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MULLER, Frauke, et al.

Abstract
Edentulous patients may be restored with conventional dentures (C/C), implant-supported overdentures (IOD) or implant-supported fixed dental prostheses (IFDP). Null-hypotheses: chewing efficiency, maximum voluntary bite force (MBF) and masseter muscle thickness (MMT) are lower in patients with C/IOD compared with the patients with bimaxillary IFDPs. Both groups perform better than C/C and are inferior to fully dentate controls.

Reference

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Key words: implant-supported fixed dental prostheses, implant-supported overdenture, masseter muscle thickness, masticatory efficiency, maximum voluntary bite force, ultrasound

Abstract

Objectives: Edentulous patients may be restored with conventional dentures (C/C), implant-supported overdentures (IOD) or implant-supported fixed dental prostheses (IFDP). Null-hypotheses: chewing efficiency, maximum voluntary bite force (MBF) and masseter muscle thickness (MMT) are lower in patients with IOD compared with the patients with bimaxillary IFDPs. Both groups perform better than C/C and are inferior to fully dentate controls.

Material and methods: Ethical approval was obtained. For this multicenter cross-sectional study, 80 patients were recruited. Four groups of different dental states comprised of either implant-supported prostheses (C/IOD and IFDP/IFDP) or served as control-groups (C/C and fully dentate D/D). Chewing efficiency was assessed with a two-colour mixing ability test. MBF was measured bilaterally with a force gauge. Two dimensional ultrasonography was used to measure MMT bilaterally.

Results: Chewing efficiency in IOD and IFDP/IFDP (difference NS) was better than in C/C, but not as good as in D/D. MBF in IOD was lower than in IFDP/IFDP. Chewing efficiency and MBF were significantly lower in IFDP/IFDP, who had experienced chipping or fracture of the prosthetic superstructure. Median MMT of patients with implant-supported prostheses was between those with C/C and fully dentate participants. There was no significant difference in MMT between C/IOD and IFDP/IFDP.

Conclusion: Supporting complete prostheses with oral implants seems to have positive effects on the thickness of the masseter muscle, maximum bite force as well as chewing efficiency. The type of implant-supported prostheses may have an influence on the magnitude of the effect.
These findings are particularly relevant for complete denture wearers who often compensate the lack of masticatory ability by changing to a softer diet (Millwood & Heath 2000). The observed atrophy of the muscle tissues in edentulous patients with conventional complete dentures may therefore be caused by a "de-training" effect.

Newton et al. (2004) have demonstrated that overdentures supported by natural roots seem to counteract atrophy of the jaw closing muscles. For implant-supported dental prostheses evidence on their effect on masticatory muscle atrophy remains scarce (Schimmel et al. 2010). Also, it remains unclear if IFDP provide better function and show a superior effect on the macroscopic structure of the jaw closing muscles than IOD (Feine et al. 1994b). Such findings would underline the preventive value of placing fixed implant-supported restorations rather than removable IODs.

The aim of the study was to test the hypotheses: Edentulous patients who were restored with maxillary complete dentures and mandibular IOD show lower masticatory efficiency (first $H_0$), lower maximum voluntary bite force (MBF) (second $H_0$) and reduced masseter muscle thickness (MMT) (third $H_0$) compared with patients with upper and lower IFDP.

Concerning these investigated parameters, both implant-borne reconstructions perform better than controls with conventional complete dentures (fourth $H_0$) and are inferior to volunteers with a natural dentition (fifth $H_0$).

Materials and methods

Approval was obtained from the ethics committees of the University Hospitals of Geneva, Switzerland (Ref.: 08-162/Psy 08-020) and the Medical Association of Baden-Württemberg, Germany (Ref.: 2009-084-f-z). Written informed consent was obtained before the experiments.

Subjects

For this multicenter cross-sectional study, 80 patients with similar age were recruited (four sites: two clinics, two private practices). Inclusion criteria comprised of edentulism and the provision of maxillary complete dentures and mandibular implant-supported overdentures (C/IOD), upper and lower implant-supported fixed dental prostheses (IFDP/IFDP) or conventional complete dentures (C/C, first control-group) at least 1 year before the experiments. Furthermore, participants were selected to be similar in gender, wearing period of the current prostheses and the time of edentulism. The second control-group (D/D) consisted of fully dentate participants. Exclusion criteria were history of neuromuscular disease, radiotherapy and clinically relevant TMJ dysfunction.

Chewing efficiency

Chewing efficiency was evaluated with a previously described two-colour mixing ability test (Schimmel et al. 2007). Commercially available chewing gum in azure and pink colour (The Wrigley Company Ltd, Plymouth, Devon, UK) served as test food. The specimen (30 × 18 × 3 mm) was placed on the tongue and the participant was asked to masticate the gum for 20 chewing cycles on his/her preferred chewing side. It was then retrieved from the oral cavity, placed into a transparent plastic bag and flattened to a 1-mm-thick wafer. The wafer was scanned with a flatbed scanner and the images subsequently copied into a template of fixed size. Using the "magic wand tool" and "histogram" function (Adobe Photoshop Elements 2.0, Adobe Systems Inc., San Jose, CA, USA) the total number of pixels of unmixed azure colour was evaluated and subsequently, the ratio of azure pixels to the total pixels of the original template was calculated (unmixed fraction [UF]).

UF shows characteristics of a logarithmic function (log$_{10}$) on the base of chewing cycles and will decrease for two reasons: a higher degree of colour mixture [lower ratio of unmixed azure] and a reduction in volume of the specimen due to sweeter extraction (Schimmel et al. 2007, 2011). Both are measures for chewing efficiency (Anastassiadou & Heath 2001; van der Bilt et al. 2010b); thus the smaller the UF, the higher is the individual chewing efficiency.

MBF

The Occlusal Force-Meter GM 10® (Nagano Keiki Co. Ltd, 1-30-4 Higashigumma, Ohta-ku, Tokyo, Japan) was utilized (Nakatsuka et al. 2006). It is a digital force gauge with an 8.6-mm-thick bite element. MBF was assessed bilaterally between the upper and lower first molar. The participant was asked to bite as hard as possible on the force gauge, but to stop clenching when she/he started feeling uncomfortable. The mean of six recordings (3 × right, 3 × left) was used for analysis. Furthermore, participants with IFDP/IFDP were asked if they had experienced a fracture of the framework and/or chipping of the veneering material since their prosthesis had been provided.

MMT

MMT was evaluated bilaterally with real time ultrasound scanners [FALCO 100 [PieMedical, Imaging BV, Maastricht, The Netherlands] or MyLab25 [Esaote, Genova, Italy]] and linear array transducers [6-8 or 4-13 MHz, respectively]. The two examiners [M. H., M. S.] had been calibrated by the experienced operator, who had developed the method (Kiliaridis & Kalebo 1991). The participants sat upright with no head support. The anterior border and subsequently the origin as well as insertion of the masseter muscle were palpated to locate the thickest part of the muscle as site for the measurement. To avoid compression of the muscle a generous amount of ultrasound contact gel was applied to the probe (Kendall Meditex, Mirandola (MO), Italy). The transducer was oriented perpendicular to the mandibular ramus to avoid oblique scanning, as this would result in artificially elevated readings (Fig. 1). The probe was then tilted until the reflection of the bone was depicted as a sharp white line. The thickest part of the muscle close to the occlusal plane level was measured [distance between ramus and fascia, resolution of 0.1 mm]. For MMT the mean of the four readings in contracted muscle condition (2 × right, 2 × left) was used for analysis. The error of the method ranged from 0.2 to 0.4 mm (Kiliaridis & Kalebo 1991; Botteron et al. 2009).

Statistical analysis

Categorical variables were compared using $\chi^2$-tests or Fisher's exact test. $A$ priori comparisons...
between C/IOD and IFDP/IFDP were performed using Mann–Whitney U-tests to assess the first, second and third H₀. Continuous data of all investigated groups of different dental state were then compared using Kruskal–Wallis tests to investigate the fourth and fifth H₀ post hoc tests were performed with adjusted P-values for multiple comparisons between groups (Siegel & Castellan 1988). Non-parametric 95% confidence intervals (95% CI) for the difference between medians of two groups C/IOD and IFDP/IFDP [point estimate of shift: \( \theta = \text{pop2} – \text{pop1} \)] was computed using the Hodges–Lehmann estimates of shift parameters. The level of significance for type 1 errors was set at \( \alpha < 0.05 \). Hypothetical sample size calculation was performed for type 2 errors with a power of \( 1 – \beta > 0.9 \) using G*Power 3.1 (Faul et al. 2009). All statistical tests were performed using Stata Statistical Software release 11 (Stata Corporation, College Station, TX, USA). Figures were drawn with StatView for Windows 5.0 (SAS Institute Inc., Carry, NC, USA).

### Results

#### Subjects

The four groups were not significantly different regarding gender (\( P = 0.85 \), Fisher’s exact test), time of edentulism (\( P = 0.557 \), Kruskal–Wallis) and wearing period of the present prostheses (\( P = 0.334 \), Kruskal–Wallis) (Table 1). All patients were satisfied with their prostheses to the degree that they did not actively seek dental treatment.

In the C/IOD-group all participants wore maxillary conventional complete dentures, six had mandibular IOD with bar-attachments on four implants, and further 14 presented with ball or Locator attachments on two implants. All IODs were placed on Straumann® implants (Basel, Switzerland). The IFDP/IFDP-group comprised one patient with 16 implants, 10 patients with 14 implants, six patients with 13 implants, one patient with 13 implants, one patient with 10 implants and one patient with eight implants. Seven patients presented with composite veneered bridges and further 13 had ceramic-fused metal prostheses. Of the 20 IFDP/IFDP patients, 13 were restored with single-unit prostheses, whereas seven patients presented with three to six unit restorations. Six patients had Nobel Biocare™ (Gothenburg, Sweden) and further 14 Straumann® implants.

#### Chewing efficiency

Chewing efficiency as evaluated with the two-colour mixing ability test was significantly different between the four groups (\( P = 0.0001 \), Kruskal–Wallis). The lowest chewing performance was found in the conventional complete denture control-group with the highest ratio of unmixed colour and the highest efficiency in the fully dentate control-group. The groups with implant-supported restorations showed median chewing efficiencies between the control-groups (Fig. 2). No difference was found between C/IOD and IFDP/IFDP (\( P = 0.339 \), Mann–Whitney). However, participants with maxillary complete dentures and mandibular implant-supported overdentures showed median MBF (with fracture: mean 176.4 \( \pm \) 112.57 N, without fracture: mean 363.6 \( \pm \) 249.85 N, \( P = 0.041 \), Mann–Whitney).

#### MBF

MBF was significantly different between groups (\( P = 0.0001 \), Kruskal–Wallis). The lowest forces were found in the C/C-group, the highest values were measured in the D/D-group. The participants, who were restored with C/IOD, showed significantly lower forces than those with IFDP/IFDP (\( P = 0.0002 \), Mann–Whitney, \( \theta = 118.165: 95\% \) CI for \( \theta : [70.33, 156.84] \)). The IFDP/IFDP-group showed a lower median MBF than the fully dentate control-group, however, this difference was not significant. The mean MBF in the C/C-group was only 69.7% of the mean MBF in the C/IOD-group, but again the difference was not significant (Fig. 4).

#### Fracture experience in IFDP/IFDP and its influence on UF and MBF

Of the 20 participants with IFDP/IFDP, 10 had experienced a chipping of the veneering material or fracture of the bridge framework of their prosthetic superstructure during time in function. The participants with such fracture occurrence showed a significantly lower chewing efficiency (with fracture: \( UF = \text{mean} 0.074 \pm 0.035 \), without fracture: \( UF = \text{mean} 0.03 \pm 0.02 \), \( P = 0.004 \), Mann–Whitney) as well as a significantly lower MBF (with fracture: mean 176.4 \( \pm \) 112.57 N, without fracture: mean 363.6 \( \pm \) 249.85 N, \( P = 0.041 \), Mann–Whitney).

### Table 1. Descriptive of the study population: maxillary complete dentures and mandibular implant-supported overdentures (C/IOD), bimaxillary implant-supported fixed dental prostheses (IFDP/IFDP), complete full dentures (C/C), fully dentate (D/D)

<table>
<thead>
<tr>
<th>N</th>
<th>C/IOD</th>
<th>IFDP/IFDP</th>
<th>C/C</th>
<th>D/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years ± SD)</td>
<td>68.1 ( \pm ) 4.6</td>
<td>61.5 ( \pm ) 8.3</td>
<td>68.2 ( \pm ) 6.2</td>
<td>66.4 ( \pm ) 8</td>
</tr>
<tr>
<td>Gender</td>
<td>9δ, 11γ</td>
<td>8δ, 12γ</td>
<td>6δ, 14γ</td>
<td>8δ, 12γ</td>
</tr>
<tr>
<td>Edentulous since (years ± SD)</td>
<td>7.3 ( \pm ) 5.9</td>
<td>7.6 ( \pm ) 6.5</td>
<td>9 ( \pm ) 11.2</td>
<td>NA</td>
</tr>
<tr>
<td>Prostheses in function (years ± SD)</td>
<td>4 ( \pm ) 2.6</td>
<td>3.89 ( \pm ) 2.1</td>
<td>3.3 ( \pm ) 3</td>
<td>NA</td>
</tr>
</tbody>
</table>

NA, not applicable.
significant difference (a to be attributed in order to demonstrate a significance of $\alpha = 0.05$). To each group C/IOD and IFDP/IFDP a Mann–Whitney test for first H0, all other P-values: Kruskall–Wallis for multiple comparisons between groups, adjusted P-value for significance: 0.004, each group with standard deviation below group descriptive.)

The thinnest masseter muscles were found in the C/C-group, the thickest muscles in the D/D-group. The results for MMT in the C/IOD-group were statistically not different from those in the IFDP/IFDP-group [P = 0.536, Mann–Whitney, θ = 0.3625002; 95% CI for θ: [-1.075, 1.925]]. To each group C/IOD and IFDP/IFDP a sample size of n = 271 (total n = 542) would have to be included in order to demonstrate a significant difference [$z = 0.05$, power = 0.9, $m_1 = 13.2875$, $m_2 = 13.9039$, $SD_1 = 2.07162$, $SD_2 = 2.14623$, $n_1/n_2 = 1$]. MMT in the two groups with implant-supported dental prostheses was higher than in the control-group of edentulous participants with conventional full dentures, notwithstanding this result was not significant when the P-value for significance was adjusted for multiple comparisons between the groups (Kruskal–Wallis, adjusted P = 0.004). Furthermore, MMT in the IFDP/IFDP-group were not significantly different from those in the fully dentate control-group (Fig. 5).

Discussion

The benefits of stabilizing complete dentures by means of oral implants are largely documented (Thomason et al. 2009). Fixed implant-supported dental prostheses seem to be a valid treatment option especially for younger patients, yet the clinical effort and cost are considerably higher (Feine et al. 1994a; Lambert et al. 2009). Little is known if fixed restorations offer superior functional and structural benefits to IOD (Brennan et al. 2010, Carlsson & Lindquist 1994).

Chewing efficiency

As expected, study participants with conventional full dentures showed the lowest chewing efficiency and fully dentate ones the highest. This result is intuitive and corresponds to evidence from the literature (Manly & Braley 1950; Ikebe et al. 2010). However, no difference between edentulous patients with C/IOD and IFDP/IFDP was found. Statistically this may be explained either by the absence of a difference or a lack of power of the current study. As post hoc power analyses are subject to controversial discussion (Thomas 1997) a hypothetical sample size calculation, to avoid type II errors on the basis of the current results, was performed. In each implant-group a sample size of 336 participants would have to be included to demonstrate a significant difference with a power of 90%. It can thus be concluded that, if there were a difference, it would be extremely small and of no clinical relevance. The first null-hypothesis must therefore be rejected. Chewing with removable prostheses may be limited by a displacement or loosening of the denture during unfavourable loading or food getting caught underneath the denture base. When the upper complete denture and the posterior parts of the lower denture are mucosa-born, chewing forces may be limited by pain from the denture bearing tissues. Removable denture wearers may further chew more cautiously, as they may be aware that the denture resin can fracture while chewing hard food-stuffs. However, the total occlusal surface area is significantly correlated with chewing efficiency (Bourdiol & Mioche 2000), and removable dentures frequently replace the second molars and restore the posterior denture teeth in their full oro-vestibular dimension. The total occlusal surface available for chewing may therefore be larger in C/IOD than in patients with fixed reconstructions. These opposed effects may have finally opposed these effects may have finally eliminated any differences in UF between C/IOD and IFDP/IFDP participants in the present study.

Reports in the literature on the masticatory efficiency of bimaxillary implant-supported prostheses are scarce. Carlsson and Lindquist com-
pared in a 10 year follow-up study patients with maxillary complete dentures/mandibular IFDP to those with bimaxillary IFDP. In their study, no difference in masticatory efficiency between those two groups was found which is in agreement with the results of the current study. Interestingly, the subjective perception of masticatory function was significantly higher in patients with bimaxillary IFDP, so that the gain for such treatment may mainly be psychological (Carlsson & Lindquist 1994).

MUF
Albeit a similar chewing efficiency, in the present study MUF was significantly lower in participants with C/IOD than with IFDP/IFDP. Both groups lack periodontal receptors in the surroundings of the dental implants and subsequently projections on the primary sensory and motor cortex (Abarca et al. 2006). But in contrast to the fixed restorations the C/IOD provide a close contact of the denature base with the underlying mucosa. Previous experiments with complete dentures showed, that a good retention of a lower denture and thus an intimate contact between the denture base and the denture bearing tissues allows for a higher inter-occlusal tactile sensitivity than in edentulous patients with poor lower denture retention (Müller et al. 1995). It is likely that the quantity and/or quality of stimuli to the mechanoreceptors in the mucosa account for this finding. The higher MUF in patients restored with IFDP/IFDP may therefore be related to a reduced peripheral input, which is necessary to tune muscle force during oral function. Haraldson (1983) reported that the reduction of muscle force during a chewing sequence along with the softening of the food bolus was less in patients with fixed implant-bridges than in dentate individuals. There seems to be unique activation patterns of the jaw closing muscles in patients with oral implants which implies a less graduated contraction of the jaw closing muscles if biting is performed on implant-supported prostheses (Gartner et al. 2000). In the current study, the fixed implant-supported dental restorations varied with regard to the number of implants and type of the superstructures used. This implies differences in the total implant–bone contact surface between the patients who might have influenced the inter-occlusal perception and consequently the fine motor control. If osseoperception is caused by vibration (Klineberg et al. 2005), the different damping characteristics of the veneering materials (ceramic/composite) would have influenced the results.

Although the current study MUF in patients with C/IOD proved higher than patients with conventional full dentures, the difference was not significant which contrasts with previous findings reported in the literature (van der Bilt et al. 2010a). This result may be related to the applied measuring technique as MUF was assessed uni-laterally with an 8.6-mm-thick gauge. The use of thinner pressure sensitive foils would have reduced the gap and allowed for higher MUF in both groups (Pröschel et al. 2008). Higher forces might have possibly accentuated a possible difference in MUF between the C/C and C/IOD groups.

A further interesting finding is the discrepancy in chewing efficiency and MUF between participants who experienced a fracture of their fixed dental prostheses and those who did not. These fractures may have resulted from an impaired mechanosensation with IFDP/IFDP (Luraschi 2009) and consequently a poor motor control (Trulsson & Gunne 1998). Another possible explanation would be technical shortcomings of the reconstructions as clear differences in fracture prevalence had occurred between the different centres. Thus particular attention should be paid to technical execution and occlusion of implant-supported prostheses. Patients might have also lost confidence in the durability of their IFDPs and consequently avoided applying maximum forces when asked during the experiments; a presumption confirmed qualitatively by several participants with fracture experience.

MBF

In the current study, MMT was assessed with ultrasound as described by Kiliaridis & Kalezis (1991). The method shows only small errors (in contracted muscle condition 0.2–0.4 mm), does not use electromagnetic radiation like computed tomography and does not necessitate supervision and interpretation of a specialist radiologist. For this multicenter study, which also included patients from private practice an added advantage was the portability of the ultrasound equipment. Although atrophy of the masseter and medial pterygoid muscles related to age and edentulism is well documented (Newton et al. 1993), there is little evidence on the morphological effects of dental prostheses on the masticatory muscles. Newton et al. (2004) had demonstrated that the retention of natural roots covered by overdentures was associated with less atrophied chewing muscles than in subjects with conventional full dentures. Schimmel et al. (2010) had described the case of a patient who had regained MMT after the stabilization of the lower denture with two implants. The current study demonstrated, with the conceptual limitations of any cross-sectional study, the positive structural effects of masticatory muscles of implant placement in edentulous patients. Because of the cross-sectional study design, it remains unclear if the placing of implants prevented atrophy of the masseter muscles or if the patients regained muscle mass through improved function.

Prolonged low activity of muscles will result in atrophy both on a macroscopic and microscopic level. Consequently, the cross-sectional area of the masticatory muscles is reduced in edentulous...
patients compared with dentate subjects, regardless of their age [Newton et al. 1993], a finding that was confirmed by the current study. Also, the radiographic density of these muscles is reduced after a long wearing time of conventional full dentures [Raustia et al. 1996]. On a microscopical level ageing muscle tissue shows a decreased fibre diameter, a degenerated sarcoplasm and a replacement of muscle fibres by fat and connective tissue [Larsson 1995]. Temporal muscle type II fibres in denture wearers, who rate their dentures as insufficient, are smaller than the corresponding fibres in the dentate patients [Ringqvist 1974]. She suggested that the low percentage and small size of these fibres in denture wearers might be attributed to reduced functional demands. The described studies may only in part explain the age- and function-related changes in the masticatory muscles. Findings from other muscles may not apply to the chewing muscles as their functioning, their embryo-genetic origin and the fibre composition are unique in the human body [Momeni et al. 1998].

Edentulous patients benefit from an improved muscle activity by stabilizing the lower denture with two implants, but there seems to be no further improvement of these parameters by providing bimaxillary IFDPs [Ferrario et al. 2004; Heckmann et al. 2009]. The current study confirmed these results on a morphological level. The third null-hypothesis must be rejected, as MMT between the two implant-groups was not statistically different. Patients with implant-supported dental prostheses showed thicker masseter muscles than edentulous patients with conventional full dentures, although the result was no longer significant when the statistical test was corrected for multiple comparisons between groups.

Summary and conclusion

Although the stabilization of conventional mandibular dentures with dental implants improves chewing efficiency significantly, the effect might not be improved further by providing edentulous patients with bimaxillary implant-supported fixed prostheses.

A fracture experience with the dental reconstruction may limit the functional benefit.

In edentulous patients, supporting or stabilizing dental prostheses by placing oral implants seems to have positive effects on the training level and dimension of the masseter muscle. The type of implant prostheses may have an influence on the magnitude of the effect. The functional advantages of implant reconstructions and their tertiary preventive properties on the masseter muscle should be considered in treatment planning.

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References


Müller et al. Masseter muscle thickness and bite force


