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Development of a new teaching tool for visualizing invisible tips by adjusting full dentures

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ABSTRACT

Aims: Dental clinical skills include subtle techniques, such as applying an appropriate amount of force depending on the procedure. This study investigated the training effects of using pressure sensors on force magnitude control during the dental procedure.

Methods: Forty-two dental trainees participated in this study. The experimental task was a fit test, assessing the pressure contact of a denture against the mandible. The force applied by each participant was measured using a modified mannequin equipped with a digital force gauge. Fit test training was performed under conditions specifying the presence or absence of fit test material and various degrees of force, with 50 N set as the standard. After training, the ability to control force magnitude was statistically evaluated by examining the error between the specified and actual values.

Results: The presence of the fit test material did not affect the force magnitude, and the time required decreased in proportion to the number of trials. Initially, not all participants were able to apply 50 N without special instructions. However, after training, the measured values exceeded 50 N. The error from the target value was significantly larger when 70 N was designated compared to 50 N. Errors between the specified and actual values obtained at 30–60 N exhibited a decreasing trend in each successive cycle.

Conclusion: Visualized numerical data are effective for developing practical force control. This form of experiential learning may contribute to the early retention of basic dental skills.

Keywords: Clinical competence, dental education, fit test, experiential learning, mannequin simulation

INTRODUCTION

Dentistry is a precise medical practice involving advanced skills, and many countries conduct various qualification examinations to ensure the competency of dentists.[1] Dental treatment performed in a narrow oral cavity involves sensory tips that are difficult for learners to visualize. Practical dental skills are typically acquired through clinical experience. Conventionally, several effective educational methods have been developed to solve this problem, including instructional videos,[2-4] simulation-based learning systems,[5,6] efficient teaching schedules,[7] objective evaluations of procedural outcomes by 3D scanner,[8-11] and verification of treatment effects or skill training using sensors.[12,13] Recently, research has been conducted to analyze behavior during dental practice for application in clinical skills education.[14,15] Experiential learning methods, such as haptic devices[16,17] and virtual reality systems[18,19] have also been introduced. One of the most critical educational factors that cannot be visualized is the application of an appropriate force to the patient or the affected teeth, depending on the procedure. Dental treatment involves the handling of various materials and tools; therefore, controlling the force magnitude applied during procedures is an indispensable technical skill required by dentists. To address this issue, a modified mannequin equipped with a pressure sensor was developed, which quantitatively demonstrated that the magnitude of the force applied by practitioners during dental treatment differs among students, resident dentists, and teaching faculty members. This study aimed to evaluate the use of this device in clinical dental training and to investigate the influence of visual information on force control during dental procedures, focusing on a fit test involving a complete mandibular denture.

METHODS

The study was carried out with the approval of the Ethics Committee of Niigata University Medical and Dental Hospital (Date: 05.08.2015, Decision No: 2015-5055). All participants were informed both in writing and orally about the content and purpose of the study, and assured that personal information would be deleted from the obtained data. They were also informed that participation carried no disadvantages and

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that they could withdraw at any time. Written consent was obtained from all participants. All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki.

Participants and Force Measurement Methods

Forty-two dental trainees (17 men and 25 women, 26.1±2.5 years old) at Niigata University Medical and Dental Hospital participated in this study. The test operation consisted of a fitting examination, in which a full denture (FD) was applied to the edentulous mandible. To quantify the force magnitude applied by the practitioner to the patient and the duration of the procedure, a modified mannequin (Simple Mannequin, Nissin, Kyoto, Japan; Figure 1) incorporating a digital force gauge (ZTA-100 N, IMADA, Aichi, Japan) was fabricated. A model of the edentulous mandible (P9-X,1133, Nissin, Kyoto, Japan) and an FD fitted to this model were prepared. Participants were instructed to place their thumbs around the second premolar of the FD and apply force with both hands, clamping the other four fingers between the metal frames corresponding to the lower margin of the mannequin's mandible (Figure 2). Measurements were recorded using dedicated software (Force Recorder; IMADA, Aichi, Japan) installed on a notebook PC connected to a force gauge. The following two experiments were conducted during the second half of the training period.

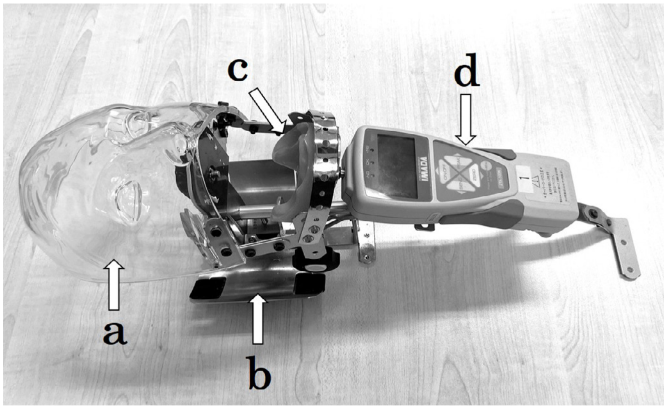

Figure 1. A modified mannequin incorporating a digital force gauge.
a: Face part of dental mannequin (Nissin)
b: Headrest mount (Nissin)
c: Model of the edentulous mandible (Nissin)
d: Force gauge (Imada)
Other than the above parts are self-made

Figure 2. The instructed method for applying force to the FD
Participants were instructed to place their thumbs around the second premolar of the FD and apply force with both hands by clamping the other four fingers between the metal frames corresponding to the lower margin of the mandible

Experiment 1: Influence of the presence of a fit checker on the magnitude and duration of the denture fit test (pressure contact). Participants were given no specific instructions other than to perform an FD fit test, and the force magnitude was measured once under each of the following two conditions: (1) checked by eye and fitting material (FC: Fit Checker: GC, Tokyo, Japan) and (2) checked by eye alone.

Experiment 2: Changes in force control through training using objective numerical values as indicators (Figure 3).

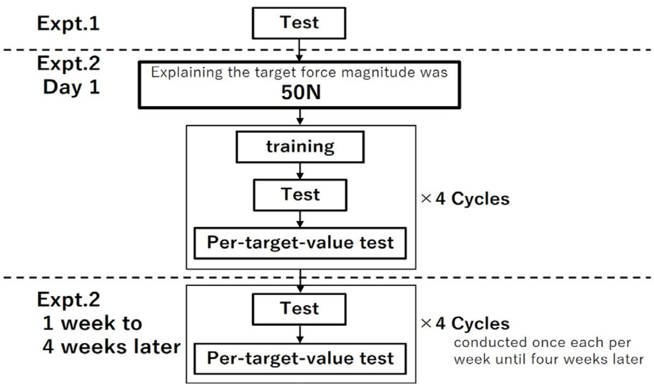

Figure 3. Flow of experiment

Participants were informed that the target force magnitude was 50 N and were trained to press the FD onto the model while observing the digital force gauge value. "Training" consisted of denture pressure contact exercises using force levels of 30-70 N, centered on 50 N. Each force application lasted 9 s, followed by a 15 s break (Figure 4). The pressure magnitude was measured in the order of "test" and "per-target-value test." In the "test," participants were instructed to pressurize the FD with the FC at 50 N, and after completing the experiment, the maximum value of the pressure magnitude was presented to each participant. A 1 min break was provided between the "test" and "per-target-value test." In the "per-target-value test," participants were instructed to pressurize without the FC at 50 N, 30 N, 60 N, 40 N, and 70 N, respectively. Pressure magnitude was not disclosed to the participant after the experiment. Four cycles of "training," "test," and "per-target-value test" were performed on the same day. Thereafter, the "test" and "per-target-value test" were conducted once per week for 4 weeks.

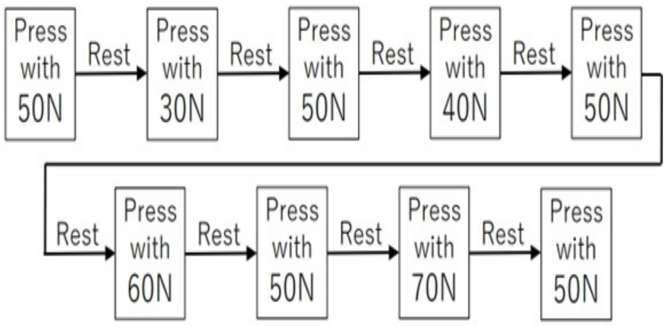

Figure 4. Force variation across training sessions in experiment 2
This cycle was repeated with 7 s of pressure and 15 s of rest. Practice pressures of 30N–70N were applied in the above order, with participants receiving feedback from the force gauge values during pressure application

Of the 42 participants in Experiment 1, 20 (11 men and nine women, 26.0±2.4 years old) participated in Experiment 2, which was conducted 1 month later.

Analysis of Measurement Results

The analysis interval was defined as the period between the maximum rate of increase or decrease in the measured pressure in each trial, and the elapsed time was defined as the pressure contact time (Figure 5). The force magnitude for each participant was the maximum value recorded by the force recorder during the analysis interval. Trials A and B in Experiment 1 were defined as T_a and T_b, respectively, and their force magnitudes and pressure contact time were analyzed using the Wilcoxon signed-rank test. Each trial from the first to eighth "test" in Experiment 2 was defined as T_1, T^2, ... T_8, respectively. Since the T_a in Experiment 1 and the "test" in Experiment 2 were performed under the same conditions using FC, the T_a was defined as T0. A Friedman test was performed on the force magnitude and compression time from T_0 to T_8, followed by multiple comparisons using the Bonferroni method. For the "per-target-value test" in Experiment 2, the absolute difference between the target value and force magnitude was determined as the error from the target value. The Kruskal–Wallis test was used to analyze the error from the target value and the pressure contact time across the first to eighth measurements. Multiple comparisons were made between the target value of 50 N and other target values using the Steel method. The coefficients of variation for the errors between the first and eighth measurements and target values were also obtained. All statistical analyses were performed using EZR (Jichi Medical University, Tochigi, Japan), a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria). EZR is a modified version of R Commander, designed to add statistical functions frequently used in biostatistics.[20] The significance level for all the tests was set at 5%.

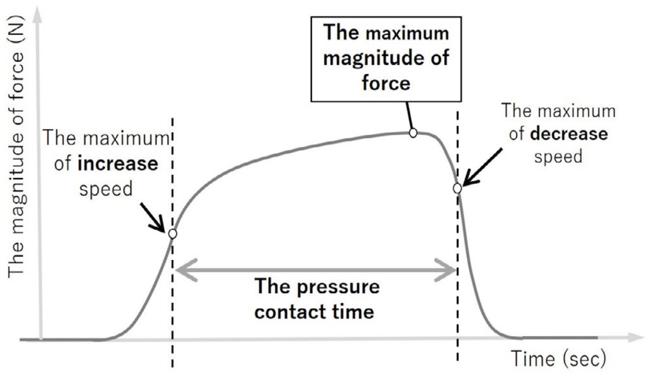

Figure 5. Definition of the maximum force magnitude and the pressure contact time

RESULTS

Experiment 1: The median and quartile ranges of the force magnitude and pressure contact time are presented in Table 1. No significant differences were observed in the force magnitude (p=0.301). The pressure contact time of Ta was significantly greater than that of Tb (p<0.001).

Table 1. Experiment 1

	Force magnitude (N)	Pressure contact time (s)
T_a	38.8 (28.5-47.8)	8.8 (6.8-11.9)
T_b	41.4 (28.9-53.5)	4.2 (2.7-6.4)
p-value	0.301	<0.001*

*: p<0.05

Experiment 2: Measurement of "test": The median and quartile ranges of the force magnitude and pressure contact time are presented in Table 2. The results of multiple comparisons for the force magnitude and pressure contact time are shown in Tables 3 and 4. The force magnitude at T0 was significantly lower than those at T1, T2, T4, and T5. For the pressure contact time, T0 was significantly longer than T1–T8, and T1 was significantly longer than T3, T4, T7, and T8 (p<0.05).

Table 2. "Test" for experiment 2

	Force magnitude (N)	Pressure contact time (s)
T_0	38.4 (27.4-48.0)	9.3 (6.7-14.1)
T_1	67.0 (58.9-73.2)	5.2 (3.9-6.6)
T_2	57.8 (54.7-63.4)	4.4 (3.1-6.2)
T_3	54.2 (51.0-59.0)	3.7 (2.8-4.8)
T_4	55.8 (53.9-60.8)	3.5 (2.5-4.9)
T_5	61.5 (53.1-71.9)	3.7 (2.9-5.7)
T_6	54.6 (50.0-59.5)	3.6 (2.7-5.5)
T_7	51.2 (44.3-57.7)	3.7 (2.5-4.5)
T_8	53.7 (42.4-61.5)	3.5 (2.7-4.0)

Table 3. Multiple comparisons of the force magnitude

	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7
T_1	<0.001*							
T_2	0.008*	>0.99						
T_3	0.071	>0.99	>0.99					
T_4	0.017*	0.34	>0.99	>0.99				
T_5	0.024*	>0.99	>0.99	>0.99	>0.99			
T_6	0.263	0.23	>0.99	>0.99	>0.99	>0.99		
T_7	0.959	0.175	0.84	>0.99	>0.99	>0.99	>0.99	
T_8	>0.99	0.263	>0.99	>0.99	>0.99	0.773	>0.99	>0.99

*:p<0.05

Table 4. Multiple comparisons of the pressure contact time

	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7
T_1	<0.001*							
T_2	<0.001*	>0.99						
T_3	<0.001*	0.003*	0.114					
T_4	<0.001*	0.037*	0.098	>0.99				
T_5	<0.001*	0.127	>0.99	>0.99	>0.99			
T_6	<0.001*	0.061	0.207	>0.99	>0.99	>0.99		
T_7	<0.001*	0.008*	>0.99	>0.99	>0.99	>0.99	>0.99	
T_8	<0.001*	0.023*	0.575	>0.99	>0.99	0.935	>0.99	>0.99

*:p<0.05

Experiment 2: Measurement of the "per-target-value test": The median and quartile ranges of the error from the target value and the results of multiple comparisons are shown in Table 5. The average error from the target value is shown in Figure 6, and the coefficient of variation is shown in Figure 7. The error from the target value was significantly larger when

Table 5. "Per-target-value test" for experiment 2

	Error from the target value (n)					Pressure contact time (s)				
Target value	**30 N**	**40 N**	**50 N**	**60 N**	**70 N**	**30 N**	**40 N**	**50 N**	**60 N**	**70 N**
Session 1	13.6 (8.6-21.5)	16.2 (11.9-21.4)	14.4 (8.9-22.9)	10.3 (7.1-18.0)	10.7 (5.5-21.2)	2.8 (1.9-3.3)	3.2 (1.8-3.6)	3.1 (2.2-4.4)	3.0 (2.5-3.7)	3.2 (2.1-3.8)
Session 2	9.1 (3.8-17.5)	6.3 (3.3-16.2)	8.8 (3.5-15.7)	3.8 (1.5-11.6)	10.7 (4.5-14.6)	2.5 (1.8-3.0)	2.5 (2.1-3.7)	3.5 (2.9-5.1)	3.0 (2.3-3.8)	3.1 (2.54.0)
Session 3	11.1 (8.8-15.3)	9.5 (6.1-13.8)	10.2 (7.2-14.4)	10.2 (4.6-17.8)	12.9 (6.9-18.8)	2.1 (1.8-2.9)	2.5 (2.1-2.9)	2.6 (2.2-3.1)	2.6 (2.3-3.8)	2.8 (2.3-3.8)
Session 4	9.0 (3.6-12.9)	7.5 (5.2-11.8)	9.1 (4.3-14.0)	6.3 (4.7-12.3)	9.3 (3.2-14.3)	2.3 (1.8-2.8)	2.5 (2.1-3.2)	2.4 (2.0-3.6)	2.7 (1.9-3.9)	3.0 (2.1-4.3)
Session 5	9.0 (4.4-15.5)	8.8 (4.7-16.8)	6.3 (3.2-14.4)	5.4 (3.6-15.5)	10.9 (2.8-23.6)	1.9 (1.3-2.5)	2.3 (1.7-2.7)	3.1 (2.1-4.0)	2.6 (1.8-3.2)	2.5 (2.1-3.2)
Session 6	11.3 (4.4-14.1)	6.9 (4.2-14.0)	8.8 (3.5-13.1)	10.6 (4.2-14.7)	16.0 (7.9-27.2)	2.0 (1.2-2.4)	1.9 (1.5-2.7)	2.4 (1.9-3.7)	2.4 (1.8-3.2)	2.6 (2.1-3.2)
Session 7	7.4 (5.0-12.4)	9.3 (4.7-13.1)	6.6 (5.1-8.7)	9.1 (3.6-16.6)	10.8 (6.7-17.9)	1.7 (1.1-2.3)	2.1 (1.6-2.7)	2.1 (1.5-3.1)	2.4 (1.6-4.0)	2.3 (1.9-3.4)
Session 8	10.8 (5.4-16.1)	7.9 (4.6-15.4)	6.9 (5.5-12.4)	11.8 (3.9-18.3)	13.2 (8.3-23.5)	1.6 (1.1-2.2)	1.9 1.5-2.4)	2.0 (1.7-2.9)	2.1 (1.5-2.9)	2.2 (1.5-3.6)
Session 1~8	10.1 (5.4-16.1)	9.2 (4.6-16.3)	8.8 (4.5-14.8)	8.5 (3.9-15.7)	11.6 (5.5-18.8)	2.0 (1.4-2.8)	2.3 (1.7-2.9)	2.8 (1.9-3.6)	2.6 (1.9-3.5)	2.7 (2.13.8)
p-value (compared with 50n)	0.462	0.975	-	> 0.99	0.032*	> 0.001*	0.010*	-	0.797	0.952

*:p<0.05

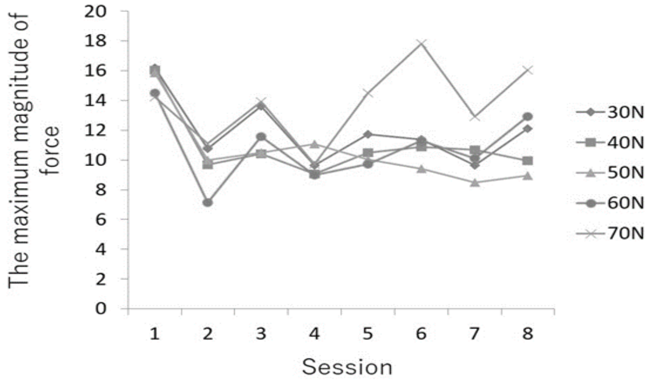

Figure 6. The average error from the target force during repeated measurements

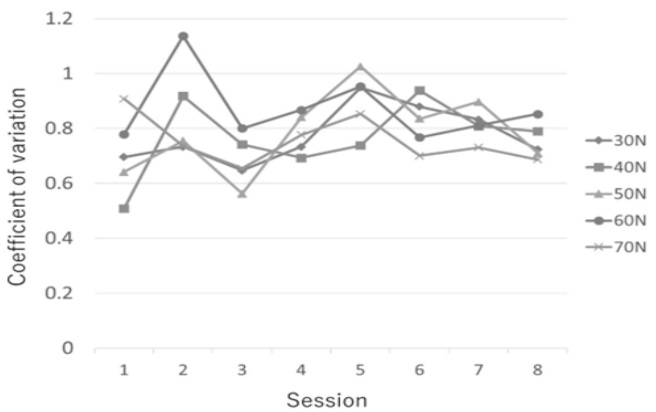

Figure 7. Coefficient of variation in the measurement "per-target-value test."

the designated force magnitude was 70 N compared to when it was 50 N. For designated forces between 30 and 60 n, the median force magnitude applied by the participants was approximately 15 N higher than the average target value in the measurement after the first training session. However, these values decreased significantly in the second measurement, and from the third measurement onward, they tended to remain approximately 10 N higher than the target value. At the target value of 70 N, the difference from the target value after the fifth time point was larger than that at ≤60 N. The coefficient of variation was>1 in the second trial, setting the target value at 60 N and the fifth at 50 N. The pressure contact time tended to increase with increasing force and decrease with an increasing number of training sessions.

DISCUSSION

In Experiment 1, visual information, such as differences in hand sensation during pressure contact with and without FC or the spread of FC, had little influence on the pressure contact force, as no significant difference in force magnitude was found between T_a and T_b. Conversely, the significantly longer pressure contact time for T_a compared to T_b was presumed to indicate that the participants judged the situation by observing how the FC spread. In Experiment 2, based on the research by Fontijn-Tekamp et al.,[21] which reported that the occlusal force on the mandibular first molar of a female wearing complete dentures was approximately 40-50 N, the target value for the pressure contact force magnitude was set at 50 N.

In this experimental environment, when the FD was pressure-welded to the model with the FC while checking the force gauge value, it spread uniformly at 50 N and showed no significant difference compared with 55 N and 60 N. Therefore, the target values set in this study were considered similar to those used in actual clinical practice. Yamaji et al.[22] reported that participants were instructed to intermittently exert grip strength at 50%, 75%, and 100% of their maximal voluntary grip contraction (MVC) and that the exerted force capacity at the 50% MVC requirement showed minimal decrease after 6 min. The test and training setup in this study lasted <5 min; therefore, it was assumed that the participants' muscle fatigue had little effect on the results. Each participant had clinical experience in denture adjustments. However, T0 was significantly smaller than T_1-T_8, and the median value did not reach the target value of 50 N. The median value exceeded 50 N from T_1 to T_8 after training with the target value. These results indicate that an appropriate amount of pressure cannot be acquired only by guidance lacking objective indicators, such as chairside advice or feedback based on actual clinical experience. Shea and Kohl[23] reported that, in an experiment where the right hand exerted 175 N of force (the criterion task), the group that practiced an insertion task, in which different force magnitudes were exerted at intervals, performed better on a test 24 h later than those who practiced only the criterion task. The results of this study were the same, suggesting that the participants reaffirmed the magnitude of the criterion while self-mapping for other force magnitudes with 50 N as the criterion. However, relatively large forces >60 N varied widely among the participants, even though they had some degree of control over them. Suzuki et al.[24] reported that the average pinch force for pinching an object with the thumb and index finger of one hand was 7.9±1.1 kg for the dominant hand and 7.5±1.1 kg for the non-dominant hand. The denture pressure application movement performed in this study had more factors related to finger pinch force than grip strength, and it is possible that some participants had difficulty controlling fine forces in the region ≥60 N. The pressure contact time decreased with each training session, and the intended force magnitude was reached in a shorter time. This suggests that the process of thinking while performing a motion can be shortened by accurately understanding force magnitude. As time greatly affects the efficiency of medical treatment, it is important to continue research with the aim of applying this device in educational settings for teaching appropriate force application. The benefits of using this system in education are two-fold: reduced patient burden and shorter skill acquisition time. It prevents patients from experiencing excessive force and pain, and also reduces chair time. Previously, preclinical training provided students only with knowledge about fitting examinations; however, by incorporating this system into the curriculum, students will be able to acquire the skills necessary to properly perform fitting examinations before entering clinical settings. In Japan, a device (iWakka) was developed in 2012 that displays grasping force and target values on a monitor in real time. The device has been introduced into the medical field as an evaluation and training tool for patients who have difficulty controlling their grasping force, such as older people and post-stroke hemiplegics.[25-28] The device used in this study was suggested to quantitatively guide technical elements that are difficult to visualize using conventional methods and has the potential to be developed into a device similar to iWakka.

Limitations

This study demonstrated that learned force control abilities, measured as objective numerical indicators of the force applied by practitioners to patients during experiential learning, were maintained for approximately 4 weeks. However, no comparison was made with a control group that did not undergo training, and factors potentially affecting force control ability, such as individual grip strength, fatigue, and sex differences, were not investigated. Previous studies have reported that cardio pulmonary resuscitation skills decline within 2-3 months after training.[29] Since force control is considered important in dental treatment, future research should address these issues by examining different conditions and survey periods with reference to prior studies, while also verifying the applicability to other treatments.

CONCLUSION

The influence of the fitting material as visual information was considered smaller than that of the numerical data, visualizing the force magnitude in objectively assessing the force applied by the operator during the fitting examination of a mandibular complete denture. In addition, this study suggested that a hands-on learning method in which the force magnitude is numerically displayed can promote early skill retention, and that a modified mannequin equipped with a force gauge can serve as an effective tool for teaching force control during procedures.

ETHICAL DECLARATIONS

Ethics Committee Approval

The study was carried out with the approval of the Ethics Committee of Niigata University Medical and Dental Hospital (Date: 05.08.2015, Decision No: 2015-5055).

Informed Consent

Written informed consent was obtained from all individual participants prior to their inclusion in the study. Participants were fully informed about the study's aims, procedures, potential risks and benefits, and their rights-including the right to withdraw at any time without consequence. All participants voluntarily signed a written informed consent form.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

Financial Disclosure

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Author Contributions

Concept: M.H.[1], T.S.; Design: M.H.[1], T.S., F.N., S.T.; Control: M.H.[1], T.S., N.F.; Data Collection and/or Processing: M.H.[1], T.S., F.N., S.T.; Analysis and/or Interpretation: M.H.[1], T.S., M.H.[2], N.F.; Literature Review: M.H.[1], T.S., M.H.[2], N.F.; Article Writing: M.H.[1], T.S., N.F.

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