A Quantitative Measurement of Hand Scaling Motion for Dental Hygienist Training

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***Abstract*— In dental hygienist education, many skills are taught that cannot be acquired without repeated training. To make this training more efficient, we need to measure the students' skills and show correction points in real-time. In this research, we focus on hand scaling work, which is one of the most important tasks of dental hygienists. We developed a measurement system to measure both the motion and force exerted during hand scaling work. This measured data can be used to quantitatively evaluate students' skills. In the experiment, we measured the hand scaling motion of several participants with different levels of job experience, including dental hygienist teachers, dental hygienists, and dental hygienist students. We showed that it is possible to extract from the measured results a quantitative index for discriminating different individual skills.**

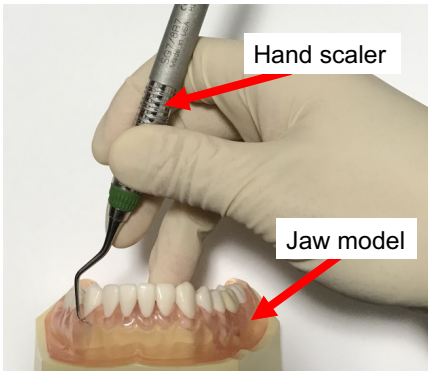

Fig. 1. Hand scaling work

I. Introduction

Dental hygienists help maintain oral health and provide medical assistance for the treatment of teeth. To get a job as a dental hygienist in Japan, they need to attend a training school for at least three years and more. During the education, students have to master the manipulation of dental instruments in the oral cavity. Textbooks have been published teaching these technical skills. However, detailed educational points such as the sense of touch in dental instrument operation are very difficult to describe in words. The quality of such skill educations is affected by the technical skills of dental hygienist teachers. Today, some visual media can be used to demonstrate techniques to students. Students can also learn the skills through self-study by using the dental manikin (i.e. head manikin including the teeth and jaw models). However, it is still not easy to understand the sense of touch when operating the dental instruments. Without feedback from the model, it is very difficult for students to know if the motion is correct, which makes the training inefficient. It is necessary to closely examine the teaching points and build an effective self-study tool.

In this research, we develop a measurement system to quantify the skills of dental hygienists and evaluate them by comparing the results of professional hygienists and students. We equip a jaw model with a force sensor to measure the force when a hand scaler touches a target tooth, as shown in Fig. 1. We also attach an inertial measurement unit (IMU) sensor to the bottom of the hand scaler to measure the hand scaling motion. In the experiment, we measure the hand scaling motions of several participants with different levels of job experience. The participants include dental hygienist teachers, dental hygienists, and dental hygienist students. From the measured results we derive a quantitative index for discriminating different individual skills and for evaluating motion. There are two major contributions to this research: (1) We create a measurement system for evaluating the hand scaling work using IMU and force sensors. (2) We succeed in evaluating the skill of hand scaling based on the measured motion information, by comparing the measured information between dental hygienists and students, the technical differences in skill levels can be clarified.

II. Related Works

In terms of research about the force applied to the teeth during hand scaling, Zappa *et al.* [1] have studied the scaling force to the front teeth. They measured the scaling force on incisors when ten dentists and ten dental hygienists treat untreated adult patients with progressive periodontitis. The mean of scaling force was 5.70 N for dentists and 5.38 N for dental hygienists. They also measured the force applied to molars [2]. The scaling force applied to molars is similar to that applied to front teeth. There is also research on the orthodontic force of teeth [3]. In this research, using a 6-axis force sensor connected to a tooth model, Lai *et al.* measured the force applied by the orthodontic appliance.

Research on measuring human motions is diverse and plentiful. Here, we focus on research using an IMU. Since IMUs are small and wireless, an IMU can be easily attached to a hand scaler. In the sports field, an IMU is used for motion

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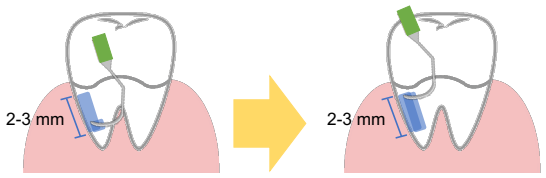


Fig. 2. Overlap trajectory of the working stroke

analysis and coaching. For example, Wang *et al.* [4] placed an IMU sensor on a player's wrist with a racket, recognized badminton strokes and classification of the skill levels of various badminton players.

Hand scaling requires manipulation of dental instruments and control of force within the limited field of view of the oral cavity so as not to cause unnecessary pain to the patient. Therefore, measuring both force and motion is the key to the successful analysis of hand scaling. This research is novel in that both the force of hand scaling was directly measured from the tooth with a 6-axis force sensor, and at the same time, the motion of the hand scaling operation was measured with an IMU.

III. Measurement System

A. Hand scaling

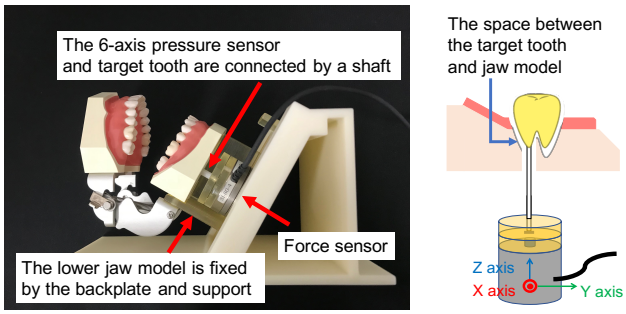
Hand scaling [5] is a typical dental treatment to remove tartar and the like deposited on a tooth surface using the hand scalers. Fig. 1 shows an example of the operation of hand scaling using a jaw model. Depending on the part of the treated tooth, there are various hand scalers with different tip shapes are used. These hand scalers should be held in a similar way as holding a writing instrument. As shown in Fig. 2, while cleaning a tooth, the tip of the scaler moves around the tooth in millimeters. The stroke trajectories should overlap with each other slightly to clean all around the tooth.

As described in the textbook, there are four major key points for evaluating hand scaling:

a) Is the hand scaler properly gripped?
b) Is the hand holding the hand scaler supported near the treated tooth with the ring finger?
c) Is the hand scaler tip correctly contacting the tooth surface?
d) Is the operation of removing dirt applying pressure to the tooth surface with the tip of the hand scaler?

Among these four points, a) and b) can be visually checked by the students. In c), however, the tip of the hand scaler is hidden by the gingiva in the oral cavity and cannot be seen. In d), also, only the students themselves can feel the degree of force they are exerting, and it is difficult for teachers to provide objective guidance.

One of the most difficult points for students and teachers is to confirm the relationship between the motion of the hand scaler tip and the contact force with the tooth surface. In this research, we develop a measurement system to investigate the quantitative evaluation of the motion of the hand scaler and the force exerted by the tip.



(a) Side view (b) Structure view

Fig. 3. Jaw model with a 6-axis force sensor under the target tooth

Fig. 4. Hand scaler equipped with an IMU sensor

B. System configuration

To evaluate the hand scaling skill described above, both the scaling force applied on the tooth surface and the motion of the hand scaler should be measured. The hand scaling work is very delicate. During the hand scaling, the hand motion should not be hindered by the sensors. Therefore, in this research, as shown in Fig. 3, we connect a force sensor to the tooth from the bottom to measure the scaling force on the tooth surface. In order to measure the hand scaling motion naturally, as shown in Fig. 4, we also place a small wireless IMU sensor on the rear end of the handle of the hand scaler.

1) Measurement of the scaling force: During the training of a dental hygienist student, dental manikins are used. This research used a jaw model (Nissin Co., Ltd., P15HD-500HPRO-S2A1-GSF). We selected the right mandibular first molar as the target tooth for hand scaling. As shown in Fig. 3, we place a 6-axis force sensor (BL Autotech, MICRO05/50) below the model and connect it with a shaft to one of the roots of the target tooth. To avoid effects from the bone, *i.e.*, the frame of the jaw model, we also set the position of the target tooth a little higher and further away from the frame.

2) Measurement of hand scaling motion: To measure the hand scaling motion without affecting the natural hand scaling motion, we used a light wireless multi-sensor board (Matilde Inc. Senstick [6]). The IMU sensor in this board can measure the acceleration, angular velocity, and magnetic field simultaneously. In this research, only the acceleration and angular velocity related to the hand scaling motion are measured. As shown in Fig. 4, we attach the sensor board to the rear end of the hand scalers (Hu-Friedy Mfg. Co., LLC., Gracey Curette Original), without inhibiting the

TABLE I

EXPERIENCE AS DENTAL HYGIENIST OF THE PARTICIPANTS

Experience	Number of participants
$\leq$ 5 years	4
$\leq$ 10 years	2
$\leq$ 15 years	3

natural grasp of the hand scaler. Using an A/D board and Bluetooth communication, the signals from both the force and IMU sensors are measured in 100 Hz.

IV. EXPERIMENT

Using the measurement system, we performed an experiment with several participants with different levels of experience in hand scaling work. The measured data were analyzed and compared based on their levels of experience. The experimental protocol of this research was approved by the research ethics board of Nara Institute of Science and Technology. Before the experiment, informed consent was obtained from the participants.

A. Setup

Same as in the case of training dental hygienist students, as shown in Fig. 5, we set the jaw model on an inclined attachment and fixed this to the table. As is the treatment in the dental clinic, the inclination of the model was 60 degrees to make the teeth easily visible by the participants. Fig. 6 shows the hand scaling position in the experiment. In this experiment, the participants scale the area of the target tooth indicated by the green arc in Fig. 6 by using the hand scaler #14 shown in Fig. 4. The target teeth have projections that mimic tartar. We measured the motion and force in hand scaling of the target tooth until the participants think they have removed the tartar. The measured acceleration, angular velocity, and force data were extracted from when the hand scaler is touching the tooth surface. During the experiment, we also took videos for all participants of the hand and upper body for verification by dental hygienist teachers.

The experiment was conducted with 15 participants, including one dental hygienist teacher, eight dental hygienists, and six dental hygienist students. Table I shows the work experience of all the dental hygienist. The dental hygienist students were first-year students studying in the same training school, with the same level of learning progress. All dental hygienist students had completed the lecture and training in hand scaling before the experiment. We easily assume that dental hygienists have better skills than the students even with their different levels of experience. Before the experiment, we prepared time for participants to practice the use of the device. Considering the level of experience, the practice time was set to 3 minutes for dental hygienists and 10 minutes for dental hygienist students.

B. Result

1) Data acquisition: Fig. 7 shows the measured data (acceleration, angular velocity, and force) for the dental hygienist teacher. A periodic motion (data in pink boxes)

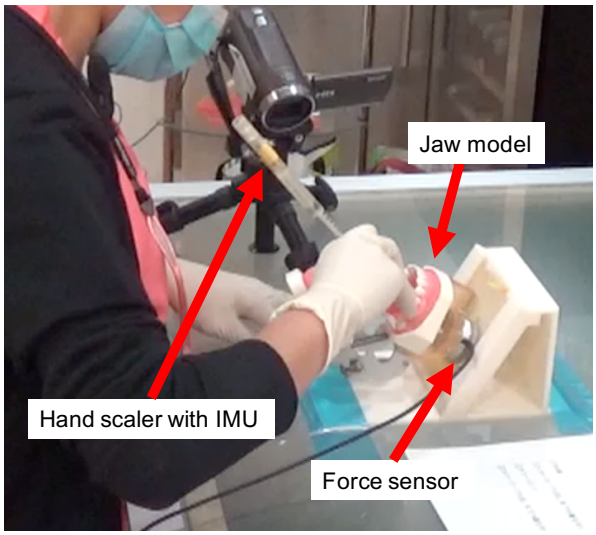


Fig. 5. Experimental setup

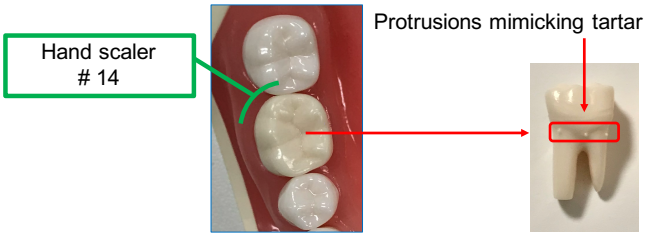


Fig. 6. Target hand scaling positions

could be measured for each stroke of several millimeters. In one stroke, the hand scaler moves up a few millimeters and the hand scaler rotates slightly. The rotation is to make the tip of the hand scaler follow the curved tooth surface. The measured data showed a clear increase in the X-axis acceleration due to the hand scaling of the curved surface transitioning from the buccal surface to the surface adjacent to the posterior molar (the acceleration data in the orange boxes). When the tip of the hand scaler returned from the adjacent surface to the buccal surface, the angular velocity of the Y-axis (the angular velocity data in orange boxes) changed significantly. The force in the Z-axis shows the force applied to the target tooth when lifting the hand scaler up. The relatively large Z-axis force (the data in the blue box) occurred when removing the tartar. The other relatively small force occurred when the participant was looking for the dirt.

From the measured movement of the hand scaler and the measured force applied to the tooth, the type of hand scaling motion being performed by the participants can be characterized.

2) Comparison of the hand scaling skills: We compared the measured data between the nine dental hygienists and the six students. In this experiment, the operating time and the number of strokes were different for each participant. So as the features of the measured data of the hand scaling motion, the minimum value, maximum value, and the range for each stroke were extracted. The big difference between the dental

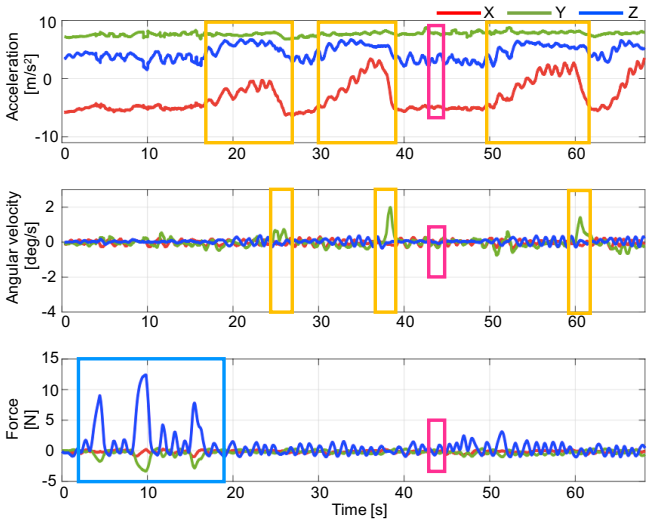


Fig. 7. An example of measured data (dental hygienist teacher)

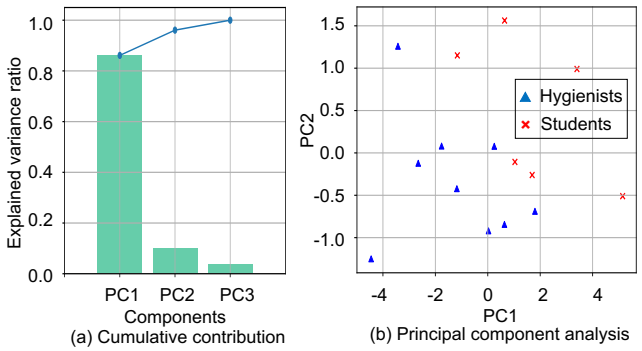


Fig. 8. Principal component analysis of maximum force

hygienists and the students was in the maximum values and the range of Z-axis forces. The average maximum scaling force of the dental hygienists (9.08 N) was larger than the students (6.07 N). The average range of the scaling force of the dental hygienists (10.45 N) was also larger than the students (7.18 N). A t-test shows that the dental hygienists exerted more force ($p < 0.05$). The dental hygienist students are not good at controlling the motion of the tip of the hand scaler while simultaneously applying pressing and lifting forces to the tooth surface.

Fig. 8 shows the results of the principal component analysis (PCA) with the force of all three axes. The force in the Z-axis, which is the force for lifting the hand scaler up, has a large effect in judging the difference in hand scaling skill. The second principal component is mainly affected by the value of the X-axis force, which is the force pushing on the tooth. These results show that the Z-axis and X-axis force are the most important values for evaluating the hand scaling skill.

Fig. 9 shows the results of the data classification of all the hand scaling data using Quadratic Discriminant Analysis (QDA). There is a clear boundary that can be used to separate the data from the dental hygienists and the students. By

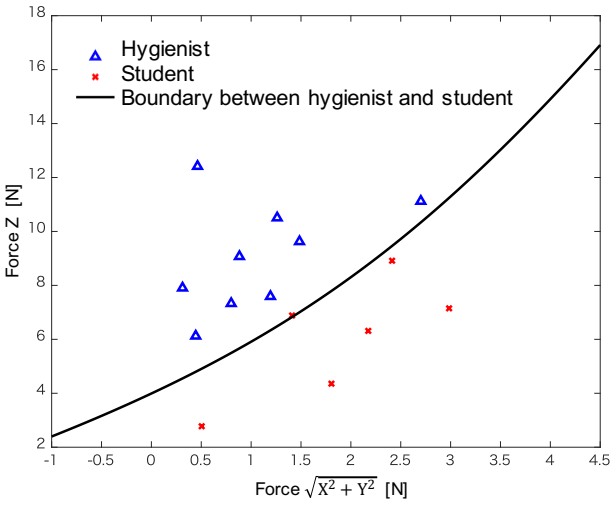


Fig. 9. Quadratic discriminant analysis of maximum force peak

comparing the skills of all participants with different levels of experience, the results show that it is possible to evaluate hand scaling skills by using the developed system and the measured data.

V. Conclusion

In this research, we proposed a measurement system for hand scaling skills and showed that these skills be evaluated using the measured data. The proposed measurement system consists of two sensors. First, a 6-axis force sensor was attached to a target tooth in a jaw model to measure the scaling forces. Second, an IMU sensor was attached to a hand scaler to measure hand scaling motion. In the experiment, we measured the hand scaling motion of 15 participants with different levels of hand scaling experience, including one dental hygienist teacher, eight dental hygienists, and six dental hygienist students. The results showed that it is possible to measure the hand scaling force and motion and evaluate the individual skills using these measured values.

In the future, we will extract various features to analyze the individual stroke in hand scaling with more detail.

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