Single mandibular implant study – chewing efficiency – 5-year results from a randomized clinical trial using two different implant loading protocols

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Abstract

Purpose: To investigate the chewing efficiency of edentulous patients wearing complete dentures, treated with a single implant in the mandible, placed underneath the existing mandibular dentures, using two different loading protocols (immediate loading or conventional loading), over an observation period of 5 years.

Methods: One-hundred and fifty-eight (158) edentulous seniors aged 60-89 years received an implant in the midline of the lower jaw and were randomized either to the immediate loaded group A (n=81) or the conventional loaded group B (n=77). Chewing efficiency was obtained before treatment, one month after implant placement during the submerged healing phase (only group B) and 1, 4, 12, 24 and 60 months after implant loading.

Results: After 5 years, chewing tests from 89 patients (45 in the immediate loading group and 44 in the conventional loading group) were available for every recall visit and thus statistically analyzed. The chewing efficiency increased over time in both groups. A significant increase was observed up to 4 months after loading (p≤0.05). Later, chewing efficiency further increased, but not significantly. Between the two loading protocols, chewing efficiency did not differ significantly (p>0.05) at any follow-up investigation.

Conclusion: A single mandibular implant placed underneath existing mandibular dentures improves chewing efficiency of edentulous patients significantly over an observation period of 5 years, irrespective of the loading protocol.

Keywords: Edentulous mandible, Single mandibular implant, Chewing efficiency

1. Introduction

In 2019, an international survey among Prosthodontists in the International College of Prosthodontists regarding the use of mandibular implant-supported dental prostheses was conducted[1]. One hundred and sixteen prosthodontists worldwide participated and responded to the questionnaire. The majority of those reported to use two (84%) or four (13%) implants to support mandibular overdentures. Only one respondent used a single implant. Although the treatment concept of placing one implant to support a mandibular overdenture does not seem to be widely used, there is clear evidence from different systematic literature reviews that this concept is a valid, cost effective and minimally invasive treatment option for edentulous patients[2–6].

The masticatory performance of edentulous patients wearing complete dentures is between one-third and one-seventh that of patients with a natural dentition[7]. According to a systematic literature review, attaching dentures to implants in the mandible seems to improve masticatory function irrespective of the number of placed
implants[8]. Two clinical trials investigated the masticatory function of mandibular overdentures retained by one or two implants in edentulous patients over an observation period of one year[9,10]. While one investigation concluded, that chewing function in the single implant overdenture group is not inferior compared to the two implants overdenture group[9], the other clinical trial found a better masticatory performance with two implants[10].

However, different clinical trials have been conducted to investigate the influence of a single implant on masticatory function compared to conventional complete dentures with overall remarkable improvements after implant placement[11–16]. To the best knowledge of the present authors, chewing efficiency of edentulous patients with mandibular overdentures retained by a single implant, loaded either immediately or conventionally three months after implant placement, has never been investigated over an observation period of 5 years.

The primary outcome of the present clinical trial was the implant survival of single implants placed underneath existing mandibular dentures in complete denture wearers using two different loading protocols. The chewing efficiency was evaluated as a secondary outcome. Here, the 5-year results are presented as a follow-up to the previously published results after four months of observation[17].

2. Materials and Methods

The study design was approved by the Institutional Review Boards of all participating centers and the study was registered with the German Registry of Clinical Trials under DRKS ID: DRKS00003730. Informed written consent was obtained from all study participants before inclusion in the investigation.

The study population consisted of edentulous male and female patients aged 60 to 89 years who were satisfied with their maxillary complete dentures but dissatisfied with their mandibular dentures, despite technical acceptance. All patients were screened by experienced prosthodontists. Standard operating procedures were installed and discussed during an initial meeting of all investigators participating in this trial before inclusion of the first patient. Dentures were evaluated as technical acceptable if no further prosthodontic intervention could improve the stability or fit of the dentures. Between December 2021 and March 2014, 224 patients were screened according to predefined inclusion and exclusion criteria (Table 1)[18,19]. For implant placement, a crestal incision was chosen and after elevating a full-thickness flap, implant site preparation was performed according to the manufacturer’s manual. Finally, 163 received an implant (3.8 x 11 mm; Promote plus, Camlog Biotechnologies, Basel, Switzerland) in the anterior mandible and 158 patients received an implant (3.8 x 11 mm; Promote plus, Camlog Biotechnologies, Basel, Switzerland) in the anterior mandible and 158 patients could be randomly assigned to either the immediate-loaded group (group A) or the conventional-loaded group (group B). The reasons for exclusion of the other 5 patients are shown in Figure 1.

The surgical procedure and the detailed randomization process have been further described elsewhere[19,20].

A ball attachment (Dalbo-Plus Elliptic, Cendres Métaux, Biel, Switzerland) was used to connect all implants to the existing denture bases irrespective of the loading protocol. The matrices were integrated intraorally into the denture base with a pink self-curing bis-acrylate resin (LuxaPick-up, DMG, Hamburg, Germany).

Chewing efficiency was assessed before implant placement (baseline) and 1, 4, 24 und 60 months after implant loading. For the evaluation of the chewing efficiency, patients chewed an artificial, standardized test food (Optocal) with 40 chewing cycles[21]. After chewing, the test food was collected in a plastic cup and disinfected with alcohol. The test food dried for 24 hours and was sent to Kiel University, where it was centrally sieved to ensure equal sieving conditions with a standardized sieving protocol[17]. A sieving apparatus (Retsch, Haan, Germany) with 5 sieves of different sizes (4 mm, 2 mm, 850 µm, 425 µm, 180 µm) was used and the particles of the test food on each sieve were weighed with a laboratory balance (Analytic, Sartorius, Göttingen, Germany). The percentage of each of the 5 sieve capacities was calculated and found to be 100% for the total test food of each chewing sample.

Statistical analysis was performed using the Wilcoxon rank-sum test (comparisons of groups) and Wilcoxon signed-rank test and the Friedman test (comparison within groups). In addition, linear interpolation was used to identify a theoretical sieve through which 50% of the chewed test food would pass. The p-values were not adjusted for multiple testing as the parameter chewing efficacy was analyzed exploratively and not confirmatory. IBM SPSS Statistics, version 25.0 and the free software version R (http://www.R-project.org) were used for the analysis.

### Table 1. In- and exclusion criteria

| Inclusion criteria                                                                 | Exclusion criteria                                                                 |
|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Edentulous male and female patients between 60 and 89 years of age                 | Edentulous patients in the age of 60–89 years with contraindication for implant placement in the mandible caused by systematic diseases or local bone deficits. |
| No contraindication for implant placement                                           | Patients satisfied with the retention of their mandibular denture or unsatisfied with the retention and/or stability of their denture in the maxilla |
| Sufficient bone in the anterior mandible to place an implant without bone augmentation procedures | Denture height between base and denture tooth central anterior less than 6 mm |
| Residual bone height is 11 to 20 mm (Class II and III according to McGarry et al.) at the least vertical height of the mandible and vertical bone height in the midline of the mandible is at least 13 mm | Subjects with SCL-90, German version index T-scores of 70 or greater or with two symptom scale scores of 70 or greater will be excluded from the study |
| Despite technically acceptable complete dentures in both jaws, the patient is unsatisfied with the retention and/or stability of the mandibular denture | Signs for incompliant subjects, who will not participate decent according to test schedule. |
| Existing dentures have been worn at least for 3 months to allow adaptation          | Patient participated in another ongoing clinical trial or participation in another clinical trial has not been finished for more than 2 weeks. |
| Dentures must have a bilaterally balanced occlusal scheme                           |                                                                                     |
**CONSORT-Flowchart**

1. **enrollment**
   - assessed for eligibility (n=224)
   - excluded (n=55)

2. **intervention 1**
   - implant placement randomized (n=158)
   - excluded (n=11)

3. **allocation**
   - immediate loading (n=81)
   - conventional loading (submerged healing) (n=77)
   - lost to follow-up (n=17)

4. **implant failure (n=5)**

5. **follow-up**
   - 1 month after loading (n=76)
   - intervention 2 (delayed loading) (n=75)
   - implant failure (n=1)

6. **interim analysis**
   - 4 months after loading (n=74)
   - lost to follow-up (n=17)

7. **limitation**
   - 12 months after loading (n=73)
   - lost to follow-up (n=4)

8. **2 year follow-up**
   - 24 months after loading (n=58)
   - lost to follow-up (n=14)

9. **5 year follow-up**
   - 60 months after loading (n=50)
   - implant failure (n=1)

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**Exclusion prior Intervention 1 (n=55)**
- Ineligible by exclusion/inclusion criteria (n=37)
- Lost to follow-up (n=3)
- Non-compliance (n=5)
- Medical contraindication (n=2)
- Withdrawal of consent (n=8)

**Excluded prior implant placement (n=6)**
- Bone augmentation required (n=5)
- Local anesthesia ineffective (n=1)

**Excluded after implant placement (n=4)**
- AE/SAE: bone augmentation required (n=1)
- Insufficient primary implant stability (n=3)

**Excluded during randomization (n=1)**
- Excluded due to therapy error (n=1)

**Lost to follow-up (n=17)**
- AE/SAE (except death or medical contraindication) (n=1)

**Implant failure (n=5)**

**Lost to follow-up (n=3)**
- Reason unknown (n=3)

**Lost to follow-up (n=1)**
- Reason unknown (n=1)
- Death of patient (n=2)

**Lost to follow-up (n=4)**
- AE/SAE (except death or medical contraindication) (n=1)
- Reason unknown (n=1)
- Death of patient (n=2)

**Lost to follow-up (n=7)**
- Reason unknown (n=4)
- Death of patient (n=2)

**Lost to follow-up (n=15)**
- Reason unknown (n=3)
- Deceased (n=3)
- Medical condition (n=3)
- No interest (n=3)

**Lost to follow-up (n=14)**
- Reason unknown (n=5)
- Deceased (n=4)
- Medical condition (n=1)
- No interest (n=1)
- Move to Gran Canaria (n=1)
- Patient was not cooperative. Telephone interview not possible (n=1)
- Two appointments - no show - lost contact (n=1)

**Implant failure (n=1)**

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Fig. 1. Study flowchart[20].
3. Results

After five years, 101 patients, 50 in the immediate loading group and 51 in the conventional loading group, attended the recall visit (Fig. 1). In the immediate loading group, 9 implants failed, all within the first 3 months after implant loading. Two implants had to be removed in the conventional loading group, one due to a lack of osseointegration at second stage surgery and one after 5 years of loading[20]. Regarding chewing efficiency over an observation period of 5 years, results from all follow-up examinations were available from 89 subjects, 45 in the immediate loading group and 44 in the conventional loading group, and were thus statistically analyzed. For 12 patients, chewing results were not available from each recall visit as patients either missed one recall visit or refused to chew. The descriptive statistics are shown in Table 2.

Over the first 4 months of observation, a statistically significant increase in chewing efficiency was observed in both groups, as evidenced by higher proportions of particles with smaller sizes (Table 2). Between 4 and 60 months of observation, chewing efficiency still increased with no statistical significance. The theoretical sieve size, through which 50% of the chewed test food would pass, decreased significantly over time in both groups, with no statistically significant difference between the two groups (Fig. 2). Again, a statistically significant difference was observed between baseline and 4 months after loading, but not between 4 months after loading and a later follow-up investigation (Table 3). Between the two treatment groups no statistically significant differences were observed at any follow-up investigation.

4. Discussion

Chewing of test food is widely used to investigate the masticatory function of dental patients in clinical trials, especially that of edentulous patients[22–27]. As some investigations used natural food like carrots or peanuts[27,28] others decided for the standardized artificial test food Optocal[25,29,30]. In the present multicenter clinical trial, Optocal was used as test food to avoid possible allergic reactions to natural foods such as peanuts or almonds. Additionally, the shelf life of natural food is limited, which is not the case for an artificial test food, and this had to be taken into account in the current multicenter study, where all chewing samples had to be sent to the main study center, where they were centrally sieved to ensure standardized sieving conditions.

Other methods, as the mixing ability of a two-coloured chewing gum[31–33] or paraffin wax cubes[34,35] have been well described in the literature to investigate the masticatory performance, but again, that did not seem to be an appropriate method for a multicenter clinical study. So far, no information is available on how storage and transportation affect a two-coloured chewing gum or paraffin wax cubes. A misinterpretation had to be avoided. In a review article on common methods for measuring the masticatory performance of edentulous patients wearing complete dentures or implant prostheses, the authors concluded, that the most valid outcomes for this type of assessment would be patient-based, i.e., questionnaires such as the Oral Health Impact profile (OHIP), which can be influenced by chewing, or dietary and nutritional assessments[36]. However, Slagter et al. found a poor correlation between the measured masticatory performance and the patient perceived ability to chew[37]. In the present clinical trial, patient based ‘subjective’ measurements as OHIP or denture satisfaction including the prostheses’ function were also evaluated, with a great improvement after implant placement[38,39].

As the present results indicated, chewing efficiency increased significantly after implant placement irrespective of the loading protocol. After 5 years of observation, it is unlikely to find differences attributable to the loading protocol. However, placing a single implant in the edentulous mandible improved chewing efficiency significantly. This finding is in line with other trials investigating the masticatory performance of complete denture wearers versus mandibular overdenture users[25] and also with shorter term investigations on single implants in the edentulous mandible[12,13,16]. They all found improvements of masticatory performance after implant insertion after an observation period between 3 months and 3 years.

In a review on implant supported dentures and masticatory performance it was stated, that masticatory performance of edentulous patients with maxillary complete dentures and implant supported overdentures in the mandible is significantly improved compared to complete denture wearers, especially if functional problems were present[40]. In the present investigation, patients were only included, if they were dissatisfied with the function of their mandibular denture, despite technical acceptability. This could explain the overall positive effect of the implant placement. If total denture wearers who were satisfied with their chewing ability had been included in this study, the results might have been different.

The chewing efficiency significantly improved during the first four months after implant loading irrespective of the loading protocol. As expected, a significant improvement was already seen after one month. A minor increase was still visible at later follow-up investigations, which might be related to adaptation and reorganization of the neuromuscular system[41]. Marcello-Machado et al. investigated the time required to identify an improvement in masticatory performance of edentulous patients treated with two implants in the mandible[42]. They also found a significant improvement already after one month of implant loading and rated one month as an excellent time to perform reliable masticatory performance tests. In another study on single implants, the treatment of the edentulous mandibles with a single implant also revealed an increasing improvement in masticatory performance up to one year[43]. A positive finding of the present study is, that the initial improvement in chewing efficiency after implant placement was maintained over an observation period of 5 years despite the further aging of the elderly patients with the associated reduction in their functional capacities[44,45]. To the best knowledge of the authors, no other mid-to long-term data on masticatory performance after placement of single implants in the mandible are available for comparison.

Unfortunately, the lost to follow-up rate is rather high, which can be seen as a limitation of the present investigation. But it has to be considered, that the participants were already seniors when the investigation started. The investigation was designed to improve the conditions of edentulous patients, which are mostly seniors. Some patients died, other were not able to attend the recall visit due to medical conditions. It remains unknown, whether the outcomes would have been different with a lower lost to follow-up rate.

5. Conclusion

Given adequate maintenance, the positive effect of inserting a single mandibular implant on chewing efficiency of edentulous pa-
Table 2. Descriptive statistics (in percent) of groups A (N=45) and B (N=44) before implant placement and at all recall visits

|                          | Sieve 1 | Sieve 2 | Sieve 3 | Sieve 4 | Sieve 5 |
|--------------------------|---------|---------|---------|---------|---------|
| **Baseline**             |         |         |         |         |         |
| Group A                  |         |         |         |         |         |
| Means                    | 49.9    | 33.8    | 13.7    | 2.1     | 0.5     |
| Standard deviations      | 30.7    | 19.8    | 12.1    | 3.0     | 0.9     |
| Minimum                  | 2.0     | 2.0     | 0.0     | 0.0     | 0.0     |
| 1st quartile             | 26.0    | 19.0    | 13.0    | 1.0     | 0.0     |
| Medians                  | 37.0    | 39.0    | 13.0    | 1.0     | 0.0     |
| 3rd quartile             | 72.0    | 50.0    | 20.0    | 2.0     | 1.0     |
| Maximum                  | 98.0    | 60.0    | 51.0    | 16.0    | 4.0     |
| Group B                  |         |         |         |         |         |
| Means                    | 40.1    | 38.3    | 17.8    | 3.0     | 0.8     |
| Standard deviations      | 29.4    | 17.6    | 12.0    | 3.1     | 1.0     |
| Minimum                  | 5.0     | 0.0     | 0.0     | 0.0     | 0.0     |
| 1st quartile             | 14.5    | 33.0    | 9.5     | 1.0     | 0.0     |
| Medians                  | 32.0    | 43.0    | 18.0    | 2.0     | 0.0     |
| 3rd quartile             | 52.5    | 49.5    | 26.5    | 4.0     | 1.5     |
| Maximum                  | 100.0   | 64.0    | 45.0    | 11.0    | 3.0     |
| **1 month after implant placement (only group B)** |         |         |         |         |         |
| Group B                  |         |         |         |         |         |
|Means                     | 39.4    | 40.7    | 16.8    | 2.5     | 0.6     |
| Standard deviations      | 31.6    | 19.3    | 12.2    | 2.3     | 1.0     |
| Minimum                  | 0.0     | 0.0     | 0.0     | 0.0     | 0.0     |
| 1st quartile             | 13.5    | 26.5    | 6.5     | 1.0     | 0.0     |
| Medians                  | 28.5    | 47.0    | 13.5    | 2.0     | 0.0     |
| 3rd quartile             | 64.0    | 56.0    | 26.0    | 4.0     | 1.0     |
| Maximum                  | 100.0   | 69.0    | 41.0    | 10.0    | 4.0     |
| **1 month after implant loading** |         |         |         |         |         |
| Group A                  |         |         |         |         |         |
|Means                     | 28.0    | 44.9    | 22.6    | 3.5     | 1.0     |
| Standard deviations      | 28.2    | 15.6    | 12.2    | 2.5     | 0.9     |
| Minimum                  | 0.0     | 1.0     | 0.0     | 0.0     | 0.0     |
| 1st quartile             | 5.5     | 39.5    | 11.0    | 1.0     | 0.0     |
| Medians                  | 20.0    | 50.5    | 23.0    | 3.0     | 1.0     |
| 3rd quartile             | 43.5    | 54.0    | 34.0    | 6.0     | 2.0     |
| Maximum                  | 99.0    | 66.0    | 43.0    | 14.0    | 3.0     |
| Group B                  |         |         |         |         |         |
|Means                     | 78.9    | 48.9    | 22.6    | 3.5     | 1.0     |
| Standard deviations      | 58.7    | 15.6    | 12.2    | 2.5     | 0.9     |
| Minimum                  | 0.0     | 1.0     | 0.0     | 0.0     | 0.0     |
| 1st quartile             | 5.5     | 39.5    | 11.0    | 1.0     | 0.0     |
| Medians                  | 20.0    | 50.5    | 23.0    | 3.0     | 1.0     |
| 3rd quartile             | 43.5    | 54.0    | 34.0    | 6.0     | 2.0     |
| Maximum                  | 99.0    | 66.0    | 43.0    | 14.0    | 3.0     |
| **4 months after implant loading** |         |         |         |         |         |
| Group A                  |         |         |         |         |         |
|Means                     | 23.4    | 48.3    | 23.1    | 4.1     | 1.1     |
| Standard deviations      | 24.7    | 14.5    | 11.9    | 3.1     | 1.0     |
| Minimum                  | 0.0     | 9.0     | 1.0     | 0.0     | 0.0     |
| 1st quartile             | 4.0     | 39.0    | 16.0    | 2.0     | 0.0     |
| Medians                  | 16.0    | 51.0    | 24.0    | 3.0     | 1.0     |
| 3rd quartile             | 31.0    | 58.0    | 32.0    | 6.0     | 2.0     |
| Maximum                  | 99.0    | 68.0    | 51.0    | 13.0    | 4.0     |
| Group B                  |         |         |         |         |         |
|Means                     | 18.0    | 51.4    | 25.2    | 4.1     | 1.3     |
| Standard deviations      | 18.7    | 11.2    | 10.9    | 3.3     | 1.4     |
| Minimum                  | 0.0     | 18.0    | 4.0     | 1.0     | 0.0     |
| 1st quartile             | 4.0     | 46.0    | 15.5    | 2.0     | 1.0     |
| Medians                  | 9.5     | 52.0    | 25.0    | 3.5     | 1.0     |
| 3rd quartile             | 28.5    | 58.5    | 33.5    | 5.0     | 2.0     |
| Maximum                  | 77.0    | 74.0    | 47.0    | 18.0    | 8.0     |
| **24 months after implant loading** |         |         |         |         |         |
| Group A                  |         |         |         |         |         |
|Means                     | 18.7    | 54.2    | 22.2    | 3.9     | 1.0     |
| Standard deviations      | 22.1    | 15.3    | 11.0    | 4.3     | 1.6     |
| Minimum                  | 0.0     | 1.0     | 0.0     | 0.0     | 0.0     |
| 1st quartile             | 2.0     | 49.0    | 14.0    | 1.0     | 0.0     |
| Medians                  | 12.0    | 57.0    | 22.0    | 3.0     | 1.0     |
| 3rd quartile             | 30.0    | 64.0    | 31.0    | 5.0     | 1.0     |
| Maximum                  | 99.0    | 79.0    | 49.0    | 21.0    | 9.0     |
| Group B                  |         |         |         |         |         |
|Means                     | 16.2    | 48.9    | 28.1    | 5.4     | 1.4     |
| Standard deviations      | 18.9    | 11.6    | 14.2    | 4.4     | 1.4     |
| Minimum                  | 0.0     | 22.0    | 3.0     | 0.0     | 0.0     |
| 1st quartile             | 0.5     | 40.5    | 16.5    | 2.0     | 1.0     |
| Medians                  | 8.5     | 50.5    | 29.0    | 4.5     | 1.0     |
| 3rd quartile             | 29.0    | 58.0    | 36.5    | 8.0     | 2.0     |
| Maximum                  | 72.0    | 71.0    | 58.0    | 19.0    | 5.0     |
patients is constant even after five years. Chewing efficiency is not influenced by the loading protocol after 5 years of observation.

Acknowledgements

The authors thank the involved staff of the participating study centers for their support.

This study was financially supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) [grant no DFG KE 477/8-1, KE 477/8-2].

Conflicts of interest

All authors declare that they have no conflict of interest.

References

[1] Kronström M, Carlsson GE. An international survey among prosthodontists of the use of mandibular implant-supported dental prostheses. J Prosthodont. 2019;28:e622–6. https://doi.org/10.1111/jopr.12603, PMID:28314082

[2] Padmanabhan H, Kumar SM, Kumar VA. Single implant retained overdenture treatment protocol: A systematic review and meta-analysis. J Prosthodont. 2020;29:287–97. https://doi.org/10.1111/jopr.13133, PMID:31849146

[3] Srinivasan M, Makarov NA, Herrmann FR, Müller F. Implant survival in 1-versus 2-implant mandibular overdentures: a systematic review and meta-analysis. Clin Oral Implants Res. 2016;27:63–72. https://doi.org/10.1111/ clr.12513, PMID:25350235

[4] Nogueira TE, Dias DR, Leles CR. Mandibular complete denture versus single-implant overdenture: a systematic review of patient-reported outcomes. J Oral Rehabil. 2017;44:1004–16. https://doi.org/10.1111/joor.12550, PMID:28805255

[5] Ahmed Elawady DM, Kaddah AF, Talaat Khalifa M. Single vs 2 implants on peri-implant marginal bone level and implant failures in mandibular implant overdentures: A systematic review with meta-analysis. J Evid Based Dent Pract. 2017;17:216–25. https://doi.org/10.1016/j.jebdp.2017.02.002, PMID:28865818

[6] Kern M, Passia N. The single implant as a minimal restoration in the edentulous mandible. Does it work long term? Implantol. 2021;29:25–35.
Passia N, Abou-Ayash S, Bender D, Fritzer E, Graf M, Kappel S, Bates JF, Stafford GD, Harrison A. Masticatory function – a review of the literature. J Oral Rehabil. 2015;42:220–33. https://doi.org/10.1111/j.1365-2842.1993.tb02193.x, PMID:7437055

Resende GP, Jordão LMR, Souza JAC, Schimmel M, Memedi K, Parga T, Katsoulis J, Müller F. Masticatory performance and maximum bite and lip force depend on the type of prosthesis. Int J Prosthodont. 2012;25:135–7. PMID:22371833

Bates JF, Stafford GD, Harrison A. Evaluation of bite force and masticatory performance: complete denture vs mandibular overdenture users. Braz Dent J. 2020;31:399–403. https://doi.org/10.1016/j.bjodent.2019.03.055, PMID:32001716

Florêncio Costa RT, Leite Vila Nova TE, Barbosa de França AJ, Gustavo da Silva Casado B, de Souza Leão R, Dantas de Moraes SL. Masticatory performance of denture users with the use of denture adhesives: A systematic review. J Prosthodont Dent. 2020;S0022-3913(20)30596-5. https://doi.org/10.1016/j.jp-jomi.2018.03.013, PMID:31719739

Kar S, Tripathi A, Fatima T. A comparative study of masticatory performance in complete denture patients before and after application of soft liners. Med J Armed Forces India. 2019;75:437–43. https://doi.org/10.1016/j.mjaf.2018.03.013, PMID:31719739

Tata S, Nandeeshwar DB. A clinical study to evaluate and compare the masticatory performance in complete denture wearers with and without soft liners. J Contemp Dent Pract. 2012;13:787–92. https://doi.org/10.5005/jp-journals-10024-1230, PMID:23404004

Miranda SB, Possebon APR, Schuster AJ, Marcello-Machado RM, Pinto L, Faot F. Relationship between masticatory function impairment and oral health-related quality of life of edentulous patients: An interventional study. J Prosthodont. 2019;28:634–42. https://doi.org/10.1111/jopr.13070, PMID:31119843

Mendonça DB, Prado MM, Mendes FA, Borges TDeF, Mendonça G, do Prado CJ, et al. Comparison of masticatory function between subjects with three types of dentition. Int J Prosthodont. 2009;22:399–404. PMID:19369080

Schimmel M, Christou P, Herrmann F, Müller F. A two-colour chewing gum test for masticatory efficiency: development of different assessment methods. J Oral Rehabil. 2007;34:671–8. https://doi.org/10.1111/j.1365-2842.2007.01773.x, PMID:17716266

Kaya MS, Guçlü B, Schimmel M, Akyüz S. Two-colour chewing gum mixing ability test for evaluating masticatory function in children with mixed dentition: validity and reliability study. J Oral Rehabil. 2017;44:827–34. https://doi.org/10.1111/joor.12548, PMID:28741713

Hama Y, Kanazawa M, Minakuchi S, Uchida T, Sasaki Y. Properties of a color-changeable chewing gum used to evaluate masticatory performance. J Prosthodont Res. 2014;58:102–6. https://doi.org/10.13063/2013.12.005, PMID:24461959

Bae JC, Jeong SH, Jeong CM, Huh JB. Comparison of the masticatory function of complete dentures and implant-retained overdentures. Int J Prosthodont. 2015;28:345–7. https://doi.org/10.1111/j.1365-2957.2014.06401.x, PMID:26218014

Khalid T, Yunus N, Ibrahim N, Saleh NBM, Goode D, Masood M. Assessment of masticatory function of mandibular implant-supported overdenture wearers: A 3-year prospective study. J Prosthet Dent. 2020;124(6):674–81. https://doi.org/10.1016/j.prosdent.2019.09.005, PMID:31952858

Feine JS, Lund JP. Measuring chewing ability in randomized controlled trials with edentulous populations wearing implant prostheses. J Oral Rehabil. 2006;33:301–8. https://doi.org/10.1111/j.1365-2842.2006.01614.x, PMID:16629885

Slagter AP, Othloff LW, Bosman F, Steen WHA. Masticatory ability, denture quality, and oral conditions in edentulous subjects. J Prosthodont. 1992;1:299–307. https://doi.org/10.1016/0278-2394(92)90034-7, PMID:15011797

Passia N, Att W, Freitag-Wolf S, Heydecke G, Freifrau von Eberhard L. Functional adaptation of the masticatory system to implant-prosthesis trials with edentulous populations wearing implant prostheses. J Oral Rehabil. 2006;33:301–8. https://doi.org/10.1111/j.1365-2842.2006.01614.x, PMID:16629885

Rosemberg FL, Frascas LCP, Rivaldo EG, Fernandes EL, Gaiavio MBD. Protocol for production of a chewable material for masticatory function tests (Optocal - Brazilian version). Braz Oral Res. 2008;22:305–10. https://doi.org/10.1590/S1518-83422008000400004, PMID:19148384

Bates JF, Stafford GD, Harrison A. Masticatory function – a review of the literature. III. Masticatory performance and efficiency. J Oral Rehabil. 1976;3:57–67. https://doi.org/10.1111/j.1365-2842.1976.tb00929.x, PMID:772184

Schimmel M, Memedi K, Parga T, Katsoulis J, Müller F. Masticatory performance and maximum bite and lip force depend on the type of prosthesis. Int J Prosthodont. 2017;30:565–72. https://doi.org/10.11607/j.ip.3289, PMID:22904301

Toman M, Toksavul S, Saracoğlu A, Cura C, Hatiçoglu A. Masticatory performance and mandibular movement patterns of patients with natural dentitions, complete dentures, and implant-supported overdentures. Int J Prosthodont. 2012;25:135–7. PMID:22371833

Possebon APR, Schuster AJ, Bielemann AM, Porto BL, Boscato N, Faot F. Evaluation of bite force and masticatory performance: complete denture vs mandibular overdenture users. Braz Dent J. 2020;31:399–403. https://doi.org/10.1590/0103-6440202003525, PMID:32001716

Florêncio Costa RT, Leite Vila Nova TE, Barbosa de França AJ, Gustavo da Silva Casado B, de Souza Leão R, Dantas de Moraes SL. Masticatory performance of denture users with the use of denture adhesives: A systematic review. J Prosthodont Dent. 2020;S0022-3913(20)30596-5. https://doi.org/10.1016/j.jp-jomi.2018.03.013, PMID:31719739

Rajkumaronkup N, Cordettiete F, Kappel S, Rammelsberg P, Schindler HJ, Eberhard L. Functional adaptation of the masticatory system to implant-supported mandibular overdentures. Clin Oral Implants Res. 2017;28:529–34. https://doi.org/10.1111/jocr.12830, PMID:27001374
Marcello-Machado RM, Faot F, Schuster AJ, Bielemann AM, Nascimento GG, Del Bel Cury AA. How fast can treatment with overdentures improve the masticatory function and OHRQoL of atrophic edentulous patients? A 1-year longitudinal clinical study. Clin Oral Implants Res. 2018;29:215–26. https://doi.org/10.1111/clr.13101, PMID:29218786

Nogueira TE, Schimmel M, Leles CR. Changes in masticatory performance of edentulous patients treated with single-implant mandibular overdentures and conventional complete dentures. J Oral Rehabil. 2019;46:268–73. https://doi.org/10.1111/joor.12744, PMID:30387869

Takata Y, Ansai T, Soh I, Akifuja S, Sonoki K, Fujisawa K, et al. Relationship between chewing ability and high-level functional capacity in an 80-year-old population in Japan. Gerodontology. 2008;25:147–54. https://doi.org/10.1111/j.1741-2358.2007.00203.x, PMID:18194329

Lamster IB, Asadourian L, Del Carmen T, Friedman PK. The aging mouth: differentiating normal aging from disease. Periodontol 2000. 2016;72:96–107. https://doi.org/10.1111/prd.12131, PMID:27501493

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