining of dentures also resulted in a significant improvement [56]. The mean values for all domains of the OHIP were comparatively low [57, 58], given that all the participants in this study were seeking treatment because of dissatisfaction with their dentures and were scheduled for implant-supported mandibular overdentures. However, it is described in the literature that age-matched edentulous patients receiving implant overdentures showed lower pre-treatment scores than those awaiting complete dentures [57]. In our study, however, the OHIP summary score was higher than that for a representative sample of the institutionalized elderly in Germany [59]. Among denture-related effects on OHIP scores, denture retention has been shown to be of major importance [58, 59]. Subjective measurements tend to overestimate objective gain in function, because psychological factors are involved [5, 60].

Conclusion

We may conclude that the stomatognathic system adapts to new dentures by keeping muscle work at the same level; this, because of improvement of the restoration, results in better masticatory performance. For better understanding of the physiological mechanisms, functional data and systematic assessment of denture quality should be taken into account.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study was approved by the ethics committee of the Medical Faculty of the University of Heidelberg (S-208/2010).

Informed consent Informed consent was obtained from all individual participants included in the study.

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