Abstract

Purpose: To evaluate masticatory performance (MP), maximum occlusal force (MOF), maximum tongue pressure (MTP) and oral diadochokinesis (ODK) among community-dwelling elderly patients without posterior occlusal support.

Methods: This study enrolled community-dwelling elderly patients (≥65 years old) who belonged to Eichner A, B4, C1, C2, and C3. Each oral function was statistically compared among groups. Correlations between MP and other variables were examined in Eichner B4 and C patients.

Results: MP and MOF values in Eichner B4 and C patients were significantly lower than in Eichner A patients. There were significant differences in MTP values between Eichner “A and C2, C3”, and “B4 and C2, C3” ODK in Eichner C patients showed significantly lower values compared to Eichner A patients in general. Although there were statistically significant correlations of MP with age, the number of remaining teeth and all oral functions were identified, and multiple regression analysis indicated that MOF and MTP were independently related to MP.

Conclusion: Oral functions in Eichner B4 and C patients were lower compared to Eichner A patients. MP was significantly correlated with MOF and MTP in elderly patients without posterior occlusal support, suggesting the importance of rehabilitation of MOF and MTP in MP.

Keywords; community-dwelling elderly, Eichner index, masticatory performance, oral functions, posterior occlusal support

Introduction

Nutritional management for the elderly plays a crucial role in the prevention of frailty and cognitive impairment [1-5]. Mastication and deglutition are essential for dietary intake. Mastication influences not only nutritional status but also oral health-related quality of life (OHRQoL) [6,7] and cognitive function [8-10]. Objective assessment of masticatory function (masticatory performance [MP] or masticatory efficiency) has been widely used to evaluate the treatment effect [6,7,9-18].

As previous studies showed, MP is influenced by various factors, such as the number of remaining teeth [12,14,15,17,18], posterior occlusal support [11-13,18], occlusal force [12,14-16], tongue pressure [14,16,17] and tongue-lip motor function [14,16]. These findings suggest that dentists should understand the crucial roles of these factors in oral rehabilitation including morphologic rehabilitation and various functional rehabilitations. In particular, occlusal stability results in the optimization of oral functions including mastication, and esthetics. In many cases, occlusal stability is attributed to stable posterior occlusal support [19-21]. Patients who lost posterior occlusal support by natural teeth showed reduced masticatory function compared to patients with complete arches [11-13]. Although there are a number of classifications according to occlusal support, the Eichner index is one of the well-known classifications. Previous studies evaluated masticatory performance in partially edentulous and edentulous patients using the Eichner index [11,12,15]. However, Eichner B groups (B1-B4) show diverse occlusal conditions depending on the number and distribution of remaining teeth [13,22]. To evaluate the effect of posterior occlusal support by natural teeth on oral functions, a relevant approach is to compare oral functions in patients who lost posterior occlusal support by natural teeth (Eichner B4 and C groups) with those in Eichner A patients. In addition, to the best of the authors’ knowledge, no studies have compared oral functions among Eichner B4, C1, C2, and C3 elderly patients, who lost posterior occlusal support by natural teeth.

The aim of this study was to evaluate oral functions such as MP in community-dwelling elderly patients who were classified into Eichner B4 and C and to compare their oral functions with those in Eichner A elderly patients. In addition, correlations between MP and other factors including age, number of teeth and other oral functions were also evaluated to validate features in elderly Eichner B4 and C elderly patients. The null hypotheses of this study were 1) no differences in oral functions among Eichner A, B4, and C elderly patients, and 2) no association of MP with other factors in those patients. Based on analyses in this study, the discussions regarding the impact of posterior occlusal support by natural teeth on oral functions and MP rehabilitation in elderly patients belonging to Eichner B4 and C were aimed.

Materials and Methods

Study design and subjects

This study was conducted as an institutional ethical review board-approved retrospective cross-sectional study (approval number #19) and was carried out in accordance with the principles of the Declaration of Helsinki.

The subjects of the present study were community-dwelling elderly patients who visited the dental department in a local hospital (Sasaguri Hospital, Fukuoka, Japan) for oral rehabilitation from April, 2018 to March, 2019. Patients who met the following inclusion criteria were extracted: 1) elderly patients more than 65 years of age as described above; 2) patients who had completed prosthetic treatment (edentulous and/or partially edentulous sites had been rehabilitated with removable dental prostheses [RDPs] including removable partial dentures [RPDs] and complete dentures [CDs] and/or fixed dental prostheses [FDPs]) without any specific problems with RDPs; 3) patients whose cognitive functions were sufficient to communicate with us and to measure oral functions; and 4) patients whose oral functions (MP, maximum occlusal force: MOF, maximum tongue pressure: MTP, and tongue-lip motor function) had been recorded. Exclusion criteria were as follows: 1) patients who had ongoing prosthetic treatment; 2) patients whose edentulous and/or partially edentulous sites had been rehabilitated with implant-supported prostheses; and 3) patients who had a dysphagia diet or very soft diet due to mastication or deglutition problems. Oral profiles such as the number of remaining teeth and Eichner index were also reviewed from their medical charts. The number of remaining teeth was counted according to the concept of oral hypofunction (remaining roots and teeth with mobility 3 were excluded) [23]. Patients who belonged to Eichner B4 and C (a lack of posterior occlusal support by natural teeth) were recruited in the present study. Patients classified into
Eichner A were also enrolled as a positive control group (patients who had all posterior occlusal support areas with premolars and molars).

Measurement of oral functions
Measurement of MP
MP was measured in the same way as reported elsewhere [11-16]. Briefly, patients were instructed to chew 2 g of gummy jelly voluntarily for 20 s. Crushed gummy jelly was moved to a cup with saliva and rinsing water and the concentration of glucose dissolved in water was measured using a measuring device (Gluco Sensor GS-II, GC Corp., Tokyo, Japan).

Measurement of MOF
MOF was measured using the occlusal force analyzing system in the same way as in previous studies [11,12,14-17]. A pressure-sensitive sheet (Dental Prescale II, GC Corp.) was placed on the dental arch and was pressed with maximum clenching force for 3 s in the intercuspal position. The sheet was analyzed using a measuring device (Bite force analyzer, GC Corp.) to calculate MOF.

Measurement of MTP
MTP was measured using a specific measuring device with a balloon of the probe (JM-TPM; JMS Co., Ltd., Hiroshima, Japan) [14,16,17]. Patients were asked to pinch the compressed balloon between tongue and anterior palate and to compress it onto the palate by tongue elevation for 7 s. The device indicated the maximum value of tongue pressure during 7 s (MTP). MTP was measured 3 times and the mean value was recorded.

Measurement of tongue-lip motor function by oral diadochokinesis (ODK)
Tongue-lip motor function was determined with ODK, rapid syllable repetitions [14,16,17]. Patients were asked to articulate /pa/, /ta/ and /ka/ sounds for 5 s as quickly as possible. These sounds were recorded using a measurement device (Kenko-kun; Takei Scientific Instruments Co., Ltd., Niigata, Japan). This device calculated the number of sounds per second after recording for 5 s. In general, /pa/, /ta/ and /ka/ are used to evaluate motor function, one for each of lip movement, anterior region of the tongue and posterior region of the tongue respectively as shown in a previous study [23].

Statistical data analysis
Numerical data were presented as the median and interquartile range (IQR) except for age, which were presented as the median and range, and were also shown as a box plot. The values of each oral function and age were statistically compared among Eichner A, B4, C1, C2, and C3 groups using Steel-Dwass test (non-parametric method, a post-hoc test after Kruskal-Wallis test) for multiple comparisons. Correlations among MP and other factors were analyzed using Spearman’s rank correlation coefficient for Eichner B4 and C group. In addition, multiple regression analysis was also used to explore the correlation between MP and other independent variables (age, the number of remaining teeth and other oral functions). All statistical analyses were performed using JMP15 software (SAS Institute Inc., Cary, NC, USA). Statistical significance was set at $P < 0.05$.

Results

Patient profiles

| Eichner index | Gender   | Age (number) | Number of remaining teeth (IQR) |
|---------------|----------|--------------|---------------------------------|
| All           | M: 64, F: 90 | 79 (65-101) | 10 (3-26)                      |
| A             | M: 21, F: 31  | 75 (65-91) | 27 (27-28)                     |
| B4            | M: 5, F: 15   | 75 (65-92) | 13.5 (10-17.75)                |
| C1            | M: 10, F: 13  | 79 (67-92) | 7 (5-12)                       |
| C2            | M: 11, F: 21  | 82 (66-92)* | 5.5 (2.25-8.5)                |
| C3            | M: 17, F: 10  | 86 (71-101)$ | 0                               |

| Gender (M: Male; F: Female); IQR, interquartile range. The number of remaining teeth was defined according to the concept of oral hypofunction defined by Minakuchi et al. [23]. The remaining roots and teeth with mobility 3 were excluded. (Steel-Dwass test: *$P < 0.01$, vs Eichner A; †$P < 0.0001$, vs Eichner A; ‡$P < 0.05$, vs Eichner B4) |

Table 1 Patient profiles

| Eichner index | Gender (number) | Age (Median (range)) | Number of remaining teeth (Median (IQR)) |
|---------------|-----------------|----------------------|----------------------------------------|
| All           | M: 64, F: 90    | 79 (65-101)          | 10 (3-26)                              |
| A             | M: 21, F: 31    | 75 (65-91)           | 27 (27-28)                             |
| B4            | M: 5, F: 15     | 75 (65-92)           | 13.5 (10-17.75)                        |
| C1            | M: 10, F: 13    | 79 (67-92)           | 7 (5-12)                               |
| C2            | M: 11, F: 21    | 82 (66-92)*          | 5.5 (2.25-8.5)                         |
| C3            | M: 17, F: 10    | 86 (71-101)$         | 0                                      |

Fig. 1 MP value in each Eichner index (Steel-Dwass test: *$P < 0.001$, vs Eichner A; †$P < 0.0001$, vs Eichner A; ‡$P < 0.05$, vs Eichner B4)

Fig. 2 MOF value in each Eichner index (Steel-Dwass test: *$P < 0.0001$, vs Eichner A; †$P < 0.05$, vs Eichner B4; ‡$P < 0.01$, vs Eichner B4)

Comparative analyses of oral functions among Eichner groups

Each oral function was compared according to Eichner index. Non-parametric analyses were conducted after Shapiro-Wilk test. In MP, Eichner A patients showed the highest MP values and significant differences were observed in comparison to Eichner B4 ($P < 0.001$) and C groups ($P < 0.0001$) (Fig. 1). In addition, MP values in Eichner B4 were statistically higher than the values in Eichner C2 ($P < 0.05$) (Fig. 1).

Similar to MP, MOF values in Eichner A group were significantly higher in comparison to values in Eichner B4 and C groups, respectively ($P < 0.0001$) (Fig. 2). The MOF values in Eichner B4 group were significantly higher than the values in Eichner C2 ($P < 0.05$) and C3 ($P < 0.01$) (Fig. 2). MTP values are shown in Fig. 3. MTP values in Eichner A group were significantly higher than values in Eichner C2 ($P < 0.05$) and C3 ($P < 0.001$) groups, and Eichner B4 group showed statistically higher values than Eichner C2 and C3 groups ($P < 0.01$).

The results of ODK are shown in Fig. 4. These results demonstrated that Eichner A group could utter statistically more /pa/ and /ta/ sounds in comparison with Eichner C groups ($P$-values were shown in Fig. 4). Additionally, Eichner A group could utter statistically more /ka/ sounds in comparison with Eichner C2 ($P < 0.01$) and C3 groups ($P < 0.001$). Eichner B4 group could also utter statistically more /pa/ and /ka/ sounds in comparison with Eichner C3 group ($P < 0.05$ in /pa/ and $P < 0.01$ in /ka/ sound, respectively).
Spearman correlation analysis

Spearman rank correlation coefficient was calculated to evaluate the correlation between MP and other variables (Table 2). These results showed that all variables had significant correlations with MP.

Multiple regression analysis

Based on the results of Spearman correlation analysis, multiple regression analysis was conducted to identify the correlation between MP and other independent variables. To assess multicollinearity in this analysis, correlation coefficients were calculated between two of all variables. The highest correlation coefficient was 0.81 between ODK /ta/ and /ka/ (data not shown), and multicollinearity was avoided. This analysis clearly demonstrated significantly independent correlations of MP with MOF ($P < 0.01$) and MTP ($P < 0.05$) (Table 3).

Discussion

Posterior teeth and their occlusal support play a crucial role in masticatory function [11-13,15]. Patients who lost posterior teeth are generally rehabilitated with RDPs and/or FPDs for better masticatory function. Mastication is a complex sensory-motor activity including masseter muscles, tongue, mandibular movements and saliva [24]. In this study, MP and other oral functions in patients who lost posterior occlusal support in terms of the tongue, mandibular movements and saliva [24]. In this study, MP and other oral functions, to the authors' knowledge, fewer studies evaluated the conversion of Kennedy classification by implant placement was an effective method to improve occlusal condition from the clinical point of view [25,26]. The analyses with consideration of Kennedy classification and RDP designs can demonstrate more meaningful results, although more patients are necessary.

Significantly higher MTP was measured in Eichner A and B4 patients compared to Eichner C2 and C3 patients. Previous studies revealed a significant association of MTP with remaining teeth and anterior teeth (sensory input) [30,31]. The method used in this study was to measure ODK for tongue-lip motor function in Eichner A were statistically higher than Eichner C2 (MP), and Eichner C2 and C3 (MOF), respectively. These findings suggest that natural tooth contacts, even in anterior teeth, can be valuable for higher MP and MOF. Considering that Eichner C2 and C3 patients wear CD, at least in one jaw, a combination of natural teeth and removable partial dentures retained by natural abutment teeth might create higher MP and MOF compared to ones in CD wearers. Although this depends on each patient’s condition, on the whole, this study could confirm the effectiveness of natural teeth and their contacts in rehabilitation of MP and MOF based on the results of this study. A limitation of this discussion, in addition to the statistical differences in age, is that the detailed distribution of the remaining teeth is not analyzed. In this study, although patients who were rehabilitated with implants including implant-assisted RDPs were excluded, previous studies demonstrated that the conversion of Kennedy classification by implant placement was an effective method to improve occlusal condition from the clinical point of view [25,26]. The analyses with consideration of Kennedy classification and RDP designs can demonstrate more meaningful results, although more patients are necessary.

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ODK for tongue-lip motor function in Eichner A were statistically higher than Eichner C patients. Eichner B4 patients could utter statistically more sounds of /pa/ and /ka/ than Eichner C3 patients. Compared to other functions, to the authors’ knowledge, fewer studies evaluated the effect of oral factors on ODK. Previous studies showed that one of the influential factors on ODK was aging [31-35]. As described above, the present study also revealed significant differences in age among groups (Table 1), although the main purpose of this study was to investigate the effect of posterior occlusal support. It is required to recognize that there are multiple confounding factors, such as the number of teeth and muscle, and further studies that focus on ODK will be required. However, these results are important in understanding the significance of tongue-lip motor function in patients.

Table 2 Spearman rank correlation coefficient against MP in Eichner B4 and C patients

| Variables                  | $\rho$ | P-value |
|----------------------------|--------|---------|
| Age                       | -0.23  | 0.02    |
| Number of remaining teeth  | 0.29   | <0.01   |
| MOF                       | 0.38   | <0.0001 |
| MTP                       | 0.42   | <0.0001 |
| ODK /pa/                  | 0.38   | <0.0001 |
| ODK /ta/                  | 0.43   | <0.0001 |
| ODK /ka/                  | 0.45   | <0.0001 |

MP, masticatory performance; $\rho$, Spearman’s rank correlation coefficient; MOF, maximum occlusal force; MTP, maximum tongue pressure; ODK, oral diadochokinesis

Table 3 Multiple regression analysis against MP

| Variables                  | B   | SE  | $\beta$ | t-value | P-value |
|----------------------------|-----|-----|---------|---------|---------|
| Age                       | 0.60| 0.73| 0.10    | 0.82    | 0.42    |
| Number of remaining teeth  | 0.47| 0.09| 0.06    | 0.53    | 0.006   |
| MOF                       | 0.07| 0.03| 0.26    | 2.81    | 0.0006  |
| MTP                       | 1.12| 0.55| 0.23    | 2.04    | 0.04    |
| ODK /pa/                  | 1.63| 0.64| 0.04    | 0.29    | 0.77    |
| ODK /ta/                  | 2.22| 3.84| 0.05    | 0.27    | 0.79    |
| ODK /ka/                  | 0.95| 0.69| 0.23    | 1.49    | 0.14    |

MP, masticatory performance; B, partial regression coefficient; SE, standard error; $\beta$, standardized partial regression coefficient; MOF, maximum occlusal force; MTP, maximum tongue pressure; ODK, oral diadochokinesis.
The correlations of MP with age, number of remaining teeth and other oral functions were assessed in Eichner B4 and C patients. Spearman correlation analysis demonstrated that MP significantly correlated with all variables. Furthermore, more specific analysis using multiple regression analysis revealed significantly independent correlations of MP with MOF and MTP. Independent variables were also investigated in previous studies. The present study confirmed that MOF and MTP were significant independent variables against MP even in Eichner B4 and C patients who lost posterior occlusal support by natural teeth. This finding is supported by previous studies [12,14-17]. MOF and MTP were related to muscle activity, status of prosthesis and distribution of natural teeth [18,27,28,31,33-35]. Patients who showed higher MP have better oral status and oral functions, and the intervention for oral rehabilitation including muscle practice and the delivery of well-functioning prosthesis might play an important role for better MP. A further distinctive point is the significance of other independent variables, especially the number of remaining teeth, which indicated a significant positive correlation with MP in Spearman correlation analysis but not in multiple regression analysis. A wide variety in the number of teeth in Eichner B4, C1, and C2 patients was observed. Further investigations are required to define the impact of other variables on MP, including a prospective intervention study.

Unfortunately, this study was conducted as a retrospective cross-sectional study. This means that the sample size was limited and it was very hard to assess the quality and design of RDPs, although all subjects used RDPs without any specific problems. In addition, the classification in the subjects was based only on the Eichner classification. These were the limitations of this study. Although the necessity for further studies was suggested, the important roles of natural teeth in these patients were confirmed in oral functions to some extent. To rehabilitate MP in this population, not only posterior occlusal support by prostheses but also MOF and MTP rehabilitation may be effective. To rehabilitate a wide range of the elderly population, further studies will be required to evaluate these functions in nursing home elderly patients, hospitalized elderly patients or patients with some specific conditions such oral cancers and radiotherapy, who need special treatment and care at specific institutions.

Conflict of interest

One of the authors (K.K.) belongs to the Division of Advanced Dental Devices and Therapeutics, Faculty of Dental Science, Kyushu University. This division is endowed by GC Corporation. GC Corporation had no specific roles in this study. The other authors declare no conflicts of interest associated with this manuscript.

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