A fundamental study of a novel method for estimating the vertical dimension of occlusion using tongue pressure of the edentulous patients

（無歯顎患者の舌圧を利用した新しい咬合高径設定法に関する基礎的研究）

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Abstract

Estimating the vertical dimension of occlusion (VDO) is essential when fabricating complete dentures to achieve efficient mastication and swallowing. The methods to estimate VDO are mainly categorized into either morphological or functional methods. However, there are few methods, except the comfortable zone (CZ) method, to estimate VDO from the patients' subjective. In addition, although several reports indicate the relationship between VDO and tongue function, research estimating VDO based on tongue pressure is still being determined. Therefore, this fundamental study aimed to investigate the reproducibility and relation between patients' comfort on a 100-mm visual analog scale (VAS) and CZ response when raising or lowering the VDO in study 1. Study 2 analyzed the tongue pressure value when raising or lowering the VDO.

Materials and Methods

Study 1

Eight edentulous patients (five men and three women, with a mean age of 78.5 ± 7.6 years) participated in the study. VAS score was obtained two times at the most comfortable position (MCP) when raised +1 to +7 mm and lowered -1 to -3 mm from the MCP. A two-way analysis of variance (ANOVA) was performed to test the relations between VAS values and CZ responses and the reproducibility and reliability of the two sessions. Bonferroni's multiple comparison tests were performed when ANOVA was statistically significant. When reproducibility was observed between two sessions, an equivalence test was performed.

One-way ANOVA was performed to analyze the difference in VAS values according to the VDOs. When the result of ANOVA was detected, Dunnett's test was used to seek significance compared to the MCP.

Study2

Ten edentulous patients participated in the study (six men and four women: mean age, 78.6 ± 7.1 years). The tongue pressure at 12 VDOs (+1 mm to 6 mm and +9 mm and from -1 mm to -4 mm), including the MCP, was measured. An ANOVA and Dunnett's test was performed to analyze the differences in tongue pressure at respective VDOs.

Result

Study 1

<The relations between the VAS values and CZ response and reproducibility>

T There was a statistical difference in VAS among the CZ responses ("high," "low," and "comfortable," $p < 0.001$) but not between sessions 1 and 6 ($p = 0.774$). There was no interaction between the CZ response and sessions ($p = 0.961$). Bonferroni's multiple comparison tests showed that the "comfortable" response was significantly higher than the "low" ($p < 0.001$)

and "high" responses ($p < 0.001$) both in sessions 1 and 6. The equivalence test results were equivalent between sessions 1 and 6 ($p=0.880$).

<Relationship between VAS value and VDO change from the MCP>

Dunnett's test showed that VAS significantly decreased when the VDO was raised by +3 mm from the MCP ($p = 0.009$) and continued to show a significant decrease at +4 ($p = 0.001$), +5 ($p <0.001$), +6 ($p < 0.001$) and +7 mm ($p < 0.001$). Moreover, VAS significantly decreased when the VDO was lowered by -2 mm from the MCP ($p = 0.048$) and continued to show a significant decrease at -3mm ($p = 0.003$).

Study 2

No significant differences existed between the stimulus intervals (-1 to -4 mm, $p = 0.99$) on lowering VDO from MCP. Tongue pressure decreased marginally when the VDO was raised +5 mm from the MCP ($p=0.054$); it continued to show a significant decrease at +6 mm ($p=0.041$) and +7 mm ($p=0.035$) from MCP.

Conclusion

It was suggested that estimating VDO in the range of -1 to +2 mm from the MCP is appropriate when fabricating new complete dentures**.**

Tongue pressure did not change significantly when VDO was lowered and raised to +4 mm from MCP. These results suggest that VDO may be set to 4 mm from MCP when fabricating new complete dentures.

I. Introduction

The 2016 Survey of Dental Diseases indicated that 47% of complete denture wearers are aged ≥ 85 years (1). Evidence suggests that the quality of life of edentulous older adults are greatly affected by the decline in their oral functions (2).

Appropriate treatment with complete dentures can contribute to oral health-related quality of life (3, 4), positively impact nutritional status and enjoyment of eating, and help avoid the risk of early mortality (5). A well-planned strategy for denture fabrication is essential to achieve these outcomes. Setting and restoring the vertical dimension of occlusion (VDO) is the key to the success of treatment with complete dentures.

Clinicians use several methods to determine VDO of edentulous patients as there is no consensus regarding the most accurate method yet (6, 7). Estimating the correct VDO can be difficult but is critical for effective oral functions (8-14). Thus, proper diagnosis, treatment planning, and consideration of a decrease in muscle tone with aging are essential (11, 15).

In general, several VDO estimation methods exist and are categorized according to morphological and functional determination. Facial measurements (16, 17) and cephalograms (18, 19) are the frequently used morphological methods to estimate VDO. Meanwhile, the resting vertical dimension (7, 15), swallowing (6, 8, 20-22), and comfortable zone (CZ) (23-25) are the functional methods.

The CZ method measures psychometric patient comfort ratings (26). A specific apparatus is used to raise or lower the patient's VDO (24, 27), while the patient subjectively responds to whether the respective VDO is high, low, or comfortable. In doing so, the clinicians can narrow down the patient’s preferred vertical dimension (24, 25, 27, 28). However, because the CZ subjective response is based on trichotomous (high, low, or comfortable) answers, it is ambiguous to distinguish differences in comfort level within and out of the CZ. Thus, it is essential to examine the relevance of the comfort levels in and out of the CZ, compared to external continuous subjective measures. We believe that this would allow more detailed clinical VDO settings.

Several reports have indicated a relationship between VDO and tongue function (29), which also influences masticatory function and swallowing (2, 10, 20, 29). The effect of VDO on tongue pressure to the palate during swallowing has been investigated among young dentate adults (29). The relationship between masticatory performance, tongue muscle force, and the speed of tongue movement has also been investigated among older adults with 28 natural teeth (2). The changes in tongue pressure among 15 edentulous older adults who wore only an upper complete denture were investigated after inserting the lower complete denture in another study (10). Therefore, further investigation of the changes in tongue pressure according to the changes in VDO among edentulous patients wearing both maxilla and mandible dentures is necessary, as

it could help determine an optimal VDO appropriate for the effective functioning of the tongue during mastication and swallowing. Moreover, data on the subjective comfort associated with VDO and tongue muscle force are lacking.

Therefore, this study aimed to examine the differences in subjective comfort on a 100-mm visual analog scale (VAS) when raising or lowering the VDO and examined the relationship among the responses to the CZ method. (Study 1)

Another objective is to examine the changes in tongue pressure on raising or lowering VDO in relation to the most comfortable position (MCP) in edentulous subjects wearing both upper and lower complete dentures. (Study2)

II. Materials, Methods and Result

1. Study participants (Study1)

The study participants were completely edentulous patients who were willing to receive new complete denture treatment at Nihon University Matsudo Dental Hospital (Matsudo Chiba, Japan) or Kurata Dental Clinic (Kawaguchi Saitama, Japan) between June 2020 and May 2022. Patients who used dentures, including overdentures, for at least 6 months without any problems were included in the study. The exclusion criteria were lesions in the alveolar bone or residual mucous membrane, difficulty in maintaining a sitting posture, involuntary movement of the oral and maxillofacial regions, sensory nerve problems, and excessive freeway space. The following baseline data were recorded: age, sex, denture history, general satisfaction with the denture scored using a 100-mm VAS, freeway space, occlusal force, and objective masticatory performance.

Before participating in the study, a research outline was provided to the patients, and their consent was obtained. The institutional review board approved the study protocol (Ethical Committee of Nihon University School of Dentistry at Matsudo; approval no. EC 20-021A, EC 20-021B).

2. Study participants (Study2)

The study was conducted after receiving approval from the institutional ethics review committee (EC20-021A and EC20-021B). Patients with edentulous upper and lower jaws visiting our University Hospital between June 2020 and May 2022, including those who used overdentures and had been using their current dentures without problems for >6 months, were enrolled. The exclusion criteria were a systemic medical history that could hinder participation in the study and a lack of fluency in Japanese. Before participating in the study, a research outline was provided to the patients, and their consent was obtained. The following baseline data were recorded: age, sex, denture

history, general satisfaction with the denture on a 100-mm visual analog scale (30), oral moisture, free-way space, occlusal force, tongue pressure, subjective and objective masticatory performance, and 14 questionnaires of oral health-related quality of life (OHIP-14) (31).

3. Fabrication of the comfortable zone (CZ) measuring device

1) Attachment of master casts to the articulator

A hydrophilic vinyl silicone impression material (Exahiflex injection type, GC, Tokyo, Japan) was used for making bite-seating impressions of the upper and lower jaws. A hard plaster (New Plastone II, GC, Tokyo, Japan) was poured into the impressions with the dentures to fabricate the master casts.

The maxillary master cast was mounted with the denture on a semi-adjustable articulator (Protar evo7, KaVo Dental Systems Japan G.K., Tokyo, Japan), positioning the incisal papillae 110 mm from the bilateral condylar balls and mounted with dental hard plaster (Hi-Mount, Sun Esu Gypsum, Osaka, Japan). The mandibular cast was then mounted by placing a dental occlusion material (Collect Quick Bite, Pentron Japan, Tokyo, Japan) between the dentures at the maximal intercuspal position.

2) Fabrication of the upper and lower base plate

A record base with a rim was fabricated using light-cured resin plates (ProTray LC II, Agussa Japan, Osaka, Japan) and adjusted with white silicone material (Fit Chucker Advance, GC, Tokyo, Japan) in the patient's mouth. The 5-mm thick apparatus on the maxillary rim, which fit with the positioning stainless-steel block, was fabricated using polyoxymethylene (Delrin, DuPont, Delaware, USA). Figure 1 shows the standard design of the occlusal rims and apparatus. The vertical height of the maxillary occlusal rim was the same as that of the subject's maxillary dentures. The widths of the rim and apparatus were customized into large (63 mm wide when the width between the bilateral mandibular first molars was 50 mm or longer) and regular (57 mm wide when the width between the bilateral mandibular first molars was 49 mm or shorter). The anteroposterior diameter of the apparatus was 45 mm from the incisal papillae to the posterior margin of the occlusal rim (Figure 2).

3) Positioning the stainless-steel blocks to adjust VDO

Twelve different height-positioning stainless steel blocks (SUS303 stainless steel, Watanabe Mfg. Co., Ltd., Chiba, Japan, hereafter: block) were fabricated and placed in the holding hole installed at the first molar of the mandibular rim. The apex of the block coincided with the holes of the apparatus. Two holes were selected based on the distance from the maxillary incisor papilla to the line connecting the bilateral hamular notch (IH). Hole A was selected when IH was ≥50 mm, and hole B was selected when IH was ≤49 mm.

4) Changing VDO using the blocks

VDO was raised (from +1 mm to 6 mm and +9 mm) or lowered (from-1 mm to -4 mm) from the MCP of the patients' existing dentures by using twelve pairs of blocks. The blocks were randomly selected and installed in the rim. The participants were subsequently instructed to determine whether the VDO was "high," "low," or "comfortable" in relation to each block (12 times in one session) after performing tapping movements. The next session was started after a 10-second interval; ten sessions were conducted.

4. Determination of CZ and MCP

One of the eleven blocks was randomly selected and installed in a holding hole. The participants were then asked to perform tapping movements at 12 different VDOs and state whether the positioning was "high," "low," or "comfortable." Subsequently, another block was selected, and the process was repeated after a 10-s interval; 10 sessions were conducted in total. After the completion of the 10 sessions, the number of "high," "low," and "comfortable" responses for each VDO was counted. The upper stimulus (UL) and lower stimulus (LL) limen values were determined according to the following formula:

$$UL = S1 - 0.5i - i \sum_{j=2}^{n} p$$

$$LL = S0 + 0.5i + i \sum_{j=2}^{n} q$$

where S1 is the stimulus value where p=1.0 (p: the proportion of "high" judgment), S0 is the stimulus value where q=1.0 (q: the proportion of "low" judgment), i is the stimulus interval (1 mm), j is the sequence of stimulus, and n is the number of stimuli.

Subsequently, the CZ and MCP were identified using the following formulas:

CZ = UL – LL

MCP = (UL + LL)/2

The calculated MCP was rounded to an integer and considered as the optimal VDO.

5. Data and Analysis

1) Study 1

(1) Measurement of VAS

In sessions 1 and 6, the participants were asked to rate their comfort level using VAS. The mean VAS score was calculated for each CZ response to examine the relations among the three responses to CZ ("high," "low," and "comfortable") and VAS. In addition, when the VDO was raised by 7 mm and lowered by 3 mm from the MCP, the VAS was recorded at 1-mm intervals.

(2) Analysis

Two-way analysis of variance (ANOVA) was performed to test the relations between VAS values and CZ responses and the reproducibility and reliability of the two sessions involving

VAS scoring. Bonferroni's multiple comparison test was performed when statistically significant differences were detected.

Moreover, one-way ANOVA was performed to analyze VAS changes (the mean value of sessions 1 and 6) when the occlusal height was raised or lowered, based on a baseline VAS score taken at the MCP. Dunnett's test was performed when statistically significant differences were detected.

The threshold for significance was set at $p < 0.05$. All statistical analyses were performed using IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, N.Y., USA).

2) Study 2

(1) Measuring tongue pressure

In sessions 1 and 6, the tongue pressure was measured using a specific device (JMS TPM-02, GC, Tokyo, Japan), wherein a measuring tube was inserted into the mouth through a 12 mm diameter semicircular pathway placed in the anterior portion of the mandibular rim. The mean tongue pressure value of sessions 1 and 6 was used for the analysis.

(2) Analysis

One-way analysis of variance (ANOVA) was performed to analyze the change in tongue pressure (mean value of sessions 1 and 6) when the occlusal height was raised or lowed based on the tongue pressure at the MCP. Dunnett's test was performed if statistically significant differences were detected. The threshold for significance was set at $p<0.05$. All statistical analyses were performed using SPSS Statistics Version 25 for Windows (IBM Corp., Armonk, NY, USA).

III. Results

1. Study1

1) Study participants

Eight participants were included (Five men and three women, with a mean age of 78.5 ± 7.6 years).

2) CZ and MCP

The mean CZ was 3.3 ± 1.1 mm. Three participants had a CZ that matched between the MCP and ICP of the existing denture. The MCP of two participants was lower than the ICP, while the MCP of three participants was higher than the ICP. The difference between the MCP and ICP ranged from -2 to +1 mm. Other baseline characteristics were denture history, 76.1 ± 59.0 month; general satisfaction, 91.3 ± 9.8 mm; free-way space, 2.3 ± 0.8 mm; occlusal force, 557.4 ± 260.8 N; and objective masticatory performance, 153.0 ± 64.3 mg/dL.

3) The relations between the VAS values and CZ response and reproducibility

Figure 3 shows the result of two-way ANOVA. The analysis showed a statistical difference in

VAS among the CZ responses (“high,” “low,” and “comfortable,” $p < 0.001$) but not between sessions 1 and 6 ($p = 0.774$). There was no interaction between the CZ response and sessions ($p = 0.961$). Bonferroni's multiple comparison test showed that the “comfortable” response was significantly higher than the “low” ($p < 0.001$) and “high” responses ($p < 0.001$) at sessions 1 and 6. The results of the equivalence test were equivalent between sessions 1 and 6 ($p=0.880$).

4) Relationship between VAS value and VDO change from the MCP

The average VAS at the MCP was 78.6 mm (n = 8; standard deviation, 15.9 mm). Figure 4 shows the result of one-way ANOVA, which showed a statistical significance ($p < 0.001$). Dunnett’s test showed that VAS significantly decreased when the VDO was raised by +3 mm from the MCP ($p = 0.009$) and continued to show a significant decrease at +4 ($p = 0.001$), +5 ($p <0.001$), +6 ($p < 0.001$) and +7 mm ($p < 0.001$). Moreover, VAS significantly decreased when the VDO was lowered by -2 mm from the MCP ($p = 0.048$) and continued to show a significant decrease at -3 ($p = 0.003$).

2. Study2

1) Study participants

Ten subjects were included (six men and four women; mean age, 78.6 ± 7.1 years). The baseline characteristics of the patients are presented in Table.

2) CZ and MCP

The average CZ was 3.3 mm (standard deviation, 1.1 mm). MCP matched with VDO of the existing dentures for three participants. MCP in four participants was lower, and that in three participants was higher than VDO of the existing dentures. The difference between MCP and VDO of the existing dentures ranged from -2 mm to +2 mm.

3) Tongue pressure

The average tongue pressure at MCP was 33.0 kPa (n = 10; standard deviation, 6.43 kPa). One-way ANOVA showed no significant differences between the stimulus intervals (-1 mm to -4 mm, Figure 4) when VDO of the denture was lower than MCP. One-way ANOVA showed significant differences between the stimulus intervals (+1 mm to +7 mm, $p = 0.033$; Figure 5) when VDO of the denture was higher than MCP. Post-hoc Dunnett’s test analysis clarified that tongue pressure decreased marginally when the VDO was raised +5 mm from the MCP; it continued to show a significant decrease at +6 mm ($p=0.041$) and +7 mm ($p=0.035$) (Figure 5).

IV. Discussion

Study 1 investigated the changes in patient-reported outcomes on comfort using a 100-mm VAS when the VDO was raised or lowered from the MCP. The VAS score did not significantly differ when the VDO was lowered by -1 mm and raised by 2 mm from the MCP.

In practice, estimating the VDO in edentulous patients has still been controversial (6-8, 16, 18, 19, 21, 22, 32). One specific method for VDO estimation is based on patient perception, using the recordings of the comfortable zone (CZ). However, determining the VDO using several methods is realistic. The studies on CZ have yet to compare its validity with the other estimation methods. In this study, CZ and VAS were compared. The results showed that patient comfort, as reflected on VAS, gradually decreased with the increase and the decrease in VDO from the MCP. No statistical difference in patient comfort was observed in the 3mm zone (-1 to +2 mm) surrounding the MCP, including at the MCP itself, including the MCP. This range indicated that the CZ ranged from 1 to 3 mm, as in previous reports (24, 25, 27). Both measures that ask for a response from the patient may strengthen the accuracy of VDO estimation. In addition, this result supports the reproducibility of VAS. Therefore, the reliability of VAS has been suggested.

Nevertheless, this study still has several limitations. The prior report indicated that the cut-off value of satisfaction with denture-wearing was > 80 mm (33) in VAS. In this study, the MCP and 1-mm raised or lowered VDO showed the median VAS at 80 mm. Although the range of VAS values that did not show significant differences was -1 to +2 mm, patients may feel differently. This may be related to the study sample, which included patients satisfied with wearing their dentures. In addition, the study excluded patients with broad freeway space, which means those with low VDO. In the clinical setting, estimating and increasing the VDO of patients with prolonged decreased VDO is critical. Thus, patients with a broader range of denture conditions must be recruited and analyzed for future studies. Despite these limitations, the findings of this study indicate that when performing VDO estimation in a clinical setting, it may be necessary to obtain a trichotomous response from the patient, and a subjective comfort score on a scale of 100.

Study 2 investigated the changes in tongue pressure when VDO was raised or lowered to MCP to determine the optimal VDO for individuals based on tongue pressure. The results showed no statistically significant differences in tongue pressure when VDO was lowered to -4 mm. In contrast, tongue pressure significantly decreased when VDO was raised by 6 mm from MCP.

In clinical practice, clinicians often encounter patients who complain of difficulty adapting to newly fabricated dentures. There are several reasons for this complaint, but one may be related to VDO. Estimating VDO in edentulous patients has been controversial (6-8, 15). However, VDO and tongue pressure are related (10, 29) and affect mastication (10-13) and swallowing (8, 20, 29). Therefore, developing a new method to estimate VDO based on tongue pressure is necessary. In the present study, the tongue pressure did not change significantly and maintained the normal values (34) when VDO was lowered from MCP. In contrast, the tongue pressure was lower than the reference values when VDO was raised more than 6 mm from MCP. This phenomenon may be explained by the fact that a higher VDO introduces a longer tongue contact

distance with the palate. The critical value of 6 mm from MCP may be shorter than that reported previously (9) on using a maxillary splint to raise the VDO in dentate subjects. This difference may be attributable to older adults having lower tongue pressure than younger adults (29, 34). The tongue may retain greater contact with the palate in younger adults even if the VDO is raised.

This study has several limitations. The average age of the study subjects was in the late 70s. Tongue pressure declines with age (29, 34). The critical value of VDO raised to MCP may decrease as the age increases. Thus, future studies should enroll subjects from a broader age spectrum. In addition, sex-related differences were demonstrated, and women tended to show lower tongue pressure values (34), indicating that a sufficient sample size is required for subgroup analysis. The apparatus used in this study was highly experimental. Its clinical application is a future challenge. This device may help estimate VDO with conventional occlusal rims or during the try-in of the wax denture.

The results of this study showed that the CZ and MCP obtained by the three methods were close to the subject-specific bite height diameter, and the sensory perception of the change in the bite height diameter obtained as the VAS value was also highly reliable. The critical point of the occlusal elevation was clarified by the fact that the tongue pressure showed a significant change when the occlusal elevation was more than 6 mm higher than the MCP.

In daily clinical practice, some cases of failure exist. There may be a certain number of cases with poor progress due to inadequate occlusal height in those cases. The Willis' method is frequently used to determine the VDO when taking occlusal measurements during complete denture fabrication. Using a reference point on the skin outside the mouth is unreliable in determining the occlusal height. It has been suggested that it cannot detect facial changes even if the occlusal height is raised in the mouth. In light of this, it is beneficial to estimate occlusal height that place importance on the discomfort and comfort level of the height sensation in determining the VDO.

Systematic reviews of raising the height of the occlusion often report that raising the occlusion by up to 5 mm is acceptable. Concerning the relationship between raising the height of the occlusion and tongue pressure, a significant difference in the decrease in tongue pressure was observed from 6 mm raising, which is consistent with these reports and changes in tongue pressure, which is one of the oral functions. Oral frailty has recently become an issue. Considering the need to restore the function of complete dentures, detecting changes in tongue pressure would be helpful.

V. Conclusion

1. Study1 confirmed that reproducibility and validity of CZ method. The changes in VAS when VDO was increased or decreased from the MCP. The VAS score did not significantly differ when the VDO was lowered by -1 mm and increased by 2 mm from the MCP. These results suggest that VDO may be set up from -1 to 2 mm from the MCP when fabricating new complete dentures for edentulous patients.
2. Study2 investigated the changes in tongue pressure when VDO was raised or lowered in relation to MCP. Tongue pressure did not significantly change when VDO was lowered from MCP or when it was raised to +4 mm from MCP. These results suggest that VDO may be set up to 5 mm from MCP when fabricating new complete dentures for edentulous patients in their late 70s, without extremely lowering tongue pressure, one of the oral functions.
3. These results suggest that a new method to estimate the VDO based on tongue pressure, closely related to mastication and swallowing functions, may be feasible. The results suggest that this method may help restore the masticatory function of complete denture wearers, improving their nutritional status, enjoyment of eating, and oral QoL.

VI. ReferencesU

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VII. Figure Legends

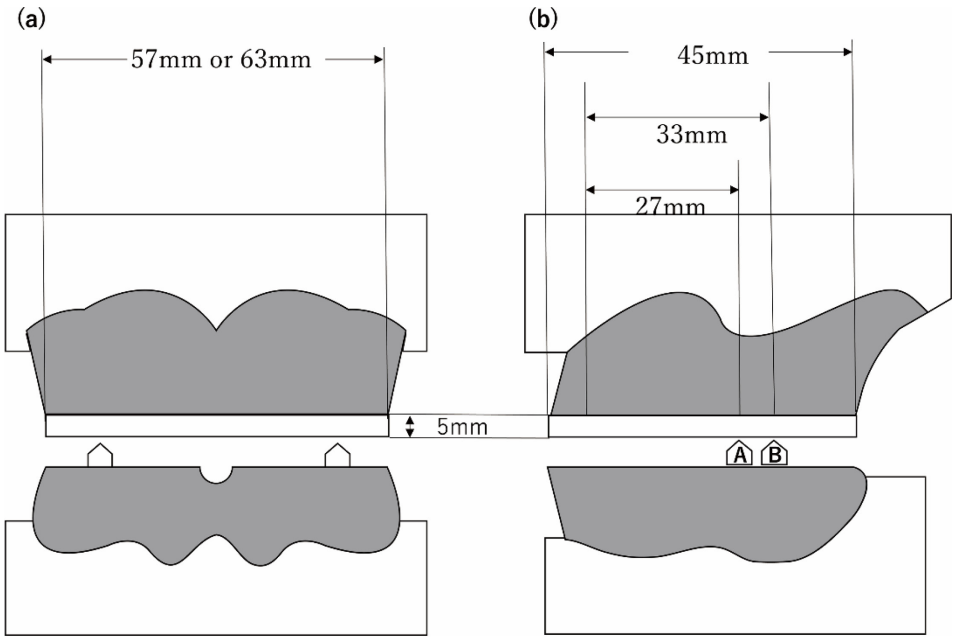

Figure 1: The standard design of occlusal rims and apparatus. (a) anterior view, (b) lateral view.

The vertical height of the maxillary occlusal rims: the same as the existing maxillary denture. The width of the rim: large (63-mm wide when the width between a participant's bilateral mandibular first molars was 50 mm or longer) and regular (57-mm wide when the width between a participant's bilateral mandibular first molars was 49 mm or shorter). The anteroposterior apparatus diameter: 45 mm from the incisal papillae to the posterior margin of the occlusal rim. Height-positioning stainless-steel block: two pit holes in the position corresponding to the blocks were installed according to the distance from the maxillary incisor papilla to the bilateral hamular notch line. A was placed 27mm anteroposteriorly from the incisor papilla, and B is placed 33 mm.

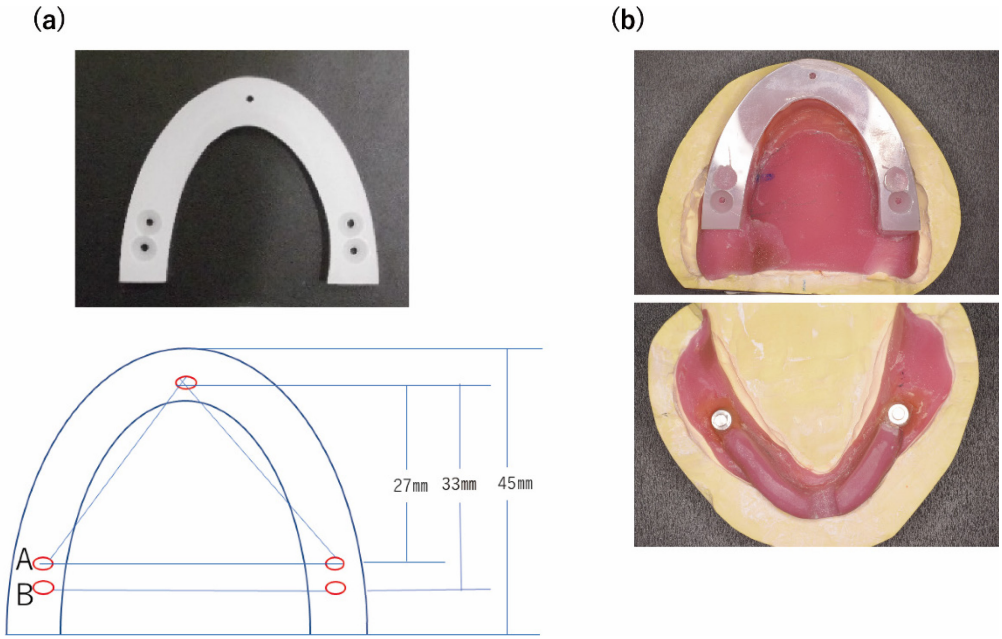

Figure 2: The anteroposterior apparatus diameter and the design of pit holes. (a) the design of pit holes, (b) rim installed on record base.

45 mm from the incisal papillae to the posterior margin of the occlusal rim. Two pit holes were selected according to the distance from the maxillary incisor papilla to the bilateral hamular notch (IH) line. Hole A was selected if IH was ≥ 50 mm, and hole B if IH was < 49 mm.

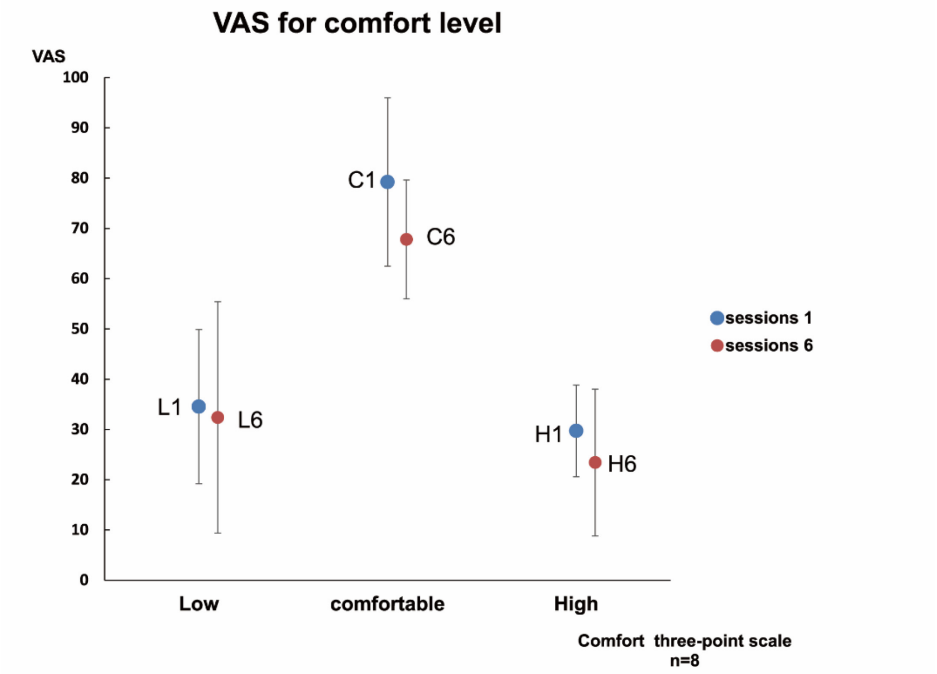

Figure 3: The relations between the 100-mm visual analog scale (VAS) values and comfortable zone (CZ) response and reproducibility.

L1: VAS when patient answered ”low” in session 1,
C1: ”comfortable” in session 1,
H1: “high” in session 1,
L6: ”low” in session 1,
C6: ”comfortable” in session 6,
H6: "high" in session 6.
Two-way ANOVA showed a statistical difference in VAS among the CZ responses ($p < 0.001$) but not between sessions 1 and 6 ($p = 0.774$). There was no interaction between the CZ response and sessions ($p = 0.961$). Bonferroni's multiple comparison test showed that the “comfortable” response was significantly higher than the “low” ($p < 0.001$) and “high” responses ($p < 0.001$) at sessions 1 and 6.

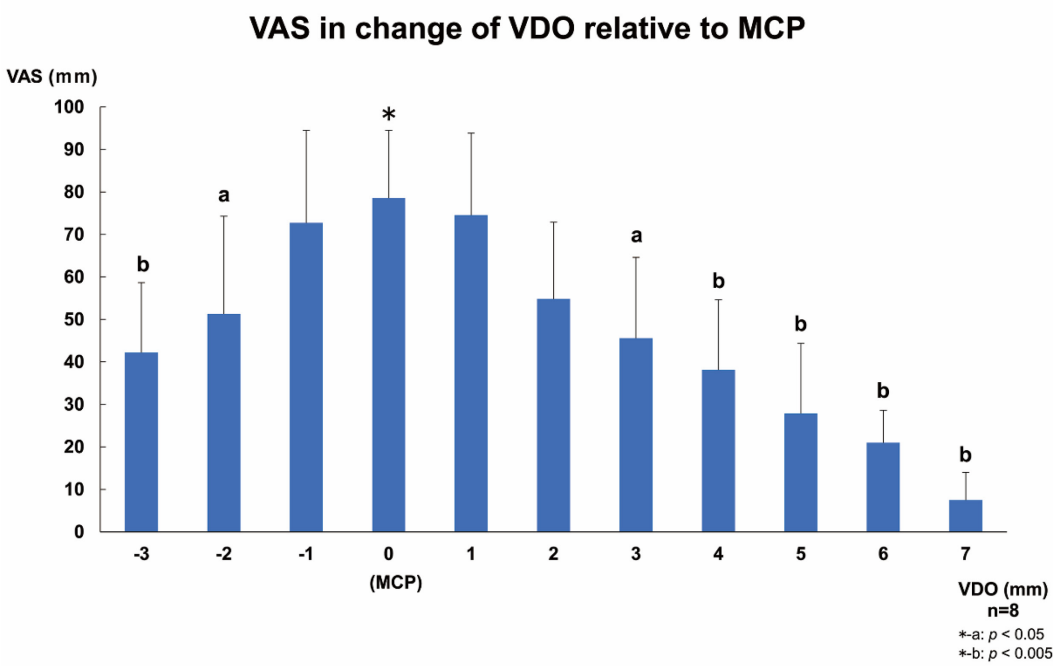

Figure 4: The VAS response on respective VDO from the most comfortable position (MCP) (MCP is indicate as 0)

One-way ANOVA showed a statistical significance ($p < 0.001$). Dunnett's test showed that VAS significantly decreased when the VDO was raised by +3 mm from the MCP ($p = 0.009$) and continued to show a significant decrease at +4 ($p = 0.001$), +5 ($p < 0.001$), +6 ($p < 0.001$) and +7 mm ($p < 0.001$). Moreover, VAS significantly decreased when the VDO was lowered by -2 mm from the MCP ($p = 0.048$) and continued to show a significant decrease at -3 ($p = 0.003$).

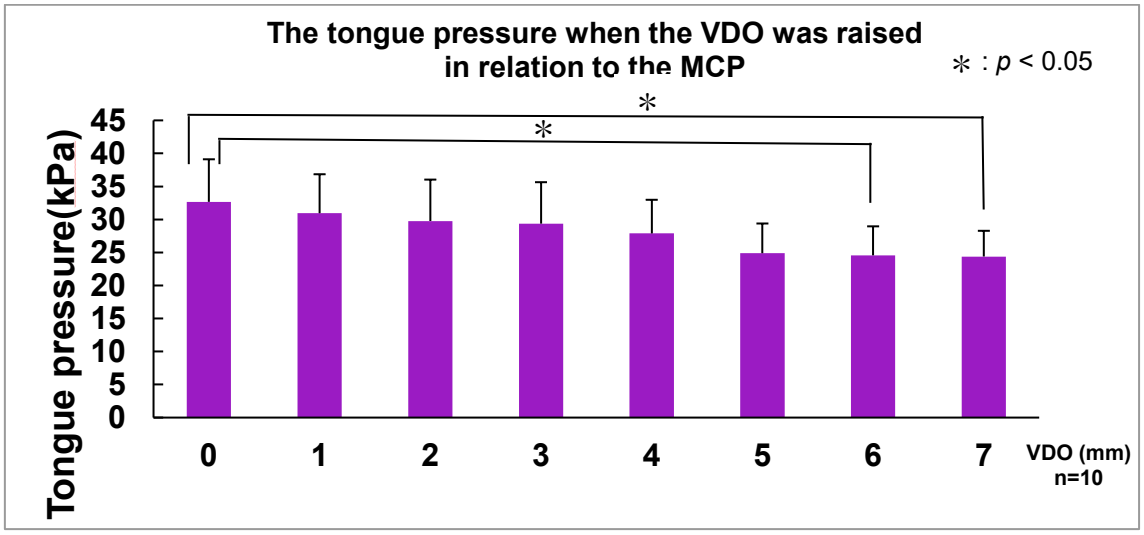

Figure 5: The tongue pressure when the vertical dimension of occlusion (VDO) was raised in relation to the most comfortable position (MCP).

When VDO was higher than MCP, One-way ANOVA showed significant differences between the stimulus intervals (+1 mm to +7 mm, p = 0.033) . Post-hoc Dunnett's test analysis clarified that tongue pressure decreased marginally when the VDO was raised +5 mm from the MCP; it continued to show a significant decrease at +6 mm (p = 0.041) and +7 mm (p = 0.035).