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Quantitative analysis of impression-taking performance-a pilot study to visualize invisible technical steps in dental procedures

Sayaka Tsuzuno[1], Takumi Sato[2,3], Futoshi Nakamura[1], Mizuki Nomura[1], Mana Hasegawa[1], Noritaka Fujii[1,2]

[1]*Department of General Dentistry and Clinical Education, Medical and Dental Hospital, Niigata University, Niigata, Japan*
[2]*Department of Dental Clinical Education, Faculty of Medical and Dental Sciences, Niigata University, Niigata, Japan*
[3]*Department of Periodontology, Faculty of Medical and Dental Sciences, Niigata University, Niigata, Japan*

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Corresponding Author: Sayaka Tsuzuno, hsayaka@dent.niigata-u.ac.jp

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ABSTRACT

Aims: Dental procedures involve intricate techniques that can be challenging to visualize, often hindering imitation and assessment. In this study, the impression-taking performance of abutment teeth was quantitatively analyzed to create objective indexes for dental skill education.

Methods: Participants were divided into two groups of different clinical experience levels: 10 dentists and 10 dental students. An aluminum model of abutment teeth was employed to simplify the experiment. An optical motion capture system (VICON, Oxford, UK) measured participants' movements. The impression accuracy, time length on the analyzed section, impression material pouring speed, total amount of impression material used, and syringe tip trajectory were evaluated. Fisher's exact test and Mann-Whitney U test were used to compare the two groups' results (α=0.05).

Results: In the dentist group, there were few apparent failures and a high impression accuracy. The amount of impression material dispensed tended to be larger in the dentist group, with longer practice time and slower syringe movement speed. This suggested that the inexperienced participants were sufficiently unable to pour out the impression material. The syringe tip trajectories were not significantly different between the groups. An instructor's advice is often limited to abstract feedback; therefore, specific suggestions might assist in effective skill education.

Conclusion: It is possible to quantitatively analyze impression-taking performance and provide helpful information for dental skill education by using this system.

Keywords: Dental skill education, impression-taking, quantitative analysis, optical motion capture, practical behavior, instrument manipulation

INTRODUCTION

Imitation is considered important in skill education as it is the first step in the educational goals of the psychomotor domain.[1] Practical dental skills education involves a program in which students who have acquired the treatment knowledge imitate and practice by observing the videos of treatment procedures or demonstrations provided by the instructors.[2] In addition, several innovations have been implemented, such as the development of videos[3] and various simulation systems[4-6] that are easier for students to understand since dental treatment involves many invasive procedures. However, skills sometimes include content that is difficult to visualize, creating a barrier for learners to imitate the expert performers, and difficulties in correctly assessing the skills have also been reported.[7-9] In recent years, methods for quantifying the morphology of abutment teeth and wax-ups and providing feedback to dental students have been developed to increase the objectivity of evaluation.[10-12] Nevertheless, these evaluations are not based on the skills themselves but on the work results. On the contrary, efforts have been made to quantitatively measure body movements,[13] which have been utilized for the transmission of skills in the field of performing arts,[14,15] facial muscle movements associated with growth,[16] and also involved the analysis of practical dental posture.[17] Dental treatments are performed using various instruments and materials, and the treatment skills include proper handling. Therefore, quantitative analysis of instrument manipulation and establishment of objective evaluation criteria would be useful for dental

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clinical skills education. However, few such studies have been conducted to date to address these aspects. The aim of this study was to quantify the practice behavior of operators in the impression-taking of abutment teeth with silicone impression material and to create an objective index for dental clinical skill education that was difficult to provide by conventional methods.

METHODS

This study was performed with the permission of the Ethics Committee of Niigata University Medical and Dental Hospital (Date: 11.03.2022, Decision No: 2021-0316). All participants were informed in writing and orally of the content and purpose of the study so that personal information could be deleted from the obtained data without failure. After providing information that there were no possible disadvantages to cooperating in the study and that they could withdraw their participation at any time, 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.

A total of 20 participants were included in the study, with 10 dentists (6 men, 4 women, average age: 39.9±6.9 years) with more than 7 years of clinical experience and 10 fifth-year dental students (3 men, 7 women, average age: 24.6±2.5 years) in clinical practice comprising two groups with different clinical experience. Practical movements on impression-taking of abutment teeth were analyzed in each group. The impression-taking was performed using a plastic syringe (GC, Tokyo, Japan) and silicone impression material (Examix Fine Injection Type, GC, Tokyo, Japan). A custom-made aluminum model of the abutment teeth of fully cast crowns was employed for impression-taking to simplify the treatment procedure.

The abutment teeth model was designed as a simplified form of the abutment teeth and gingival sulcus after gingival retraction (Figure 1). A conical base was simulated as a crown, and a circular groove was placed around it to simulate a gingival sulcus. A longitudinal groove was created on the side of the conical part. Impressions were taken over an area that included the assumed gingival sulcus and the finish line of the abutment teeth.

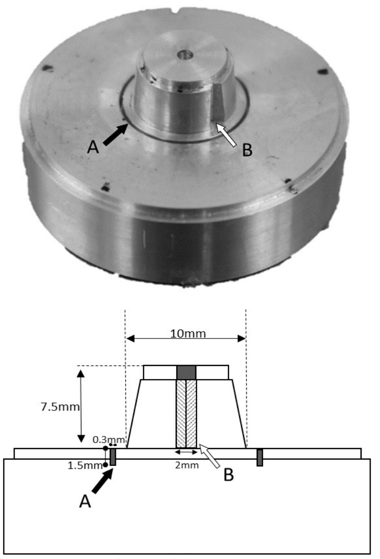

Figure 1. The abutment teeth model and its cross-sectional view: A, a groove simulates the gingival sulcus. B, a longitudinal groove

An optical motion capture system (VICON, Vicon Motion System Ltd, Oxford, UK) and infrared reflective markers (Marker set with a 9.5 mm plastic base, InterReha, Tokyo, Japan) were used for motion measurement. The system can display the three-dimensional positions of the markers in a virtual coordinate system by capturing the infrared reflective markers with two or more infrared cameras (T20S, 2 megapixels 1600 × 1280 pixels, up to 2000 FPS, 690 Hz at full frame frequency). In this experiment, 10 infrared cameras were set up so that three or more cameras could capture all the infrared reflection markers simultaneously at any time without disturbing the participant's movements. A dedicated personal computer (SYS-5039A-iL, Super micro, San Jose, USA) with platform software (NEXUS, InterReha, Tokyo, Japan) was used for system control, data recording, and analysis. The sampling frequency was set at 100 Hz.

Infrared reflective markers were fixed to the syringe body and plunger to measure the syringe motion. Additionally, a removable instrument was fabricated to calculate the position of the syringe tip (Figure 2). Two infrared reflective markers were affixed, one of which was designed to match the tip of the syringe. The direction of the line segment connecting the two markers was aligned with the direction of the ejection of the silicon impression material.

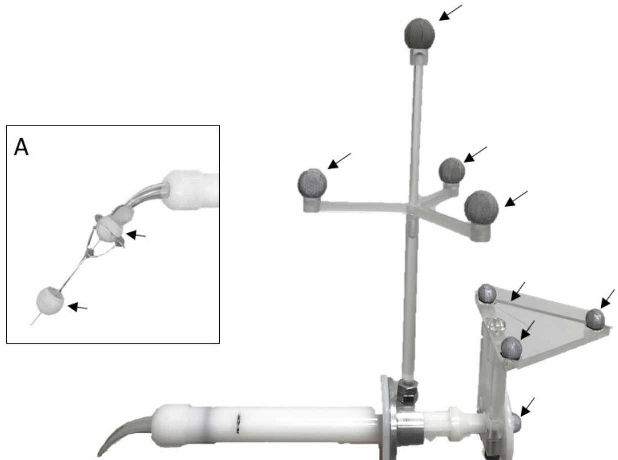

Figure 2. The syringe customized for experiment: black arrows, infrared reflective markers. A, removable instrument attached to syringe tip

To measure the three-dimensional position of an arbitrary point, a pen-shaped digitizing device (referred to as a "digitizer pen") was made with four markers fixed at the top and a jig with a removable marker at the tip. Three markers were placed on the metal plate and the abutment teeth model was fixed.

All participants made impressions on the abutment teeth model set up on a desk (Figure 3). They were instructed to move the syringe in a single stroke and make impressions only once in a clockwise or counterclockwise direction. Furthermore, two additional precautions were taken: do not use finger rests during the movement and do not cover the infrared reflective markers. The measurements were performed before, during, and after the impression-taking operation to calculate the syringe tip position on the syringe coordinate system and correct the measured values. Three random measurements were obtained for each trial performed by each participant under the aforementioned conditions. Considering the learning effect, the third data point in each direction was used for analysis.

Figure 3. The condition of the experiment: white arrows, infrared cameras. The abutment teeth model was bonded to a metal plate and fixed to the desk

The movement of the syringe was evaluated based on the position of the syringe tip relative to the coordinate system of the abutment teeth model. The system was developed by measuring the longitudinal groove assigned to the abutment teeth model using a digitizer pen. The volume of the ejected silicone impression material was calculated from the movements of the markers placed at the rear and inner diameters of the syringe. The mean and standard deviation of the time-series data of the pour volume for 1 s after the start and 1 s before the end defined the analysis for this experiment. The following five parameters were evaluated: impression accuracy, analysis section length, impression material pouring speed, total amount of impression material used, and syringe tip trajectory. The impression accuracy was evaluated by the same evaluator for errors, such as tears and defects. The length of the analysis section was the time of the analysis. The impression-material pouring speed and total impression material used were calculated from the time-series data of the impression-material pouring volume. The horizontal and vertical distances from the finish line of the abutment teeth model to the syringe tip were calculated to determine the syringe tip trajectory. The horizontal distance was expressed as a positive value when the tip of the syringe was positioned outside the finish line equivalent of the abutment teeth model and as a negative value when the tip was positioned inside. In addition, the angle between the syringe tip and the z-axis of the abutment teeth model was calculated (Figure 4). For the impression material pouring speed and syringe tip trajectory, the mean values during the operation were calculated and used as representative values for each participant. Fisher's exact test was conducted to determine the association between the presence of impression tears or defects and the dentist or dental student group. Other parameters were compared between the dentist and dental student groups using the Mann-Whitney U test. To examine the influence of impression-taking direction, the clockwise and counterclockwise results for each group were compared using the Wilcoxon rank-sum test. The data were analyzed using IBM SPSS Statistics ver. 28.0.0.0 (IBM, Armonk, NY, USA), with a statistical significance of $p<0.05$.

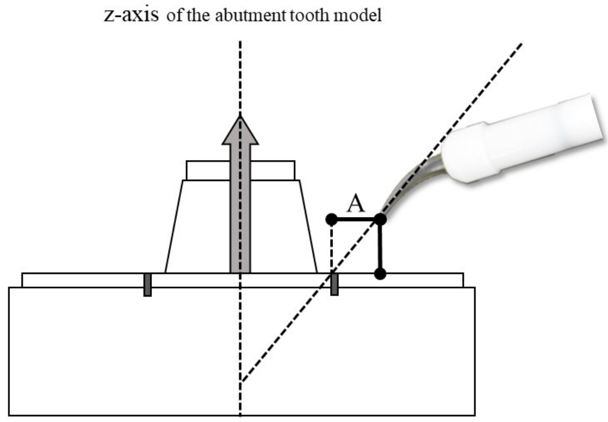

Figure 4. Three parameters calculated for the syringe tip trajectory: A, the horizontal distance from the finish line. B, the vertical distance from the finish line. C, the angle between the syringe tip and the z-axis of the abutment teeth model

RESULTS

None of the participants in the dentist group made impression-taking errors. However, several participants in the dental student group had tears and defects in the silicone impression material (Figure 5). There were significant differences between the two groups in both the clockwise and counterclockwise directions ($p<0.05$), and the dentist group had fewer errors in impression-taking (Table 1).

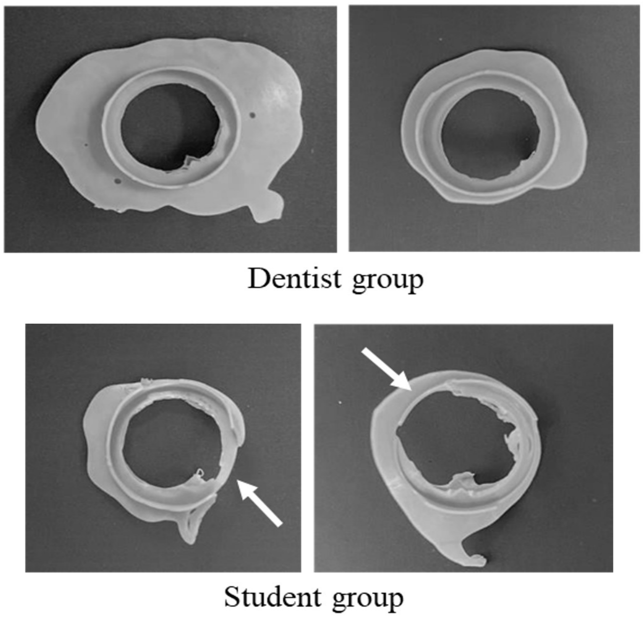

Figure 5. Example of results of impression-taking. White arrows, tears or defects of silicon impression material

The means and standard deviations of other parameters are listed in Table 2. Regarding the angle of the syringe tip, one participant in the dentist group was found to have an incomplete setting of the syringe tip marker during measurement; therefore, this participant was excluded from the analysis. The length of the analysis section was longer in the dentist group than in the dental student group. In addition, handling the impression material in the dentist

Table 1. Results of the analysis of impression accuracy

	Clockwise direction			Counterclockwise direction		
	Dentists (n=10)	Dental students (n=10)	p	Dentists (n=10)	Dental students (n=10)	p
No error	10	4	0.005	10	6	0.043
There were tears or defects	0	6		0	4	

Table 2. Results of the analysis of syringe operation

	Clockwise direction		Counterclockwise direction	
	mean±SD		mean±SD	
	Dentist group	Dental student group	Dentist group	Dental student group
Analysis section length (s)	15.53±5.61	9.17±4.14	13.80±5.05	8.64±3.03
Impression material pouring speed (ml/s)	0.023±0.014	0.015±0.006	0.025±0.010	0.015±0.009
Total impression material used (ml)	0.36±0.13	0.15±0.04	0.40±0.19	0.15±0.06
Syringe tip trajectory				
Horizontal distances (mm)	-0.18±0.53	-0.20±0.41	0.17±0.64	-0.20±0.54
Vertical distances (mm)	0.61±0.90	0.03±0.80	0.22±0.94	0.03±0.63
Angle (°)	17.50±4.90	20.09±6.23	16.72±6.31	21.51±13.56

SD: Standard deviation

group resulted in a faster-pouring speed and larger amount than in the dental student group. There were significant differences between the dentist and dental student groups in all parameters except for the impression material pouring speed in the clockwise direction (Figure 6). However, there were no significant differences in the three parameters of the syringe tip trajectory (Figure 7).

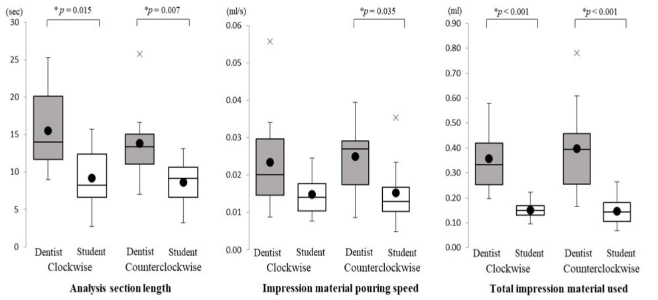

Figure 6. The results of the analysis section length, impression material pouring speed, and total amount of the impression material used: *, $p<0.05$. ●, mean value in each group

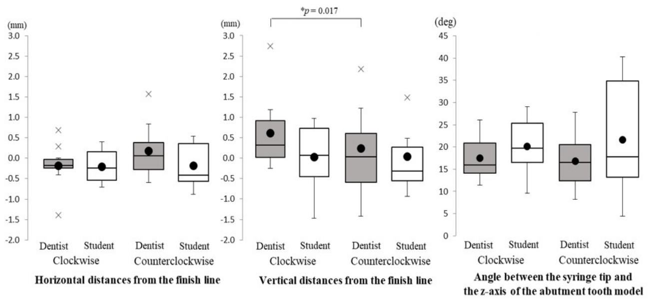

Figure 7. The results of the syringe tip trajectory: *, $p<0.05$. ●, mean value in each group

In the clockwise and counterclockwise comparisons, a significant difference was observed only in the vertical distance from the finish line to the syringe tip in the dentist group (Figures 6, 7).

DISCUSSION

The tears and defects observed in the cured silicone impression materials indicated that the impression accuracy was higher in the dentist group than in the dental student group. The higher pouring speed and longer treatment time of the impression material in the dentist group indicated that more than a certain amount of impression material was required for a precise impression of the abutment teeth. In contrast, there were few differences in the results in the direction of syringe movement and the trajectory of the syringe tip as expected. While these parameters may not affect the results, it was also considered that the simplified abutment teeth model in this study allowed for a relatively high degree of freedom in syringe manipulation, and the differences in clinical experience were less noticeable in the results. Therefore, it is deemed necessary to conduct further measurements under other clinical conditions and study the effect of these parameters on the impression-taking results.

It is not easy for dental students and trainee dentists to understand the speed of syringe operation and the amount of impression material injected, which were clarified by this study only from observing the demonstrations by instructors. Although directions from the instructor play an important role in skill training,[18] abstract advice such as "move slowly" or "use a little more impression material" are frequently provided. It has been shown that differences in experience can be objectively manifested by operation time or injection speed. From the above discussion, providing specific suggestions to learners by utilizing the indicators obtained in this study might contribute to effective dental skill education. Furthermore, the image of the syringe operation and silicone impression material pouring volume obtained from this analysis system was also considered useful for visualizing and explaining the operator's behavior (Figure 8). In recent years, various educational systems using robots, VR, and MR have been examined and investigated.[19-22] In the future, these systems can be combined with motion analysis to develop an educational system that allows learners to receive real-time feedback during skills training.[23,24]

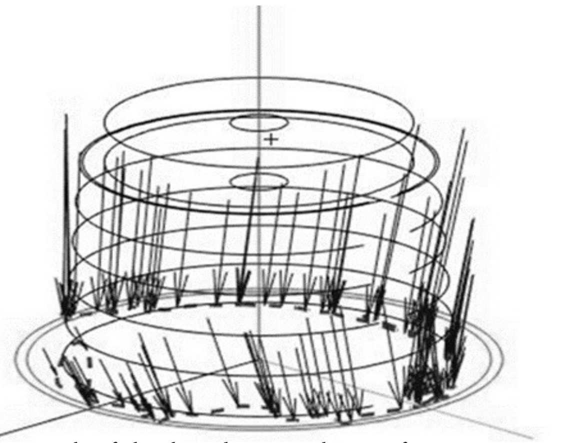

Figure 8. Example of the three-dimensional view of syringe operation and silicone impression material pouring volume: dotted line, syringe tip trajectory; arrow direction, syringe tip direction; arrow length, amount of impression material poured

Limitations

The limitation of this study was that it did not replicate various factors related to the success or failure of impression-taking in clinical practice, such as the morphology of the abutment teeth, the condition of the adjacent teeth and gingiva, and saliva. However, this system makes it possible to quantify the essential steps of the dental practical techniques that cannot be visualized by conventional methods. Further investigations and analyses, including measurements in additional clinical settings, are needed.

CONCLUSION

This study showed that a measurement system using an optical motion capture system can be used to analyze in detail the time-series changes in syringe movements and impression material delivery volumes during impression-taking. This system could be useful in creating new objective indexes for dental clinical education.

ETHICAL DECLARATIONS

Ethics Committee Approval

The study was carried out with the permission of of the ethics committee of Niigata University Medical and Dental Hospital (Date: 11.03.2022, Decision No: 2021-0316).

Informed Consent

All patients signed and free and informed consent form.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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