令和 4 年度　学位論文

Effect of Mandibular Bilateral Distal Extension Denture Design on Masticatory Performance

－下顎両側遊離端義歯の設計が咀嚼能率に与える影響－

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Abstract

Purpose: Removable partial dentures have a wide range of applications as missing tooth prostheses, and the denture design can be quite diverse. However, the factors affecting masticatory function remain unclear. We investigated the effect of denture design, especially the use of indirect retainers and major connectors, on masticatory function in patients with mandibular bilateral distal extension dentures.

Methods: Fifty-three patients with mandibular Kennedy Class I and Eichner classification B occlusal support were included in this study. Masticatory performance (MP) was assessed using gummy jelly. For the dentures, the type of major connector (bar or apron), presence or absence of indirect retainers, number of rests, and number of artificial teeth were evaluated. The number of functional teeth and occlusal support, Eichner classification, maxillary denture usage, mandibular residual ridge height, and duration of denture use were also evaluated. The factors influencing MP were evaluated using the Mann-Whitney U test, Spearman's correlation coefficient, and logistic regression analysis.

Results: MP was significantly higher when the major connector was bar-type or when there was an indirect retainer than with an apron-type or no indirect retainer. MP was positively correlated with the number of functional teeth, occlusal support, and number of rests. Logistic regression analysis revealed that the number of functional teeth and the presence or absence of an indirect retainer were factors that significantly influenced the MP.

Conclusion: An indirect retainer setting is useful for achieving good masticatory performance in mandibular bilateral distal extension dentures.

Keywords: mastication, removable partial denture, denture stability, denture design, major connector

1. Introduction

In today's aging society, prosthetic treatment using dentures can improve the health expectancy of older adults. In Japan, removable partial dentures (RPDs) are currently used by approximately 35% of patients aged 65–75 years and 45% of those aged ≥75 years [1]. RPDs have a wide range of applications, including esthetic restoration, and play an important role in restoring oral function, particularly mastication. The maintenance and restoration of mastication through the fabrication of a good removable denture enables a well-balanced diet [2], which contributes to the maintenance of normal motor and physiological functions and reduces the risk of developing lifestyle-related diseases such as diabetes and hypertension. As a result, these devices are believed to increase the life expectancy of older adults [3].

Owing to the wide range of indications for RPDs, the condition of dentition in patients is diverse. In addition, there are a wide range of denture component options (retainers, connectors, artificial teeth, and denture bases). Many studies on RPDs have been reported in many areas, including studies on the effects of different components [4,5,6], dynamic analyses of dentures [7–11], and studies on the effects of RPDs on the surrounding tissues [12–14]. The reduction in denture movement during mastication reportedly leads to successful prosthetic treatment [15]. Therefore, it is important to control denture movement during mastication by adopting an appropriate RPD design.

Controlling denture movement is particularly difficult in patients with missing mandibular bilateral distal extension [6]. This is because the denture base has a large amount of tissue displacement, and the denture needs to be supported by both the abutment tooth and the crest of the residual ridge. Distal extension dentures are more difficult to maintain and stabilize than that of tooth-bound saddle dentures [16].

The design of mandibular distal extension dentures has been described in various ways. However, very few studies have investigated the effect of denture design on masticatory

performance (MP). Matsui et al. [17] reported that the MP was improved when the major connector was a lingual apron compared to that of a lingual bar. Sánchez-Ayala et al. [18] reported that the length of the occlusal support of the RPD influences masticatory function. Indirect retainers placed on abutment teeth away from the defect are used to control denture movement [19]. However, no report has clarified the effect of the presence or absence of an indirect retainer on the masticatory function of the RPD.

Therefore, the present study investigated the effects of differences in major connectors and the presence or absence of an indirect retainer on the objective MP of patients with mandibular free-end defects.

2. Materials and Methods

2.1. Participants

The study participants were registered in the database of a progress prospective observational study approved by the Human Research Ethics Committee (Approval Number 2015-3038) and registered in the University Hospital Medical Information Network (UMIN) Clinical Trials Registry (UMIN000043338). The study was performed in accordance with STROBE guidelines. The participants in this study visited the Removable Prosthodontic Clinic or General Dentistry and Clinical Education Unit at the University Medical and Dental Hospital between October 2015 and July 2020, and routinely wore mandibular bilateral distal extension dentures.

The inclusion criteria were as follows: missing teeth nos. 6 and 7 on both sides of the mandible; Kennedy classification class I (bilateral free end defect) not including intermediate defects; Eichner classification (a method of evaluating occlusal support areas) group B2 with two support areas and group B3 with one support area [20]; those who did not complain of any pain or functional disturbances; those with denture abutment teeth in good periodontal condition [21]; those with no known history of temporomandibular joint disorders; and those who were able to understand and appropriately respond to a questionnaire. Participants were excluded for the following reasons: limited usage of their RPDs (e.g., wearing them only during meals or typically removing them), no molar occlusal support, wearing coping-supported RPDs and implant-supported RPDs, wearing RPDs fabricated using a one-piece metal framework, RPDs used as maxillofacial prostheses, and mandibular or maxillary complete dentures. All participants provided written consent after receiving verbal and written explanations of the study purpose and methods.

2.2. Denture design

The dentures were designed by a dentist in the Denture Department. The selection of the major connectors and placement of the indirect retainers were determined by a prosthodontist according to the patient's missing and remaining teeth. One piece of wax (Base Plate Wax, thickness, approximately 1.5 mm; G.C., Tokyo, Japan) was pressed onto the model obtained from the alginate impression as a spacer. Custom trays were prepared using an immediate curing resin (Quickie; Nissin Dental Products, Inc., Kyoto, Japan).

Using custom trays, the first impression was made using a compound. The second impression was then made using silicone rubber impression material [22].

This study included only dentures that could be fabricated with coverage under the medical insurance system in Japan. Therefore, all lingual bars and retainers of the denture were cast in a Co-Cr alloy, except for some wire clasp-hook arms. The lingual apron of the major connectors and the base of the denture were made from polymethyl methacrylate.

The subjects' RPDs were confirmed to have a good fit on the mucosal surface of the denture base by using a fit testing material (FIT CHECKER II; G.C., Tokyo, Japan) before the oral examination [23].

2.3. Oral examinations

Oral health status was assessed by five dentists affiliated with the Niigata University Medical & Dental Hospital. Clinical calibration was performed by all dentists twice (2 h/day for a total of 4 h) before the assessment. To avoid measurement bias, the dentists who performed the assessments were blinded to the objectives of this study. In an outpatient dental examination room, dentists affiliated with Niigata University Medical & Dental Hospital examined the number of functional teeth, occlusal supports, Eichner classification,

presence/absence of maxillary dentures, mandibular ridge height, and duration of RPD use.

The number of functional teeth was defined as the total number of natural teeth and teeth that were restored with crowns or replaced with bridge pontics and implants. Retained roots and third molars were excluded [24,25]. The number of occlusal supports was defined as the number of occlusal contacts between the remaining contralateral teeth. The mandibular residual ridge height was defined as the vertical distance from the top of the residual ridge of the projected central fossa of the left and right first molars to the outer buccal ridge in the mandibular study model [26].

2.4. The assessment of the objective MP

The MP was evaluated by the "MP Scoring Method" using a piece of test gummy jelly developed by Nokubi et al. [27,28]. All evaluations were performed by a supervising technician who relayed instructions to the participants. The participants were instructed to chew on a piece of test gummy jelly (dimensions:20×20×10 mm; weight:5.5 g; UHA Mikakuto, Osaka, Japan) 30 times and subsequently expectorate the masticated fragments onto a piece of gauze spread over a paper cup. Any saliva adhering to the surface of the gauze or comminuted gummy jelly pieces was removed by running water over the surface for 30 s. The MP was evaluated by visual scoring using a 10-stage scale based on the crushed status of the gummy jelly (**Fig. 1**). The MP was then further divided into two groups: good chewers (≥5.0) and poor chewers (≤4.0) using the cut-off point, an indicator of decreased masticatory function in the Eichner B group classification [29].

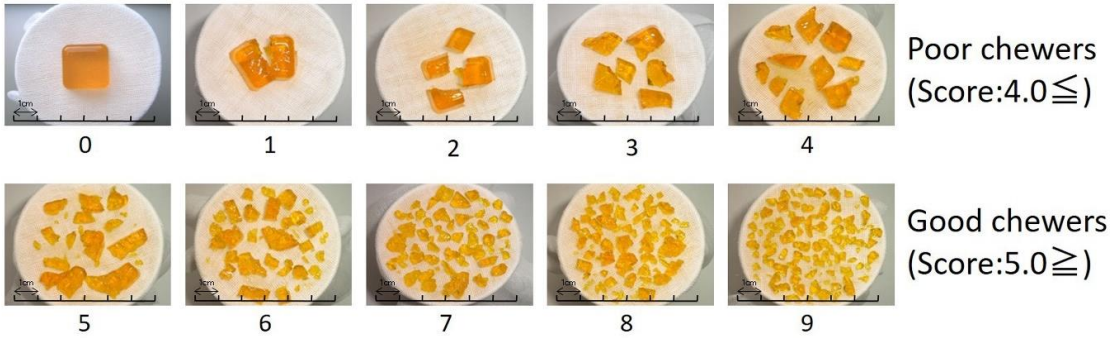

Fig. 1. Visual material scored on a 10-stage scale according to the crushed status of gummy jelly
In this study, gummy jelly for measuring mastication ability was chewed 30 times freely, and the MP was visually evaluated by visual scoring on a 10-stage scale based on the crushed status of the gummy jelly. The MP was then further divided into two groups: good chewers (≥5.0) and poor chewers (≤4.0), using the cut-off point, an indicator of decreased masticatory function in the Eichner B group.

2.5. The evaluation and classification of dentures

We evaluated the type of major connector, presence or absence of indirect retainers, number of rests, and number of artificial teeth on the participants' mandibular bilateral distal extension dentures.

The major connectors are the lingual apron and lingual bar [17]. The rests are the occlusal, cingulum, and incisal rests. If one clasp had two rests, two rests were counted. Patients with one or more retainers on the opposite side of the fulcrum line were defined as the group with an indirect retainer (w-IR) (**Fig. 2**). Patients without a retainer on the opposite side of the fulcrum line were defined as the group without an indirect retainer (w/o-IR) (**Fig. 3**) [30]. An indirect retainer could be an occlusal, cingulum, or an incisal rest [19]. The direct retainer could be a casted, wire, or a combination clasp using casted and wire clasps [5].

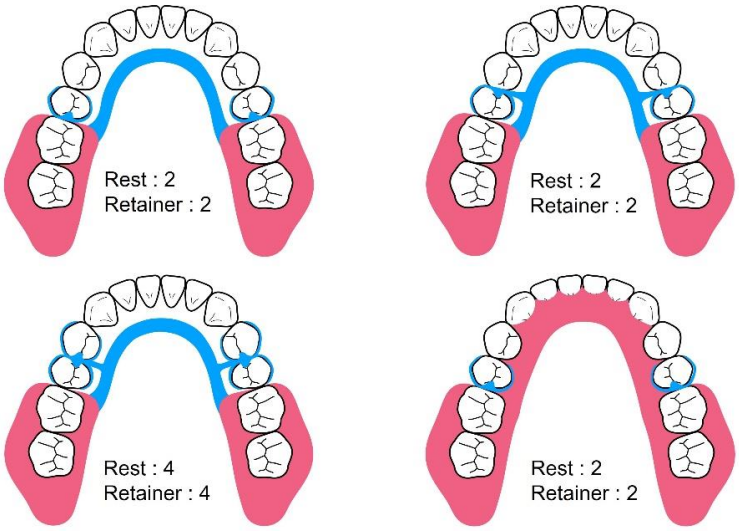

Fig. 2. Design example of cases with indirect retainers
Patients with one or more retainers on the opposite side of the fulcrum line were defined as those with an indirect retainer. The figure shows the typical design for the subjects of this study.

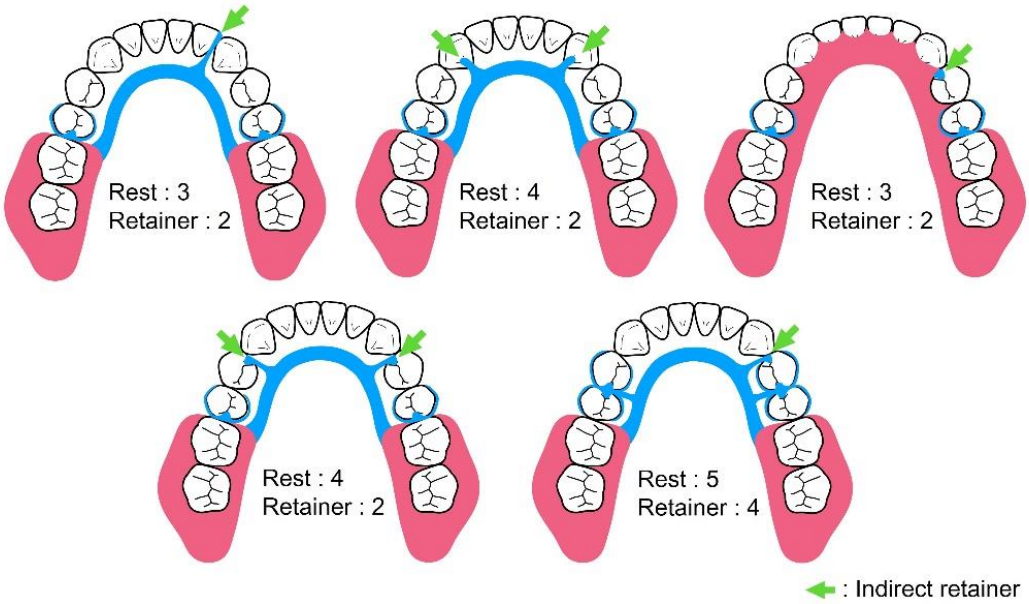

Fig. 3. Design example of cases without indirect retainer
Patients without a retainer on the opposite side of the fulcrum line were defined as the group without an indirect retainer (w/o-IR). The figure shows the typical design for the participants of this study.

2.6. Sample Size Calculation and Statistical Analysis

This was a retrospective cross-sectional study, and the sample size was calculated based on data from previous studies that assessed the relationship between Eichner classification and MP [24]. Because Eichner classification is closely related to the masticatory performance of patients wearing RPDs [24], we found it appropriate to determine the sample size of this study based on Eichner classification. Therefore, the minimum number of participants required in each group was 18, and the analysis was performed with data from participants who were enrolled in our study by December 2019 (at this time, the number of participants in each group exceeded the required number as per the sample size calculation).

All data were assessed using a normality test (Shapiro-Wilk test) and a test of homogeneity of variance, after which an appropriate statistical method was selected. Spearman's rank correlation coefficient was used to study the relationships between masticatory function and age, number of functional teeth, number of occlusal supports, mandibular residual ridge height, duration of RPD use, number of rests, and the number of artificial teeth. Participants were classified by sex, Eichner classification, denture use in the maxilla, type of major connector, and presence or absence of an indirect retainer. Each subgroup’s masticatory function was compared using the Mann-Whitney U test.

We performed a rank transform two-way ANOVA with the main effects as the type of major connector (apron or bar) and indirect retainer (presence or absence), and the first-order interaction effect between them.

To examine differences in age, oral status, or denture components for the type of major connector used and the presence of indirect retainer, we performed group comparison using the Mann-Whitney U test or Kruskal-Wallis test and four combination group comparisons using the Mann-Whitney U test with Bonferroni correction.

A logistic regression analysis (stepwise method, likelihood ratio) was performed to

examine factors contributing to MP, with good/poor MP considered the dependent variable (poor chewers (≤4.0) = 0, good chewers (≥5.0) = 1). The independent variables were those that showed differences in MP between the groups and those that correlated with MP. If strong collinearity was found between the explanatory variables, variables with stronger correlations with the independent variables were retained. The type of major connector used and presence of an indirect retainer were included in the analysis.

Statistical analyses were performed using SPSS Statistics 24 software program (IBM, Tokyo, Japan), and the level of statistical significance was set at 5%.

3. Results

3.1. Characteristics of participants

Table 1 presents the participants' characteristics. This study recruited 53 patients (29 men, 24 women; mean age ± standard error, 74.7±1.1 years old). The mean MP was 5.3±0.3, and 73.6% of the patients were classified into the good masticatory group. The mean numbers of functional teeth, missing mandibular teeth, and occlusal supports were 19.8±0.5, 5.2±0.2, and 7.5±0.3, respectively. According to the Eichner classification, group B2 was the most common group, with 33 patients, accounting for 62.3% (B2/B3:33/20). A total of 41.5% of the participants had maxillary dentures. Regarding denture design, 52.8% of the major connectors were apron-type, and 50.9% of the dentures had indirect retainers. Among 27 participants with indirect retainers, 4 (14.8%) had clasps, and 23 (85.2%) did not have clasps in the indirect retainer. The numbers of rests and artificial teeth were 3.5±0.2 and 5.2±0.2, respectively.

3.2. Relationship between the MP and survey items

Table 2 shows the correlation between the MP and survey items. MP was positively correlated with the numbers of functional teeth ($p<0.001$), occlusal supports ($p=0.002$), and rests ($p=0.04$). There were significant differences in the MP between the groups based on the presence of maxillary dentures ($p=0.05$), type of major connector ($p=0.014$), and presence of an indirect retainer ($p=0.001$). Alternatively, regarding denture design, the MP tended to be significantly higher with a bar-type major connector design, without a maxillary denture, the presence of an indirect retainer, and a large number of rests. Considering these findings, it was concluded that denture design, particularly the type of major connector used and the presence of an indirect retainer, affected the MP.

Figure 4 and **Table 3** depict the association of major connectors and indirect retainers with masticatory performance. The MP was significantly higher in cases with than in those without indirect retainers (F (1,49) = 12.6, p=0.001, partial η2=0.2). Meanwhile, MP did not differ significantly among the different types of major connectors (F (1,49)= 0.3, p=0.6, partial η2= 0.006), and no significant difference was noted in the interaction between major connectors and indirect retainers (F (1,49)= 1.9, p=0.18, partial η2=0.04). In addition, multiple comparisons were performed as a post hoc test, and a significant difference was found between bar-type major connectors with indirect retainers and apron-type major connectors without indirect retainers, bar-type major connectors with indirect retainers and bar-type major connectors without indirect retainers (Mann-Whitney U test with Bonferroni correction, **Fig. 4**).

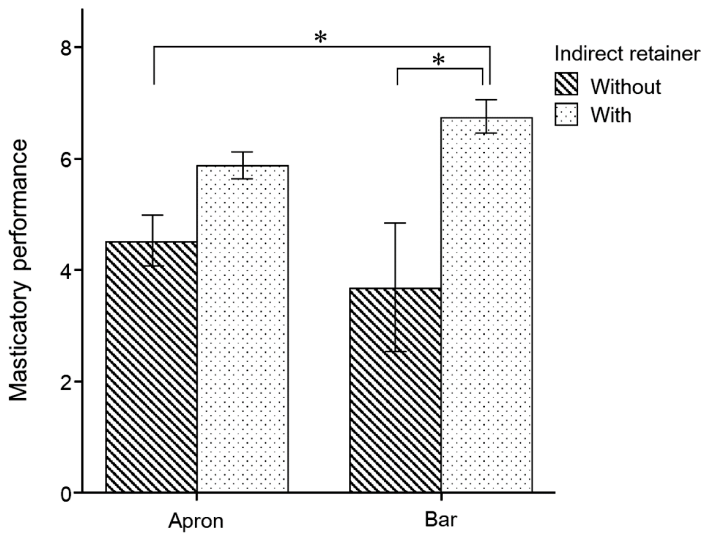

Fig. 4. Masticatory performance for each group
A rank transform two-way ANOVA was performed with the main effects as the type of major connector (apron or bar) and presence of an indirect retainer (with or without) and the first-order interaction effect between them.
Data are presented as the mean ± standard error.
* Significant difference in masticatory performance by Mann-Whitney U test with Bonferroni correction.
Variables are the same as those in **Table 1**.

Patient factors and denture components for the type of major connector (**Table 4**) and presence or absence of an indirect retainer (**Table 5)** were examined in detail. There were no significant differences in patient factors between the different groups according to denture design. However, the number of rests was significantly higher in the group with bar-type major connectors ($p=0.03$) and indirect retainers ($p<0.001$). In addition, the associations of major connectors and indirect retainers with each item was examined, and significant differences were found in age and number of rests. There were biases such that, cases with apron-type major connectors were relatively younger (major connector: Apron and indirect retainer: with), and that the number of rests were higher in participants with indirect retainers, regardless of the type of major connector used.

3.3. An examination of factors that contribute to the MP

Logistic regression analysis revealed that the number of functional teeth and the presence or absence of an indirect retainer were factors that significantly influenced the MP (**Table 6**). Partial regression coefficients were positive for both the number of functional teeth and the presence or absence of an indirect retainer, and the odds ratio was higher for the presence or absence of an indirect retainer than for the number of functional teeth present.

4. Discussion

This study investigated the effect of denture design on the MP in mandibular distal extension cases. We focused on the differences in the major connectors used and the presence or absence of an indirect retainer as a component of denture support and retention. As a result, cases in which the major connector was a bar-type or an indirect retainer was present were associated with a higher MP than those with an apron-type major connector or no indirect retainer. MP was also affected by the number of functional teeth and the presence or absence of an indirect retainer, even when the number of functional teeth was small, suggesting that a good MP can be maintained by designing dentures with appropriately placed indirect retainers.

4.1. Participants in this study and the dentures they wear

Owing to the wide range of indications, RPD designs are diverse. The mode of support of the RPD differed depending on the defect. The support of the periodontal ligament is used for intermediate defects wherein only a few teeth are missing, whereas the support of the mucosa is needed in cases with many missing teeth. It is difficult to evaluate cases with vastly different defect patterns by using the same criteria. Therefore, in our study, only patients missing bilateral distal extensions in which denture stability was difficult to obtain and those with remaining bicuspids with room to add an indirect retainer or lingual bar were selected as participants [24]. Masticatory function reportedly varies according to the Eichner and Kennedy classifications [17,24,31]. In the present study, only Kennedy Class I cases in the Eichner B group were considered. Bilateral mandibular distal edentulous cases not only account for about half of the mandibular defects encountered in clinical practice [32,33] but are also ideal for investigating the influence of RPD design on mastication because of denture

design, in which the functional forces are borne by both the periodontal ligament of the abutment teeth and the mucosa of the crest of the residual ridge.

In this study, although there were relatively younger participants who had apron-type major connectors with indirect retainer cases, no differences were noted in the numbers of functional teeth, occlusal supports, or other intraoral factors that may be strongly related to MP in the groups with different denture designs **(Tables 4, 5).** This negates the possibility that the MP of patients using a particular denture design is higher than that primarily using a different design.

In addition, the presence or absence of a clasp in an indirect retainer may have influenced the movement in the direction toward the ridge; thus, we considered the MP between indirect retainers with or without a clasp. MP did not differ between indirect retainers with and without a clasp (Mann-Whitney U-test, p=0.72). Therefore, this study did not consider the presence or absence of a clasp in indirect retainers. Furthermore, to confirm the influence of the denture material on the MP, we used the Mann-Whitney test to compare the MP between lingual aprons made from resin (28), which were included in this study, and lingual aprons made from metal (7), which were not included in this study. This analysis revealed no significant differences between the two groups (P =0.43).

4.2. The influence of denture design on the MP

The present findings show that MP was higher when the number of functional teeth and occlusal support was greater, there were no missing teeth in the maxilla, a bar-type major connector, and an indirect retainer were present. Several studies have reported that the greater the number of functional teeth and occlusal support, the better the MP [31,34,35]. In patients wearing maxillary removable dentures, the presence of only a small number of functional teeth

may affect the MP. Denture use in the maxilla was associated with a significant decrease in the number of functional teeth ($p > 0.001$). Therefore, in cases involving denture use in the maxilla, a decrease in the number of functional teeth may affect MP.

Matsui et al. [17] reported that the masticatory values of apron-type major connectors were significantly greater than those of bar-type major connectors one month after denture placement. The authors believe that the use of an apron-type major connector may have provided denture stability, not only in terms of support but also in terms of grasping and maintenance. The lingual apron covers the lingual aspect of the mandibular anterior teeth and has a larger floor area than that of the lingual bar. Therefore, the apron type is considered superior to the bar type in terms of the grasping function. However, Watt and MacGregor [36] in "Partial Denture Design" stated that because the lingual surface of the mandibular incisor is almost vertical, an apron-type major connector will not provide support if no clasp is placed.

The present findings revealed that the number of functional teeth and indirect retainers were factors that contributed to mastication. The odds ratio of 2.1 for the indirect retainer was larger than that of 1.4 for the number of teeth, indicating that the indirect retainer has a stronger influence on the MP than that of the number of teeth. In other words, a large number of functional teeth was effective in improving the MP of mandibular RPD wearers.
However, even in cases with a small number of functional teeth, RPD design with appropriate indirect retainers has shown the possibility of exceeding the expected MP value based on the original number of functional teeth.

Although improved MP, diet quality, and nutritional status have been reported while wearing RPDs [37-41], the present study demonstrated for the first time the clinical impact of including an indirect retainer in denture design on MP. The role of an indirect retainer is to

suppress the lifting of the RPD [8], when a highly viscous food adheres to the occlusal surface of artificial teeth and tends to lift the RPD during chewing. The indirect retainer limits the lifting of RPDs during gummy chewing, thus improving masticatory performance [42].

Kikuchi et al. [24] reported that the effect of denture placement on restoring the MP in patients with partial dentition loss depended on the remaining teeth, occlusal support, denture placement site, and missing teeth classification, with the effect of restoring the MP varying widely, especially when the numbers of occlusal supports and functional teeth were reduced. This may be largely attributed to a decrease in the number of remaining teeth followed by the fact that denture retainers are no longer feasible to be installed, based on the results of our present study, which demonstrate that denture design affects the masticatory function as well as the number of remaining teeth. Given the present findings, it is necessary to examine whether indirect retainers, such as incisal rests, affect the MP in cases with relatively few remaining teeth or in difficult cases, such as those of non-vertical stop occlusion without occlusal contact.

4.3 Study limitations

This was a retrospective cross-sectional study, and there were variations in the personal factors and oral conditions of the participants, which limited the generalizability of the results. This study was conducted with a limited number of patients, and the position of the rest in the direct retainer and the effect of the material of the major connectors on masticatory function were not taken into consideration.

Notably, Kosaka et al. [29] reported that differences in sex did not influence the MP of the Eichner B classification group. However, because occlusal force is affected by age and sex, a randomized controlled trial in which dentures of different designs are fabricated for the

same participants should be considered. In addition, participants in the present study were limited to those who agreed to participate, and patients with denture pain and dysfunction were excluded, which may have introduced selection bias.

Gordon et al. [43] reported that patients' perceived problems with mastication had a greater influence on MP than on the actual function. Ritchie et al. [44] reported that denture wear did not improve nutritional intake when there was pain or dissatisfaction with the dentures. In the present study, only the objective MP was evaluated. However, when evaluating the masticatory function of denture-wearing patients, it is necessary to consider a subjective viewpoint as well, a point that should be addressed in the future.

4.4 Clinical implications

RPDs have a wide range of indications and are effective prosthetic treatments in elderly patients with economic and physical limitations. Some of the findings from the present study on denture design and masticatory function that was previously unknown may be useful for better denture designing in the future.

5. Conclusion

This study revealed that the MP of patients with Eichner B mandibular bilateral distal extension dentures was affected by the presence of an indirect retainer. The results suggest that even when only a few functional teeth remain, good masticatory function can be maintained by designing dentures with the appropriate placement of an indirect retainer.

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Conflict of Interest Statement

The authors have no financial or other kinds of personal conflicts to declare in relation to this work.

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Legends to Figures

Fig. 1. Visual material scored on a 10-stage scale according to the crushed status of gummy jelly

In this study, gummy jelly for measuring mastication ability was chewed 30 times freely, and the MP was visually evaluated by visual scoring on a 10-stage scale based on the crushed status of the gummy jelly. The MP was then further divided into two groups: good chewers (≥5.0) and poor chewers (≤4.0), using the cut-off point, an indicator of decreased masticatory function in the Eichner B group.

Fig. 2. Design example of cases with indirect retainers

Patients with one or more retainers on the opposite side of the fulcrum line were defined as those with an indirect retainer. The figure shows the typical design for the subjects of this study.

Fig. 3. Design example of cases without indirect retainer

Patients without a retainer on the opposite side of the fulcrum line were defined as the group without an indirect retainer (w/o-IR). The figure shows the typical design for the participants of this study.

Fig. 4. Masticatory performance for each group

A rank transform two-way ANOVA was performed with the main effects as the type of major connector (apron or bar) and presence of an indirect retainer (with or without) and the first-order interaction effect between them.

Data are presented as the mean ± standard error.

* Significant difference in masticatory performance by Mann-Whitney U test with Bonferroni correction.

Variables are the same as those in **Table 1**.

Table 1. *Participants' characteristics*

Total (num)		53 patients	min - Max
Personal factors			
Gender	Male (%)	29 (54.7)	
	Female (%)	24 (45.3)	
Age (years)		74.7 ± 1.1	57 - 88
Masticatory Performance	Score	5.3 ± 0.3	0 - 8
	Good chewers (≧5.0)	39 (73.6)	
	Poor chewers (≦4.0)	14 (26.4)	
Oral condition			
Number of functional teeth		19.8 ± 0.5	13 - 24
Number of missing teeth		5.2 ± 0.2	4 - 7
Number of occlusal support		7.5 ± 0.3	2 - 11
Eichner classification	B2	33 (62.3)	
	B3	20 (37.7)	
Denture use in the maxilla	No wearing	31 (58.5)	
	Wearing	22 (41.5)	
Mandibular residual ridge height(mm)		6.3 ± 0.4	2 - 10.5
Duration of wearing RPDs (days)		464 ± 106	4 - 2160
Denture design			
Type of major connector	Apron	28 (52.8)	
	Bar	25 (47.2)	
Presence of indirect retainer	with	27 (50.9)	
	without	26 (49.1)	
Number of rests		3.5 ± 0.2	2 - 7
Number of artificial teeth		5.2 ± 0.2	4 - 7

Data are presented as the mean ± standard error or number of participants(%) .
Masticatory performance (Score): Gummy jelly Score evaluation by visual inspection.
The participants were divided into two groups: good chewers and poor chewers, using score 4 as the cut-off point [28].
Number of functional teeth: Natural teeth and treated teeth that have a crown, as well as bridge pontics and implants.
Number of occlusal support: Number of pairs of occlusal contacts between remaining homonymous opposing teeth.
Eichner classification: Occlusal support classification, our study patients were those two groups; "B2" has two support zones, "B3" has one support zone.
Mandibular residual ridge height: The left and right lateral mean of the vertical distance from the buccal lateral to the alveolar apex of the mandibular first molar equivalent.
Type of major connector are classified into two types: lingual apron (made from PMMA) and lingual bar (made of Co-Cr).
Presence of Indirect retainer "with": Cases with at least one rest installed proximal to the direct retainer.
Presence of Indirect retainer "without": Cases other than "with".

Table 2. *Relationship between masticatory performance and surveyed items*

		Masticatory performance	*r*	*p*
Demographic factor				
Gender	Male (29)	5.6 ± 0.4		0.15
	Female (24)	5.0 ± 0.4		
Age			-0.16	0.25
Oral condition				
Number of functional teeth*			0.56	<0.001
Number of occlusal support*			0.41	0.002
Eichner classification	B2 (33)	5.7 ± 0.4		0.06
	B3 (20)	4.8 ± 0.5		
Denture use in the maxilla†	No wearing (31)	5.8 ± 0.4		0.05
	Wearing (22)	4.7 ± 0.5		
Mandibular residual ridge height			0.20	0.26
Duration of wearing RPDs			-0.04	0.78
Denture design				
Type of major connector†	Apron (28)	4.8 ± 0.4		0.02
	Bar (25)	6.0 ± 0.4		
Presence of indirect retainer†	with (27)	6.3 ± 0.3		0.001
	without (26)	4.3 ± 0.5		
Number of rest*			0.29	0.04
Number of artificial teeth			-0.14	0.33

Data are presented as the mean ± standard error.
r: Spearman's correlation coefficient with masticatory performance.
p: Spearman's rank correlation or Mann-Whitney U test.
*: Significant correlation with masticatory performance by the Spearman's correlation coefficient.
†: Significant difference in masticatory performance by the Mann-Whitney U test.
Variables are the same as in Table 1.

Table 3. The relationship between major connector/indirect retainer and masticatory performance

	Type III SS	df	MS	F	*p*	$p\eta^2$
Type of major connector	49.0	1	49.0	0.3	0.6	0.006
Presence of indirect retainer*	2191.2	1	2191.2	12.6	0.001	0.2
Type of major connector × Presence of indirect retainer	326.3	1	326.3	1.9	0.18	0.04
Correction model	3530.8	3	1176.9	6.8	0.001	0.3
Constant	26564.1	1	26564.1	153.3	< 0.001	0.8
Error	8492.2	49	173.3			
Total	50660.0	53				
Correction total	12023.0	52				

R2 = 0.3

Data are presented as the mean ± standard error.
Type III SS: Type Ⅲ sum of squares.
df: Degree of freedom.
MS: Mean square.
F: F-value
Type of major connector ×Presence of indirect retainer: Interaction term between type of major connector and presence of indirect retainer.
p: Comparison of Means by factors with a rank transform two-way ANOVA.
$p\eta^2$: partial η^2
*: Significant difference in masticatory performance by the rank transform two-way ANOVA with Bonferroni correction.
Variables are the same as in Table1.

Table 4. *Examination of the differences in each factor for the type of major connector and* presence of *indirect retainer*

	Type of major connector				*p1*	Presence of indirect retainer				*p2*	Group Comparison
Personal factors											
Age†	Apron	73.7	±	1.2	0.07	with	69.1	±	1.1	0.003	Apron×with - Apron×without
						without	75.50	±	1.493		Apron×with - Bar×with
	Bar	75.8	±	1.9		with	74.0	±	2.1		Apron×with - Bar×without
						without	81.7	±	3.0		
Oral condition											
Number of functional teeth	Apron	19.4	±	0.6	0.23	with	20.6	±	0.7	0.54	
						without	19.0	±	0.8		
	Bar	19.8	±	0.8		with	20.1	±	0.9		
						without	18.7	±	1.5		
Number of occlusal support	Apron	7.0	±	0.4	0.08	with	7.6	±	0.6	0.25	
						without	6.8	±	0.5		
	Bar	8.0	±	0.6		with	7.9	±	0.7		
						without	8.3	±	0.4		
Mandibular residual ridge height	Apron	5.8	±	0.5	0.06	with	6.9	±	0.9	0.06	
						without	5.2	±	0.4		
	Bar	7.1	±	0.6		with	6.7	±	0.7		
						without	9.0	±	1.5		
Duration of wearing RPDs	Apron	712.3	±	308.7	0.94	with	232.0	±	188.7	0.8	
						without	499.1	±	161.1		
	Bar	826.6	±	278.6		with	557.7	±	209.8		
						without	283.6	±	232.8		
Denture design											
Number of rest*†	Apron	3.3	±	0.3	0.03	with	4.5	±	0.6	<0.001	Apron×with - Apron×without
						without	2.8	±	0.2		Apron×with - Bar×without
	Bar	3.7	±	0.2		with	4.1	±	0.2		Bar×with - Apron×without
						without	2.5	±	0.3		Bar×with - Bar×without
Number of artificial teeth	Apron	5.4	±	0.3	0.28	with	6.3	±	0.7	0.34	
						without	5.1	±	0.2		
	Bar	5.0	±	0.1		with	4.9	±	0.1		
						without	5.2	±	0.4		

Data are presented as the mean ± standard error.
*p*1: Two-group Comparison with Mann-Whitney U test.
p2: Kruskal-Wallis test of the difference among the four groups.
Group Comparison: Significant difference among the four combination groups of each factor combined with/without indirect retainer. Mann-Whitney U test with Bonferroni correction.
*: Statistically significant by the Mann-Whitney U test.
†: Statistically significant by the Kruskal-Wallis test.
Variables are the same as in Table 1.

Table 5. *Examination of the differences in each factor for indirect retainer*

	Presence of Indirect retainer					*p*
Personal factors						
Age	with	72.6	±	1.6		0.55
	without	76.9	±	1.4		
Oral condition						
Number of functional teeth	with	20.7	±	0.7		0.07
	without	18.9	±	0.7		
Number of occlusal support	with	7.9	±	0.5		0.14
	without	7.1	±	0.4		
Mandibular residual ridge height	with	6.8	±	0.5		0.08
	without	5.7	±	0.5		
Duration of wearing RPDs	with	617.6	±	212.2		0.47
	without	929.9	±	359.0		
Denture design						
Number of rest*	with	4.2	±	0.2		<0.001
	without	2.7	±	0.1		
Number of artificial teeth	with	5.3	±	0.2		0.95
	without	5.0	±	0.2		

Data are presented as the mean ± standard error.
p: Two-Group Comparison: Mann-Whitney U test.
*: Statistically significant by the Mann-Whitney U test.
Variables are the same as in Table1.

Table 6. *Result of the logistic regression analysis*

	B	s.e.	Wald	*p*	EXP(B)	EXP(B) 95% CI
Number of functional teeth*	0.3	0.1	8.0	0.005	1.4	1.1 - 1.8
Presence of indirect retainer*	2.2	0.9	5.8	0.02	2.1	0.02 - 0.7
Type of major connector	1.2	1.9	0.06	0.81	0.6	0.02 - 25.7
Type of major connector × Presence of indirect retainer	- 0.3	2.5	0.01	0.91	0.7	0.06 - 99.3
Denture use in the maxilla	- 2.6	1.5	2.9	0.09	0.07	0.03 - 1.9
Number of Rest	- 0.5	0.6	0.9	0.33	0.6	0.2 - 1.8
Constant	- 5.1	3.5	2.2	0.14	0.02	

Logistic regression analyses with stepwise methods.
Good or poor masticatory performance (Score), by an indicator of a decreased masticatory function in the Eichner B group [29], was considered the dependent variable. (poor chewers (≤4.0) = 0, good chewers (≥5.0) = 1).
The independent variables were variables that showed differences in MP between groups, variables correlated with the MP. If strong collinearity was found between explanatory variables, variables with stronger correlations with the independent variables were retained. The type of major connector and the presence of an indirect retainer were put into the interaction term.
*: Statistically significant by the logistic regression analyses.
B: Unstandardized coefficient.
s.e.: Standard error.
EXP(B): Odds ratio.
CI: 95% Confidence interval for unstandardized coefficient EXP(B).
Variables are the same as in Table1.