The impact of a newly constructed removable denture on the objective and subjective masticatory function

Simonne Salazar, Yoko Hasegawa, Satsuki Kikuchi, Koh Kaneda, Hiroyuki Yoneda, Takashi Nokubi, Kazuhiro Hori, Takahiro Ono

Abstract

Purpose: This study investigated the impact of the renewal of a removable prosthesis on the masticatory function by subjective and objective measures and its variation among the types of occlusal support.

Methods: Seventy-eight patients who received newly fabricated removable denture patients participated in this study. For the objective assessment, masticatory performance was measured using test gummy jelly. For the subjective assessment, standardized questionnaires about food acceptability and the oral health-related quality of life (OHRQoL) were used. Pre- and post-insertion assessments were performed for each subject. Subjects were divided into three groups according to their posterior occlusion: with posterior occlusion (w/PO), without posterior occlusion (w/o PO) and edentulous. Wilcoxon’s signed rank test was used to compare the pre- and post-treatment measurements of each assessment. The analysis of covariance and a multiple comparison were used to assess the effect of new dentures and differences due to occlusal support.

Results: The masticatory performance, OHRQoL and food acceptability following prosthodontic treatment were significantly improved by new denture insertion. The masticatory performance among groups varied to a relative degree. The rate of masticatory performance improvement for edentulous subjects was twice that in w/PO subjects. The OHRQoL was significantly lower in the w/o PO and edentulous groups with old denture than patients w/PO. The food acceptability improved most markedly in the edentulous group.

Conclusions: The improvement in the masticatory performance by new denture insertion varied among types of occlusal support. Re-establishing the occlusal support of edentulous patients may help restore their OHRQoL and improve food acceptability.

Keywords: Masticatory function, Masticatory performance, OHRQoL, Food acceptability

1. Introduction

The decline in the masticatory function is greatly influenced by the loss of natural teeth [1], and this decline is believed to affect the nutrient intake [2], food selection [3], oral health-related quality of life (OHRQoL) [4, 5] and even the general health of the patient. Thus, prosthodontic rehabilitation with conventional removable dentures aims to provide and restore a satisfactory masticatory function. Previous studies have attempted to determine the effect of removable denture treatment on the masticatory function. Improvements were seen after the insertion of partial [6] and complete dentures [7-14]. However, some studies have suggested that even after prosthodontic rehabilitation, no significant changes were seen in the masticatory performance of partial [15] and complete denture patients [6, 8-12, 14, 16, 17] Therefore, the changes in the masticatory function after new denture insertion remain unclear.

To quantify the changes in the masticatory function, it is fundamental to measure the treatment outcome either objectively or subjectively. One of the most widely recognized objective assessments is the masticatory performance (MP), which demonstrates a patient’s ability to comminute a specific type of food during mastication. Several methods such as sieving [17], color-changeable chewing gum [18] and gummy jelly [19] have been used for such assessments. Notably, masticatory performance assessment by using gummy jelly [19-23] was widely used as a diagnostic tool due to its fast, easy and accurate application, which is beneficial in a clinical setting. However, while objective assessments evaluate the actual masticatory function, it has been stressed that subjective evaluations are also appropriate and sensitive for measuring treatment outcomes.

Standardized questionnaires (such as the oral health impact profile [OHIP], food intake questionnaires, etc.) have been used to subjectively evaluate the masticatory function. In this way, we evaluate the patient’s perception of their oral status regarding their chewing satisfaction [24], chewing ability [14] and even the impact of their oral condition on their well-being [25, 26]. Recent studies regarding the...
correlation of objective and subjective assessment have obtained differing results. No correlation was found when self-administered questionnaire scores and objective assessments of healthy dentate [27] and edentulous subjects [28] were assessed. However, Shiga et al. [19] suggested that complete denture patients with a high masticatory performance tended to have a high food intake ability [19]. Thus, further clarification is needed with regards to the relationship between these two types of assessment.

In addition, the number of remaining teeth and functional tooth units have been said to affect the masticatory function. We considered the need to classify each patient according to their available occlusal support area. In this way, changes in the masticatory function may be observed according to the type of occlusal presence [1]. This prospective cohort study investigated the changes in the objective and subjective aspects of the masticatory function following the insertion of a newly constructed removable denture and the relationship between these assessments. In addition, the changes in the masticatory function for each type of occlusal support area were also evaluated.

2. Materials and Methods

The study protocol was approved by the institutional ethics committees of the Niigata University Faculty of Dentistry (#28-R42-7-2). Oral and written informed consent from the patients was obtained after a thorough explanation of the nature of the study. Informed consent was obtained prior to fabrication of new dentures.

2.1. Participants

Patients with removable partial and complete dentures in the Departments of Removable Prosthodontics and General Dentistry of Niigata University Medical and Dental Hospital participated in this study from October 2015 to February 2018. Patients were selected according to the following inclusion criteria: currently wearing a removable denture and needing a replacement; no known history of temporomandibular joint disorders; and able to understand and appropriately respond to a questionnaire. We selected patients who were able to undergo an assessment twice (before and after the fabrication of new dentures).

Each patient underwent an oral examination to determine the number of remaining natural teeth using a mouth mirror and exploratory probe. The Eichner classification was determined based on the available supporting zones of antagonist contacts in their premolar and molar regions [29]. They were further classified into three groups according to their available posterior occlusal support. The group with posterior occlusion (w/PO) comprised patients classified as Eichner A3, B1, B2 and B3; the group without posterior occlusion (w/o PO) comprised patients classified as Eichner B4, C1 and C2; and the edentulous group comprised patients classified as Eichner C3.

2.2. Study protocol

The masticatory function was assessed by two methods: an objective and subjective assessment. A total of two measurements were done for each patient. The first measurement was done using the old denture before the fabrication of the new dentures, termed the “pre-insertion” data, and was considered the baseline data. The second measurement was scheduled after the initial adjustment of the new denture, termed the “post-insertion” data, to ensure that pain and discomfort had improved and an appropriate adjustment period had been provided for each patient.

2.3. The objective assessment

A test gummy jelly (UHA Mikakuto, Osaka, Japan) and a fully automatic measuring device (Fig. 1) were used to measure the masticatory performance [23]. Each patient was asked to chew 30 times on their preferred side without swallowing any particles. The patient was then asked to expectorate the chewed gummy jelly on a prepared gauze receptacle. Comminuted gummy jellies were collected and rinsed to prevent further dissolution. Specimens are then transferred into a clear cell that was placed in the fully automatic measuring device (Tokyo Photoelectric, Tokyo, Japan). The degree of comminution was measured by the concentration of β-carotene dissolved from the comminuted pieces of gummy jelly and expressed as the increase in the surface area (mm²) after calculation [23]. Practice in chewing of the gummy jelly was performed before each measurement. The relative value of the change in the masticatory performance (RVMP) was calculated using the following formula: RVMP = (post-insertion masticatory performance / pre-insertion masticatory performance) × 100.

2.4. The subjective assessment

For the subjective assessment, each patient was asked to answer a standardized questionnaire. Data were obtained through the self-assessment of their OHRQoL using the shortened OHIP and food acceptability questionnaire, which included 10 Japanese food items and 10 universally available food items.

2.4.1. OHIP-14

To measure the adverse impact of oral conditions on the quality of life of the patients, the short form of the OHIP (Table 1.1), which is a 14-item questionnaire designed to focus on the 7 dimensions of impact (functional limitation, pain, psychological discomfort, physical disability, psychological disability, social disability and handicap), was used [30]. Each dimension included two questions. Patients were asked to respond according to the frequency of impact on a simple 5-point Likert-type frequency scale, which denotes the following choices and numerical codes: Never = 0, Hardly ever = 1, Occasionally = 2, Fairly often = 3, and Often = 4. The sum of all answers denotes the OHRQoL of the patients, with a high OHIP score indicating a poor OHRQoL. Subscale scores were then calculated by summing all items for each subscale to determine the impact of each dimension. The relative value of the OHIP-14 change (RV OHIP-14) was calculated using the following formula: RV OHIP-14 = (post-insertion OHIP-14 score / pre-insertion OHIP-14 score) × 100.
Table 1. A subjective assessment using standardized questionnaires.

| 1.1 OHI-14 questionnaire. |
|--------------------------|
| 1. Functional limitation |
| i. Have you had trouble pronouncing any words because of problems with your teeth, mouth or dentures? |
| ii. Have you felt that your sense of taste has worsened because of problems with your teeth, mouth or dentures? |
| 2. Physical pain |
| i. Have you had painful aching in your mouth? |
| ii. Have you found it uncomfortable to eat any food because of problems with your teeth, mouth or dentures? |
| 3. Psychological discomfort |
| i. Have you been self-conscious because of your teeth, mouth or dentures? |
| ii. Have you felt tense because of problems with your teeth, mouth or dentures? |
| 4. Physical disability |
| i. Has your diet been unsatisfactory because of your teeth, mouth or dentures? |
| ii. Have you had to interrupt meals because of problems with your teeth, mouth or dentures? |
| 5. Psychological disability |
| i. Have you found it difficult to relax because of problems with your teeth, mouth or dentures? |
| ii. Have you been a bit embarrassed because of problems with your teeth, mouth or dentures? |
| 6. Social disability |
| i. Have you had difficulty doing your usual job because of problems with your teeth, mouth or dentures? |
| ii. Have you felt that life in general was less satisfying because of problems with your teeth, mouth or dentures? |
| 7. Handicap |
| i. Have you been totally unable to function because of problems with your teeth, mouth or dentures? |

1.2 Food acceptability questionnaire.

| Group 1 | Group 2 | Group 3 |
|---------|---------|---------|
| Tofu    | Bean sprouts | Peanuts |
| Rolled omelette | Grilled fish-paste (kanaboko) | Pickled radish |
| Boiled potatoes | Potato chips | Hard biscuit |
| Boiled carrots | Burdock root | Hard Japanese crackers |
| Group 4 | Group 5 |
| Hard pickled radish | Dried squid |
| Egg cockle | Dried scallop |
| Group 3 |
| Arare (bite-sized rice crackers) | Grilled meat | Gum |
| Grilled meat | | Apple |

Each food item is classified according to its chewing index.37

2.4.2. Food acceptability questionnaire (FAQ)

A set questionnaire composed of 20 different food items was used to evaluate the food intake for each patient (Table 1.2) [3]. Patients were asked to describe their intake ability as “easy to chew”, “difficult to chew”, “impossible to chew” and “no experience in eating”. Each food item was then classified into five subclasses according to its masticatory difficulty [3]. The percentage of “easy to chew” foods was then calculated as the food intake score. In addition, each of the five subclasses scores were calculated based on the percentage of “easy to chew” foods in the subclass. A high score denoted a good chewing ability for the patient. The relative value of the FAQ change (RV FAQ) was calculated using the following formula: RV FAQ = (post-insertion FAQ - pre-insertion FAQ) x 100.

2.5. Statistical methods

After confirming the normality and equal variance of the data, non-parametric methods were used for all statistical analyses. The RV was analyzed using an analysis of covariance, including the logarithm of the pre-insertion measurement as the main effect or covariate, occlusal support group as the simple main effect and the interaction between them, with adjustments made for the age, gender and duration of old dentures. In the analysis of covariance, the RV was log-transformed, since the RV had a skewed distribution, and the number of teeth was excluded from these analyses due to its strong multicollinearity with the occlusal support group. The multiple comparison test was performed to compare occlusal support groups. To compare the pre- and post-insertion measurements Wilcoxon’s signed rank test was used. Correlations between the relative changes in each assessment was analyzed using Spearman’s rank correlation coefficient. All statistical analyses were carried out using the SPSS version 23.0 software program for Windows (IBM Corporation, NY, USA), and probability values less than 5% were considered significant.

3. Results

The characteristics of the study population are shown in Table 2. The 78 patients were 67% female with a mean age of 73.1 ± 9.4 years old. The mean number of remaining natural teeth for each category was significantly different among the groups. However, the duration of denture use did not significantly differ between pre- and post-insertion among the three groups. The population was composed of the following Eichner classes: A3 = 3; B1 = 9; B2 = 8; B3 = 9; B4 = 10; C1 = 9; C2 = 16; and C3 = 14. Although there were no significant differences, the post insertion adjustment period for patient w/PO was shorter than in the other groups.

3.1. The objective and subjective assessments

The analysis of covariance (Table 3) showed that the RVMP and RVFAQ for occlusal support were significantly affected by the difference in the pre-insertion measurement value (interaction p=0.004 for RVMP and P=0.022 for RVFAQ). These results indicate that the changes in masticatory performance and food acceptance questionnaire responses due to the new dentures were affected by not only the condition of the old dentures but also the occlusal support of the subject. In all patients, the median value of the masticatory performance post-insertion was significantly increased by 27% (Table 4). Comparing the pre- and post-insertion values, all of the groups showed a significantly improved masticatory performance using new dentures. However, the masticatory performance value in the edentulous group remained the lowest, followed by the w/o PO group and with the w/PO group showing the highest value among the groups, by 25%-70%

Comparatively, the relative value of change in the masticatory performance (RVMP) is exactly the opposite of the masticatory performance value, the edentulous group demonstrated the highest improvement with a value of two times more than the pre-insertion
Table 2. Characteristics of subjects.

|                  | All n=78 | with posterior occlusion n=29 | without posterior occlusion n=35 | Edentulous n=14 | Comparison among three groups; p value |
|------------------|----------|-------------------------------|---------------------------------|-----------------|--------------------------------------|
| Gender: Male (%) | 26 (33)* | 8 (38)*                       | 13 (59)                         | 5(56)           | 0.15                                 |
| Age (years)      | 73.1± 9.4 | 70.7± 9.9                     | 73.8± 8.3                       | 76.4± 10.5      | <0.001**                             |
| Number of functional teeth | 11.08± 8.6 | 20.4± 4.5                     | 8.7± 4.7                        | 0              | <0.001**                             |
| Duration of denture use (months) | 7.9± 0.2 | 76.8± 59.0                    | 64.2± 51.3                      | 93.0± 105.9     | 0.42                                 |
| pre-insertion (old denture) | 1.5± 0.04 | 1.2± 0.7                      | 1.6± 1.0                        | 1.5± 1.1       | 0.08                                 |
| post-insertion (new denture) | 1.6± 1.0  | 3.8± 1.2                      | 5.6± 1.3                        | 7.4± 1.1       | 0.02                                 |

Data are presented as the mean ± standard deviation unless otherwise mentioned. With posterior occlusion: Eichner A3, B1, B2 and B3; without posterior occlusion: B4, C1, C2; and edentulous group: C3.

*Significant differences were seen between genders using the chi-square test.

**Significant differences were seen in the remaining natural dentition among the three groups calculated with an analysis of variance.

Table 3. Factors affecting the relative changes in the masticatory performance.

| Relative change | Interaction | Occlusal support | pre-insertion measurement |
|-----------------|-------------|------------------|---------------------------|
| RVMP            | 0.004       | 0.034            | <0.001                    |
| RVOHIP          | 0.436       | 0.028            | <0.001                    |
| RVFAQ           | 0.022       | 0.019            | <0.001                    |

RV: (post-insertion measurement / pre-insertion measurement) × 100

The RV was analyzed using an analysis of covariance, including the logarithm of the pre-insertion measurement as the main effect or covariate, occlusal support group as the simple main effect and the interaction between them, with adjustments made for the age, gender and duration of old dentures. Interaction: P-value of the interaction between occlusal support group and pre-insertion measurement. Occlusal support group with the highest improvement (73.1± 9.4 vs. 70.7± 9.9) was the w/PO group, which showed a significant increase in the masticatory performance (7.9± 0.2 vs. 64.2± 51.3). A significant difference was seen between the edentulous group and the w/PO group. Overall, the total score of OHIP-14 (Table 4) was significantly lower after insertion of a new denture, indicating an improved OHQoL. Post-insertion of new dentures, the total scores improved significantly in both w/PO and edentulous patients. Significant decreases in scores were observed for all 7 subscales of OHIP-14 for patients w/ PO (Table 5), while edentulous patients' median subscale scores for physical disability, psychological disability, social disability and handicap were significantly improved post-insertion. However, neither the median total nor subscale scores for patients w/PO showed any significant change.

The total food acceptability score for all subjects (Table 4) indicated a significant improvement in the state of food acceptability with new dentures (p = 0.001). The groups with (p = 0.21) and without (p = 0.07) PO showed minimal changes in their food acceptability overall. However, for the w/PO group, a significant decrease in acceptability for subgroup 5 (hard foods such as dried squid, dried scallop, gum and apple) was observed (Table 6). Conversely, the edentulous group showed a significant increase in their food acceptability, with the foods in subgroup 2 (p = 0.004), 3 (p = 0.03) and 5 (p = 0.01) becoming easier to chew.

3.2. Correlation between the objective and subjective assessments

The correlation between the relative change in the objective and subjective assessments is presented in Table 7. A significant weak correlation (r = 0.23, p = 0.045) was found between the change in the masticatory performance and food acceptability overall. Furthermore, while it did not reach significance, a negative correlation was seen between the relative change in the masticatory performance and the OHIP-14 score (r = -0.33, p = 0.06) for the w/o PO group, while a positive correlation between the masticatory performance and food acceptability (r = 0.48, p = 0.07) in the edentulous group.

4. Discussion

In the present study, we assessed the changes in the masticatory function after insertion of a newly constructed removable denture. The masticatory performance, OHQoL and food acceptability were used to assess the treatment outcome. Significant improvements in the masticatory function were obtained, and the rates of response differed for each assessment. A 27% increase in the removable denture patients' objective masticatory performance was seen, while an 11% decrease in the impact of dentures on the OHQoL and a 3% increase in food acceptability were obtained subjectively. These findings may suggest that the instruments or methods used were efficient in detecting the effect of denture replacement. Furthermore, relative changes in the masticatory performance were found to be significantly correlated with the change in food acceptability. This may signify the positive effect of new dentures, which may help restore the masticatory performance and thus improve the food acceptability. In addition to the overall improvements in the masticatory function of removable denture patients, various changes were seen among the different types of occlusal support.

4.1. Effects of new dentures

An overall improvement in the objective and subjective assessment of the masticatory function was observed after removable denture treatment. The present results quantified the changes in each assessment. The greatest change was observed in the patient's masticatory performance, followed by the OHQoL and food acceptability. Each assessment was able to identify the degree of impact by new denture treatment, which is in agreement with the findings of previous studies, wherein prosthodontic rehabilitation helped improve both the objective [6,17] and subjective [7-14] masticatory function.

Improvement in the masticatory performance was the most evident change after treatment. This assessment has the advantage of being an unbiased evaluation, which may reflect the actual status of the masticatory function. The results show that the method used was sufficiently sensitive to detect the effect of denture rehabilitation. A previous study that measured the masticatory efficiency indicated the importance of a methodology that can detect small differences between treatments [31]. By using a test gummy jelly and a fully automatic measuring device [23], we were able to quantify the effect of the new denture treatment. One of the advantages with this approach is the simulation of physiologic chewing was
Table 4. Changes in the masticatory functions due to a newly constructed removable denture.

|                      | All n=78 | with posterior occlusion n=29 | without posterior occlusion n=35 | Edentulous n=14 | Comparison among three groups p value |
|----------------------|----------|-----------------------------|---------------------------------|-----------------|---------------------------------------|
| Masticatory performance (mm²) |          |                             |                                 |                 |                                       |
| RVMP                 |          |                             |                                 |                 |                                       |
| pre-insertion (old denture) | 127 (129-519) | 117 (106-138) | 121 (97-548) | 229 (255-1749) | < 0.001* |
| post-insertion (new denture) | 3525 (140-5894) | 4120 (537-5894) | 3071 (140-5854) | 1208 (211-4431) | < 0.001* |
| p value              | < 0.001* | 0.02*                       | 0.005*                          | 0.02*           |                                       |
| OHIP-14              |          |                             |                                 |                 |                                       |
| RVOHIP               | 103 (44-400) | 106 (44-162) | 104 (55-294) | 139 (84-400) |                                       |
| pre-insertion (old denture) | 10.5 (0-41) | 7 (0-41) | 11 (11-30) | 14.5 (0-35) | 0.16 |
| post-insertion (new denture) | 7 (0-25) | 8 (0-25) | 7 (0-25) | 8.5 (0-22) | 0.64 |
| p value              | 0.002* | 0.746                       | < 0.001*                        | 0.006*          |                                       |
| FAQ                  |          |                             |                                 |                 |                                       |
| RVFAQ                | 89 (0-1600) | 100 (0-1600) | 75 (0-200) | 84 (9-300) |                                       |
| pre-insertion (old denture) | 77.2 (0-100) | 90 (27.3-100) | 76.5 (27.8-100) | 42.9 (10-88.9) | < 0.001* |
| post-insertion (new denture) | 84.2 (30.8-100) | 92 (36.8-100) | 83.3 (40-100) | 60.6 (30.8-95) | 0.002* |
| p value              | 0.001* | 0.21                       | 0.07                             | 0.02*           |                                       |

Data are presented as the median (minimum-maximum) for assessment variables and median (confidence interval) for relative values. Pre-insertion: masticatory performance before new denture insertion, post-insertion: masticatory performance after new denture insertion, RV= (post-insertion measurement / pre-insertion measurement) * 100. §Significant differences were seen between pre- and post-insertion by Wilcoxon's signed rank test. Significant differences were seen among (a) with and without posterior occlusion, (b) with posterior occlusion and edentulous and (c) without posterior occlusion and edentulous using a multiple comparison with the Mann–Whitney U test. P value corrected by Bonferroni’s method.

Table 5. Changes in the OHRQoL OHIP-14 with new dentures (7 domains).

| OHIP-14               | all | with posterior occlusion | without posterior occlusion | Edentulous | P value |
|-----------------------|-----|--------------------------|-----------------------------|------------|---------|
|                       | pre-insertion | post-insertion | p value | pre-insertion | post-insertion | p value | pre-insertion | post-insertion | p value | pre-insertion | post-insertion | p value |
| Functional limitation  | 2 (0-8) | 2 (0-7) | 0.02* | 2 (0-5) | 2 (0-5) | 0.49 | 2 (0-8) | 2 (0-7) | 0.008* | 3 (0-7) | 2 (0-4) | 0.11 | 0.08 | 0.80 |
| Physical pain         | 2 (0-6) | 2 (0-5) | 0.02* | 2 (0-5) | 2 (0-4) | 0.90 | 2 (0-6) | 1 (0-5) | 0.01* | 3 (0-6) | 3 (0-6) | 0.22 | 0.42 | 0.32 |
| Psychological pain    | 1 (0-8) | 0.5 (0-4) | 0.03* | 0 (0-8) | 2 (0-4) | 0.14 | 2 (0-6) | 0 (0-4) | 0.001* | 0 (0-6) | 2.5 (0-5) | 0.07 | 0.20 | 0.34 |
| Physical disability   | 2 (0-6) | 1 (0-4) | < 0.001* | 1 (0-5) | 1 (0-4) | 0.50 | 1 (0-7) | 0 (0-4) | 0.002* | 3 (0-7) | 0 (0-4) | 0.02* | 0.09 | 0.26 |
| Psychological disability | 1 (0-8) | 0.5 (0-4) | < 0.001* | 1 (0-8) | 1 (0-4) | 0.82 | 1 (0-5) | 0 (0-3) | < 0.001* | 2 (0-5) | 1.5 (0-3) | 0.02* | 0.21 | 0.42 |
| Social Disability     | 2 (0-7) | 0 (0-4) | 0.04* | 0 (0-7) | 1 (0-4) | 0.36 | 1 (0-4) | 0 (0-3) | 0.01* | 0.5 (0-3) | 0 (0-3) | 0.02* | 0.20 | 0.19 |
| Handicap              | 1 (0-8) | 0 (0-5) | 0.008* | 1 (0-6) | 0 (0-4) | 0.95 | 1 (0-5) | 0 (0-5) | 0.04* | 2.5 (0-5) | 0.5 (0-3) | 0.01* | 0.06 | 0.95 |

Data are presented as the median (minimum-maximum). OHIP-14= Oral Health Impact Profile-14. *Significant differences were seen between pre- and post-insertion using Wilcoxon’s signed rank test. Significant differences were seen among (a) with and without posterior occlusion, (b) with posterior occlusion and edentulous and (c) without posterior occlusion and edentulous using the Kruskal-Wallis test with Bonferroni’s adjustment.

Relative improvements were also seen in the subjective assessments. Subjective assessments have been widely used to evaluate the effect of dentures on patients’ OHRQoL as well as their food intake. A significant decline in the impact of dentures on the OHRQoL was seen for most removable denture patients, with all seven domains showing improvement. This suggests that patients may have benefited from denture renewal. Most importantly, this treatment was able to address issues that patients had encountered with their previous dentures. The food acceptability assessment demonstrated the lowest significant improvement among all of the other methods. One possible explanation for this finding is that most of the patients had sufficient remaining natural dentition that they already had reasonably good food acceptability, leaving little room for further improvement.

4.2. Correlations between assessments

Several studies on the relationship between the objective and subjective assessments have yielded different outcomes. In the study by Yamamoto et al. [2], the masticatory performance significantly correlated with the total score for OHIP and some of its parameters achieved with a uniform test food.
Table 6. Changes in the food acceptability with new dentures (5 groups).

| Food intake | all with posterior occlusion | without posterior occlusion | edentulous | p value |
|-------------|------------------------------|-----------------------------|------------|--------|
|             | pre-insertion | post-insertion | p value | pre-insertion | post-insertion | p value | pre-insertion | post-insertion | p value | pre-insertion | post-insertion | p value |
| Group 1     | 20 (10-20) | 20 (10-20) | 0.45 | 20 (15-20) | 20 (15-20) | 1.00 | 20 (15-20) | 20 (10-20) | 0.41 | 20 (10-20) | 0.010 * | 0.004 * 0.84 |
| Group 2     | 20 (20-20) | 20 (20-20) | 0.03* | 20 (20-20) | 20 (20-20) | 0.93 | 20 (20-20) | 20 (20-20) | 0.68 | 10 (20-20) | 15 (20-20) | 0.004* < 0.001* 0.09 |
| Group 3     | 15 (20-20) | 20 (20-20) | 0.10 | 20 (20-20) | 20 (20-20) | 0.40 | 15 (20-20) | 15 (20-20) | 0.61 | 0 (20-20) | 7.5 (20-20) | 0.03* < 0.001* 0.004* |
| Group 4     | 5 (2-20) | 10 (2-20) | 0.55 | 15 (2-20) | 10 (2-20) | 0.63 | 5 (2-20) | 10 (2-20) | 0.40 | 0 (2-20) | 2.5 (2-20) | 0.24 0.19 |
| Group 5     | 5 (2-20) | 5 (2-20) | 0.88 | 15 (2-20) | 10 (2-20) | 0.03* | 5 (2-20) | 5 (2-20) | 0.51 | 5 (2-20) | 0 (2-15) | 0.01* < 0.001* 0.03* |

Data are presented as the median (minimum-maximum).
*Significant differences were seen between pre- and post-insertion using Wilcoxon’s signed rank test.
Significant differences were seen among (a) with and without posterior occlusion, (b) with posterior occlusion and edentulous and (c) without posterior occlusion and edentulous using the Kruskal-Wallis test with Bonferroni’s adjustment.

Table 7. The correlation between the relative changes in the objective and subjective assessments.

| RV406 | All with posterior occlusion | without posterior occlusion | Edentulous |
|-------|-----------------------------|-----------------------------|------------|
| RVHIP | RVFAQ | RVHIP | RVFAQ | RVHIP | RVFAQ | RVHIP | RVFAQ |
| r-value | -0.18 | 0.23 | -0.14 | 0.28 | -0.33 | 0.12 | -0.39 | 0.48 |
| p value | 0.11 | 0.045* | 0.46 | 0.16 | 0.06 | 0.50 | 0.16 | 0.07 |

RVMP= relative value of masticatory performance, RVHIP= relative value of OHIP-14, RVFAQ= relative value of food acceptability. With posterior occlusion: Eichner A3, B1, B2 and B3, without posterior occlusion: B4, C1, C2 and edentulous group: C3.
Significant differences between the objective and subjective assessments were calculated with Spearman’s rank correlation.

4.3. Influence of the occlusal status

A reduced number of teeth may markedly affect the masticatory function [34]. Several reports have suggested that a decline in the masticatory function impacts the chewing ability, OHRQoL, nutrient intake and even meal enjoyment. According to our study, the lowest and highest pre- and post-insertion scores for both the objective and subjective evaluations were found in edentulous patients and w/PO, respectively. The masticatory function of edentulous patients may not be comparable to that of partially edentulous patients, which is a consequence of their severely diminished dentition [35]. This is in accordance with the findings of Kosaka et al. [35], who showed that the masticatory performance of subjects with partial loss (Eichner B) and complete loss (Eichner C) of occlusal supporting areas was around 70% and 50%, respectively, of the Eichner A value, even with prosthetic support.

A different perspective is seen in terms of the relative change in the masticatory function. Marked changes in both objective and subjective assessments were seen in the w/o PO and edentulous groups, with the latter having the greatest advantage in recovering the loss in masticatory function after denture renewal. The remarkable increase in the masticatory performance (about 129%) from the previous evaluation in edentulous patients may be explained by a number of reasons, such as the re-establishment of all occluding pairs, recovered vertical dimension and comfort provided by better-fitting dentures [10].

In contrast, the w/PO and w/o PO groups only managed to increase their masticatory performance by 21% and 18%, respectively. Partially edentulous patients usually improve after prosthodontic rehabilitation at a minimum due to their remaining functional dentition. These patients tend to favor the side with natural dentition during mastication as this results in greater masticatory force and support [36].

Regarding the OHRQoL, marked improvements in both the total and domain scores of w/o PO patients (7 domains) and edentulous patients (5 domains) were revealed. While patients w/PO had the lowest score, thus indicating a better quality of life than the other groups even after treatment with new dentures. This finding also correlates with the study by Cardoso et al. [28] where correlations were only seen between the masticatory performance and the OHRQoL after treatment of conventional prosthesis. Recent studies that determined the correlation between the objective and subjective assessments analyzed the correlation by two separate assessments according to the timing of the evaluation. In order to clearly quantify the effect of treatment, we computed the relative value of changes.

A significant positive correlation was seen between the change in the masticatory performance and food acceptability. The association of an improved masticatory performance with food acceptability can be seen in removable denture patients, especially in edentulous. This shows the positive effect of an improved masticatory function and was in accordance with the study by Shiga et al. [19], which found an association between improvements in the food acceptability and masticatory performance after denture treatment. It was also emphasized that a patient’s texture acceptability is important for their perceived mastication, which helps them maintain and recover their masticatory performance [32].

Although there was no significant change, a negative correlation was noted between the changes in the masticatory performance and OHRQoL for patients w/o PO. Since these patients have sufficient food acceptability, the treatment was beneficial for their OHRQoL. The various correlations seen between the objective and subjective assessments may be attributed to several factors (such as individual personality, experiences, sense of coherence, motivation or socio-demographic status) [33], which may result in a unique and intra-individual understanding for each patient type. The present findings suggested that each occlusal type might yield a different correlation between assessments as well as that there might be a gap between subjective and objective assessments. Therefore, assessing the masticatory function requires consideration of both subjective and objective views.
after insertion of new denture. Steele et al. [37] suggested that the OHIP scores tend to increase rapidly when a person possesses fewer than 25 natural teeth. The different responses may give distinction to the extent of discomfort and negative experiences each patient has encountered in the course of being edentulous [30]. Each patient’s adaptive mechanism for recovering and improving their OHROqOL may vary depending on their transition to their current state. Given that edentulous patients have transitioned from being dentate to partially edentulous to being edentulous, they may have adjusted their expectations to a more realistic level, which may be comparable to that of partial denture patients. Bae et al. [4] suggested that edentulous patients are more aware of being handicapped and are thus more capable of functioning with dentures than partially edentulous patients.

The food acceptability was only markedly improved in edentulous patients, since w/PO and w/o PO patients already had relatively good food acceptability pre-insertion. Limitations in food acceptability are particularly obvious in edentulous patients due to their lack of confidence and motivation to try foods. A previous study suggested that the decrease in the masticatory function caused by tooth loss may limit an individual’s food intake [38]. One of the underlying causes of altered food options may be a reduction in available PO and insufficient support by old dentures. Renewal of dentures may improve and restore their ability to enjoy a variety of foods. However, the use of dentures may not fully support a better food selection. Suzuki et al. therefore suggested that supplementary dietary advice might help patients positively change their perceptions about available food options [40].

4.4. Limitations of the study
One of the limitations of this study is the small sample size for each occlusal support category [39]. Furthermore, the authors were also unable to attain an equal number of subjects for each group or an even gender distribution. Due to the fact that the study subjects were limited to hospital patients who provided their consent to participate and were able to undergo an evaluation twice (with the old and new dentures), there might have been some bias and/or limitations in the comparison of the changes after the insertion of new dentures. These assessments are still ongoing at present, so further examinations are expected to be possible in the future.

4.5. Clinical implications
In order to achieve a successful recovery of the masticatory function, both the objective and subjective aspects should be clarified. This may help clinicians fully understand the changes and administer appropriate treatment as needed. The present findings indicate that the objective and subjective masticatory functions are not necessarily in agreement, especially for edentulous patients, who easily perceive improvements in their subjective masticatory function with new denture insertion even if the objective masticatory function might not be markedly restored.

5. Conclusion
Improvement of the masticatory performance with new dentures and its relationship with subjective measures varied among types of occlusal support. Both objective and subjective evaluations are needed in order to evaluate the treatment outcomes of removable dentures.

Conflict of interest statement
None of the authors have any conflicts of interest to disclose.

References
[1] Nguyen TC, Witter DJ, Bronkhorst EM, Gerritsen AE, Creugers NH. Chewing ability and dental functional status. Int J Prosthodont. 2011;24(5):428-36.
[2] Yamamoto S, Shiga H. Masticatory performance and oral health-related quality of life before and after complete denture treatment. J Prosthodont Res. 2018;62(3):370-4.
[3] Sato Y, Ishida E, Minagi S, Akagawa Y, Tsuru H. [The aspect of dietary intake of full denture wearers]. Nihon Hotetsu Shika Gakkai zasshi 1988;32(4):774-9. Japanese.
[4] Bae KH, Kim C, Paik DL, Kim JB. A comparison of oral health related quality of life between complete and partial removable denture-wearing older adults in Korea. J Oral Rehabil. 2006;33(5):317-22.
[5] Emami E, Allison PJ, de Grandmont P, Rorphe PH, Feine JS. Better oral health related quality of life: type of prosthesis or psychological robustness? J Dent 2010;38(3):252-6.
[6] Asakawa A, Fueki E, Ohyama T. Detection of improvement in the masticatory function from old to new removable partial dentures using mixing ability test. J Oral Rehabil. 2005;32(9):629-34.
[7] Gunne HS, Wall AK. The effect of new complete dentures on mastication and dietary intake. Acta odontologica Scandinavica 1985;43(5):257-68.
[8] Ellis JS, Pelikis ND, Thomason JM. Conventional rehabilitation of edentulous patients: the impact on oral health-related quality of life and patient satisfaction. J Prosthodont. 2007;16(1):37-42.
[9] Rito HC, Kuo YS, Lee IC, Wang JC, Yang YH. The association of responsiveness in oral and general health-related quality of life with patients’ satisfaction of new complete dentures. Qual Life Res. 2013;22(7):1665-74.
[10] Viola AP, Takamisy AS, Monteiro DR, Barbosa DB. Oral health-related quality of life and satisfaction before and after treatment with complete dentures in a Dental School in Brazil. J Prosthodont Res. 2013;57(1):36-41.
[11] Persic S, Celebic A. Influence of different prosthodontic rehabilitation options on oral health-related quality of life, orofacial esthetics and chewing function based on patient-reported outcomes. Qual Life Res. 2015;24(4):919-26.
[12] John MT, Slade GD, Szentpetery A, Setz JM. Oral health-related quality of life in patients treated with fixed, removable, and complete dentures 1 month and 6 to 12 months after treatment. Int J Prosthodont. 2004;17(5):503-11.
[13] Veyrune IL, Tubert-Jeannin S, Dutheil C, Riordan PJ. Impact of new prostheses on the oral health related quality of life of edentulous patients. Gerodontology 2005;22(1):3-9.
[14] Gunji A, Kimoto S, Koido J, Murakami H, Matsumaru Y, Kimoto K, et al. Investigation on how renewal of complete dentures impact on dietary and nutrient adequacy in edentulous patients. J Prosthodont Res. 2009;53(4):180-4.
[15] Arak K, Hasanreisoglu U, Shingotaya T. Masticatory performance, maximum occlusal force, and occlusal contact area in patients with bilaterally missing molars and distal extension removable partial dentures. J Prosthodont. 2009;22(2):204-9.
[16] Ribiero JA, de Resende CM, Lopes AL, Mestriner W, Jr., Roncalli AG, Farias-Neto A, et al. Evaluation of complete denture quality and dietary intake of edentulous patients. J Prosthodont Res. 2014;58(2):102-6.
[17] Shiga H, Ishikawa A, Nakajima K, Tanaka A. Relationship between masticatory performance using a gymnical jelly and food intake ability in Japanese complete denture wearers. Odontolgy 2015;103(3):356-9.
[18] Ikebe K, Morii K, Matsuoka K-i, Hazeyama T, Nokubi T. Reproducibility and Accuracy in Measuring Masticatory Performance Using Test Gummy Jelly. Prosthdontic Research & Practice 2005;4(1):9-15.
[19] Igarashi K, Watanabe Y, Kugimiyu Y, Shioke M, Edahiro A, Kaneda K, et al. Validity of a visual scoring method for gummy jelly for evaluating chewing efficiency in a large-scale epidemiological survey. J Oral Rehabil. 2019;46(5):409-16.
[20] Nokubi T, Yoshimuta Y, Nokubi F, Yasui S, Kusunoki C, Ono T, et al. Validation and reliability of a visual scoring method for masticatory ability using test gummy jelly. Gerodontology 2013;30(1):76-82.
[21] Nokubi T, Yasui S, Yoshimuta Y, Kida M, Kusunoki C, Ono T, et al. Fully automatic measuring system for assessing masticatory performance using beta-carotene-containing gummy jelly. J Oral Rehabil. 2013;40(2):199-105.
[22] Celėliūtė A, Knezović-Zlatarić D. A comparison of patient’s satisfaction between complete and partial removable denture wearers. J Dent. 2003;31(7):445-51.
[23] Bonnet G, Batissé C, Segoy JW, Veyrune JL, Nicolas E, Bessadat M. Influence of the renewal of removable dentures on oral health related quality of life. SpringerPlus 2016;5(1):2019.
[26] Komagamine Y, Kanazawa M, Kaiba Y, Sato Y, Minakuchi S. Reliability and validity of a questionnaire for self-assessment of complete dentures. BMC Oral Health. 2014;14:45.

[27] Pedroni-Pereira A, Marquezin MCS, Araujo DS, Pereira LJ, Bommarito S, Castelo PM. Lack of agreement between objective and subjective measures in the evaluation of masticatory function: A preliminary study. Physiol Behav. 2018;184:220-5.

[28] Cardoso RG, Melo LA, Barbosa GA, Calderon PD, Germano AR, Mestriner WJ, et al. Impact of mandibular conventional denture and overdenture on quality of life and masticatory efficiency. Braz Oral Res. 2016;30(1):e102.

[29] Eichner K. [Renewed examination of the group classification of partially edentulous arches by Eichner and application advices for studies on morbidity statistics]. Stomatologie der DDR 1990;40(8):321-5. German.

[30] Slade GD. Derivation and validation of a short-form oral health impact profile. Community Dent Oral Epidemiol. 1997;25(4):284-90.

[31] De Carvalho Dias K, Da Fonte Porto Carreiro A, Bastos Machado Resende CM, Soares Parva Torres AC, Mestriner Junior W. Does a mandibular RDP and new maxillary CD improve masticatory efficiency and quality of life in patients with a mandibular Kennedy class I arch? Clin Oral Investig. 2016;20(5):951-7.

[32] Wayler AH, Kapur KK, Feldman RS, Chauncey HH. Effects of age and dentition status on measures of food acceptability. J Gerontol. 1992;57(3):294-9.

[33] Fenlon MR, Sherriff M, Douglas Walter J. An investigation of factors influencing patients’ use of new complete dentures using structural equation modelling techniques. Community Dent Oral Epidemiol. 2000;28(2):133-40.

[34] Ueno M, Yanagisawa T, Shinada K, Ohara S, Kawaguchi Y. Category of functional tooth units in relation to the number of teeth and masticatory ability in Japanese adults. Clin Oral Investig. 2010;14(1):113-9.

[35] Kosaka T, Ono T, Yoshimura Y, Kida M, Kikui M, Nokubi T, et al. The effect of periodontal status and occlusal support on masticatory performance: the Suita study. J Clin Periodontol. 2014;41(5):497-503.

[36] Bakke M. Bite Force and Occlusion. Semin Orthod. 2006;12(2):120-6.

[37] Steele JG, Sanders AE, Monteiro DR, Barbosa DB. Oral health-related quality of life and satisfaction before and after treatment with complete dentures in a Dental School in Brazil. J Prosthodont Res. 2013;57(1):36-41.

[38] Hildebrandt GH, Dominguez BL, Schork MA, Loesche WJ. Functional units, chewing, swallowing, and food avoidance among the elderly. J Prosthodont. 1997;7(6):588-95.

[39] Wang R, Lagakos SW, Ware JH, Hunter DJ, Drazen JM. Statistics in Medicine - Reporting of Subgroup Analyses in Clinical Trials. N Engl J Med. 2007;357(21):2189-94.

[40] Suzuki H, Kanazawa M, Komagamine Y, et al. The effect of new complete denture fabrication and simplified dietary advice on nutrient intake and masticatory function of edentulous elderly: A randomized-controlled trial. Clin Nutr. 2019;37(5):1441-7.