# Development of an Education System for Tooth Carving Skills Based on Shared Tactile Perception using a Wearable Skin Vibration Sensor: A Pilot Study

## Keywords

*Dental Education*
*Tactile Sensation*
*Skill Training*
*Tooth Carving*
*Wax Carving*

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Received: 07.11.2024
Accepted: 07.08.2025

doi: 10.1922/EJPRD_2839Kihara09

## ABSTRACT

*Objectives: In tooth carving training, learners cannot feel the instructors' sensations during procedures. This study aimed to develop and evaluate a system based on shared tactile perception to assess the educational effectiveness of tooth carving to convey the instructor's tactile sensations to learners. Methods: The system utilizes a wearable skin vibration sensor to capture the instructor's tactile sensations and transmit them to learners with vibrators. Twenty-three dental students tested the system using four approaches: model observation, video watching, tactile sharing (carving after feeling tactile sensations), and tactile synchronization (carving with feeling tactile sensations simultaneously). Performance was assessed based on chamfering, smoothing, shaping the fossa and grooves, and questionnaires. Results: Quantitative evaluations indicated that the tactile sharing and tactile synchronization may improve skills related to surface texture, and the depth of the fossa and grooves. Questionnaires revealed that the tactile-assisted approaches were perceived as less difficult. Conclusions: The tactile sharing system may support more effective skill acquisition in tooth carving. The tactile sensation provided was considered helpful for surface smoothing, shaping the fossa and grooves, and force of carving. Clinical Relevance: This system enables digital sharing of tactile sensations, enhancing dental education by preserving expert skills and improving tooth carving training.*

## INTRODUCTION

Education in dental skills is essential in dentistry. In skills training such as tooth carving, tooth preparation, and wax-ups, learners primarily rely on visual information from model observations and instructor demonstrations, while advancing their proficiency through repeated practice. However, mastering these skills is often difficult and time-consuming. In particular, clinical dentistry involves several blind techniques that rely on tactile feedback, such as root canal treatment and scaling, making tactile information crucial for acquiring clinical knowledge.[1] Previous studies have reported that tactile information plays a significant role in enhancing motor skills in dental education and practice.[2] Instructors attempt to facilitate learners' skill acquisition by verbally conveying the movements and finger sensations involved in the tasks. However, learners cannot actually feel the instructors' sensations, and there is currently no approach to sharing this tactile sensation with them. The skills possessed by experienced dentists and dental technicians are further imbued with a significant sensory component, making them difficult to impart to learners.

Tooth carving practice is conducted at the initial stage of skill training, where students learn anatomical knowledge of teeth, the skills to replicate tooth morphology, and the motor skills required through the process of carving crowns.[3-7] To enhance the educational effectiveness of tooth carving, various studies have reported methods such as the use of instructional DVDs, modified anatomical modules, and video demonstrations.[8-10] However, even with these methods, the tactile sensations experienced by instructors during tooth carving cannot be shared with learners.

A wearable skin vibration sensor measures the skin vibrations when something is touched. The sensor is worn on the finger pad which is remote from the contact fingertip and detects skin-propagated vibrations when the fingertip touches an object.[11,12] The sensor is made from polyvinylidene fluoride (PVDF) film, which is a polymer piezo material with properties similar to human tactile receptors. Bending deformation of the PVDF film generates output voltage, allowing it to capture skin vibrations when attached to the skin, and it does not respond to overall finger movements, enabling the measurement of vibrations propagated through the skin during fast tactile movements such as tracing. Typically, tactile sensors are placed between the finger and the object being touched. However, wearable skin vibration sensors can be attached between the first and second knuckles of the finger, directly measuring tactile sensations of a fingertip. The receivers can feel those tactile sensations with a vibrator. In the medical field, wearable skin vibration sensors have been applied to systems for diagnosing contractures, enabling the sharing of individual tactile sensations with others.[13] While many studies related to virtual haptics have been reported in dentistry,[14-16] there are no reports in dentistry on technologies to transmit tactile and force sensation between the sender and the receiver.[17] Tactile sharing system with the wearable skin vibration sensor enables the sharing of an individual's tactile sensations with others. By digitizing the tactile aspects of dental skills, which have traditionally been considered tacit knowledge, and allowing learners to share the instructor's sensations, this technology is expected to make dental skills training more effective.

The aim of this study was to develop a digitization system in shared tactile perception for the educational effectiveness of tooth carving to convey the instructor's tactile sensations to learners during the carving process and evaluate the system's performance.

# MATERIALS AND METHODS

## DEVELOPMENT OF AN EDUCATION SYSTEM FOR TOOTH CARVING SKILLS IN SHARED TACTILE PERCEPTION

Tactile sharing system utilizing the wearable skin vibration sensor and vibrators was applied to construct an online education system for tooth carving. The sender side (instructor) consisted of a wearable skin vibration sensor (SDT shielded piezo sensors 1-1000288-0, TE Connectivity, Galway, Ireland),[11,12] microphone (MPM-1000, marantz Professional, CA, USA), stereo audio interface (Rubix22, Roland, Shizuoka, Japan), equalizer (M108SM ten band eq, Dunlop manufacturing, CA, USA), sensor amplifier, camera (iPhone 14 pro, Apple, CA, USA), and computer (Letsnote, Panasonic, Osaka, Japan), as shown in Figure 1. The sensor amplifier was custom-built using an integrated circuit (INA126, Texas Instruments, TX, USA) with a gain of 5, and included a band-pass filter with a frequency range

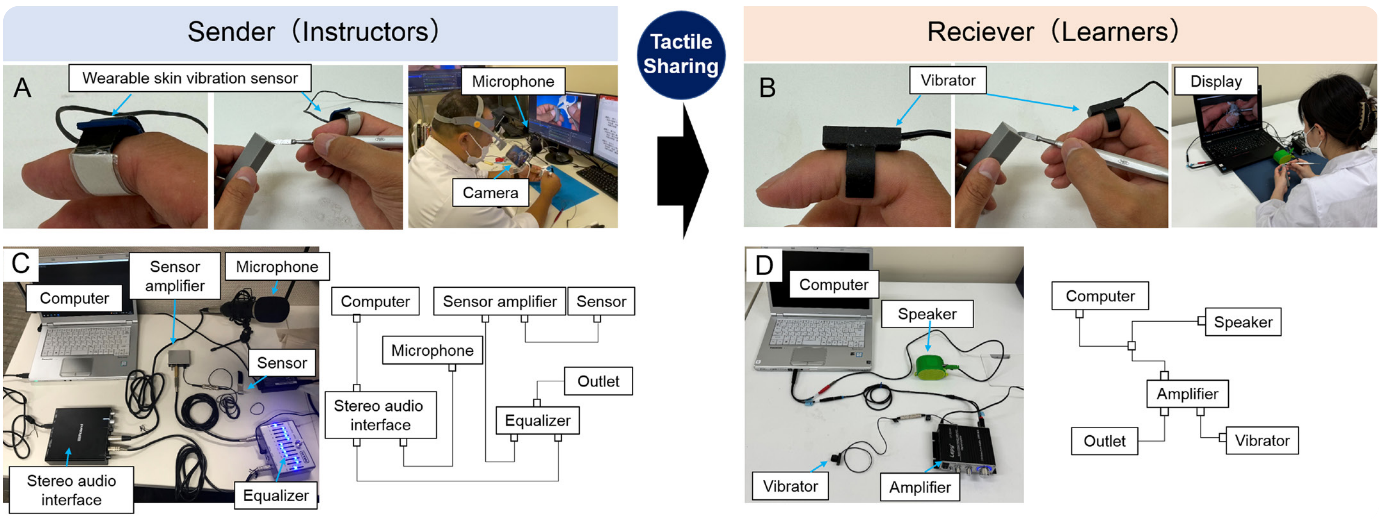


**Figure 1:** Education system for tooth carving based on shared tactile perception. (A) Wearable skin vibration sensor on the index finger and recording the tactile sensation; (B) Vibrator on the index finger to feel for learners; (C) Setup for sender as instructors; (D) Setup for receiver as learners.

of 15.9–2341 Hz. The wearable skin vibration sensor was attached between the first and second joints of the index finger, allowing the sensor to not interfere with holding instruments for carving. The microphone has high sensitivity and can capture not only the instructor's explanations but also ambient sounds (e.g., the sound of carving wax during tooth carving), providing learners with immersive visual and auditory experiences. The tactile sensor output and microphone output are inserted into the computer with the stereo audio interface. The tactile sensor output was modulated with the amplifier and equalizer before the input to the computer. The camera used was not the one built into the computer but one that could capture various angles of the instructor's workspace and perform zooming, enabling a detailed depiction of dental-specific fine operations.

The receiver side (learner) was equipped to receive input video, audio, and tactile sensations simultaneously. The video was output on the computer's display. Audio and tactile sensations were divided into stereo signals and output to the vibrator in which a vibrotactile actuator (sprinter γ, NIDEC, Japan) was covered with a plastic case involving a ring and speaker (SRS-XB01, Sony, Tokyo, Japan), respectively, from the headphone jack. Since the vibrator was connected to an amplifier (Lepy LP-2024+, Kyohritsu Electronic Industry, Osaka, Japan), learners could adjust the volume of the vibrations. Zoom, a commonly used tool for classes and meetings, was chosen as the platform for the online system due to its ease of use for both instructors and learners. The learner could feel the vibration while holding the instrument by attaching the vibrator to their finger.

After assembling the above-mentioned equipment and software for constructing the system targeted at tooth carving education, an experiment was conducted to determine whether video, audio, and tactile sensations during tooth carving could be effectively transmitted to the learner from an instructor. The instructor, a skilled dental technician with over 20 years of clinical experience, wore the wearable skin vibration sensor between the first and second knuckles of their dominant index finger pad and performed tooth carving using a carving knife (Wax carver evan, YDM, Saitama, Japan) and a wax square prism.

## EVALUATION OF THE FEASIBILITY OF THE TACTILE SHARING SYSTEM IN TOOTH CARVING

The effectiveness of the tooth carving education system in shared tactile perception was verified. The participants consisted of 23 dental students from various academic years (9 first-year, 3 second-year, 6 third-year, and 5 fourth-year students). The instructor was an experienced dental technician with over 20 years of clinical experience. Ethics approval was obtained for the conduct of this study.

The tasks included chamfering, smoothing, and shaping fossa and grooves on a wax square prism (*Figure 2*). Chamfering involved carving a flat surface on the corners of the square prism. Smoothing required carving a 4 mm radius curvature on the corners of the square prism. Shaping fossa and grooves involved carving a groove on the top surface of the square prism, 5 mm wide, 2 mm deep, and angled at 102 degrees. The wax square prism measured 15 x 15 x 1000 mm. In regards to this wax carving, the instructor recorded a video demonstrating the wax carving process, which included both visual and tactile sensations (*Figure 3*). All participants used the same carving knife (Wax carver Evan). To ensure consistency across all participants, all instruments were newly prepared and had not been used prior to the experiment.

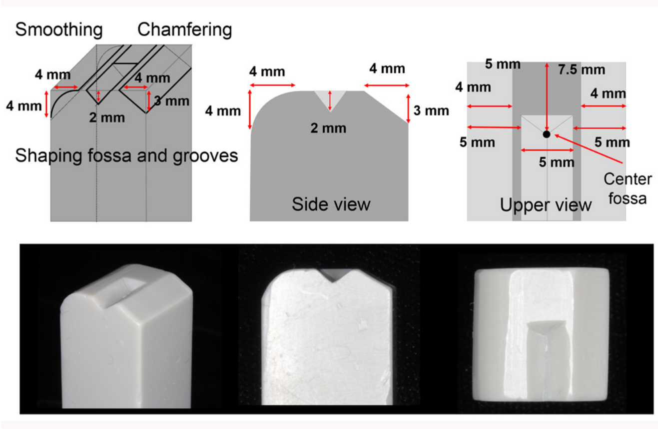


**Figure 2:** Carving tasks that encompassed fundamental skills including chamfering, smoothing, and shaping the fossa and grooves.

**Figure 3:** Video demonstration recorded by the instructor, including visual, audio, and tactile sensations.

Four different approaches were compared to evaluate the feasibility of Tactile sharing system to assist learners during tooth carving. Model observation: Required the participants to complete the task while observing a reference model without video and tactile sensation. Video watching: Allowed participants to watch a video before performing the task. Tactile sharing: Allowed participants to watch the video and feel tactile sensations before performing the task. Tactile synchronization: Allowed participants to watch video, feel tactile sensation, and perform the task simultaneously. The completion time for each task was recorded.

# PERFORMANCE METRICS

## Quantitative Metrics

The wax carving works were scanned with E4 (3Shape, Copenhagen, Denmark), superimposed to the ideal carving model, and evaluated using Rapidform2006 (INUS Technology, Seoul, South Korea). The morphological parameters for wax carving works included: 1) the volume and angle of chamfering, 2) the radius of curvature and surface texture, and 3) the depth of fossa and grooves, and opening angle. The controls were geometrically calculated numerical values, and the difference from the measured values was calculated.

## Qualitative Metrics

Participants completed a wax carving-related questionnaire after each task. The questionnaire used a 3-point rating scale for evaluation, where "O" indicated good, "Δ" indicated average, and "X" indicated poor for each item. The items of the questionnaire were understanding three-dimensional morphology, proper grip on instruments, selecting appropriate instruments, correct way to move instruments, surface texture, and force during carving. After all tasks, participants completed the Single Ease Question (SEQ), System Usability Scale (SUS), and assessment of the location of the vibrator attachment. The SEQ is a 7-point rating scale that assesses how difficult it is for users to find a task.[18] The SUS offers a quick, cost-effective, and accurate method to evaluate the usability of hardware or software. It consists of a 10-item questionnaire with five response options ranging from "strongly agree" to "strongly disagree".[19]

## Statistical Methods

The Kolmogorov–Smirnov test was used to test for normality. The Levene test was used for the test of homoscedasticity. Data comparisons among the three evaluation scenarios were performed using the Friedman test with the Bonferroni correction for multiple comparisons. Statistical analyses were performed using the SPSS statistical software version 24 (IBM), and the level of statistical significance was set at 5%.

# RESULTS

## DEVELOPMENT OF AN EDUCATION SYSTEM FOR TOOTH CARVING SKILLS IN SHARED TACTILE PERCEPTION

The education system for tooth carving skills enabled learners to simultaneously observe the instructor's work and perceive tactile sensations. The tactile sharing of tooth carving using this system was feasible both within the same facility and across geographically separated institutions. The selection of locations was based on the availability of cooperating facilities, rather than on a specific distance criterion. This study confirmed that the system can operate effectively in remote environments using standard online communication infrastructure. Moreover, bidirectional education was made possible by equipping both the instructor and the learners with the sender and receiver side devices.

## EVALUATION OF THE FEASIBILITY OF THE TACTILE SHARING SYSTEM IN TOOTH CARVING

### Quantitative Metrics

The evaluation results of the wax carving tasks are shown in Figure 4. For chamfering, both excessive and insufficient material removal were observed compared to the control across all approaches. There were no significant differences in volume between the approaches (p=0.142). The angle of chamfering in all approaches was smaller compared to the control. In first to third-year students, the video watching approach showed greater variability (*Figure 5*). In fourth-year students, the angle of chamfering improved with the video watching approach.

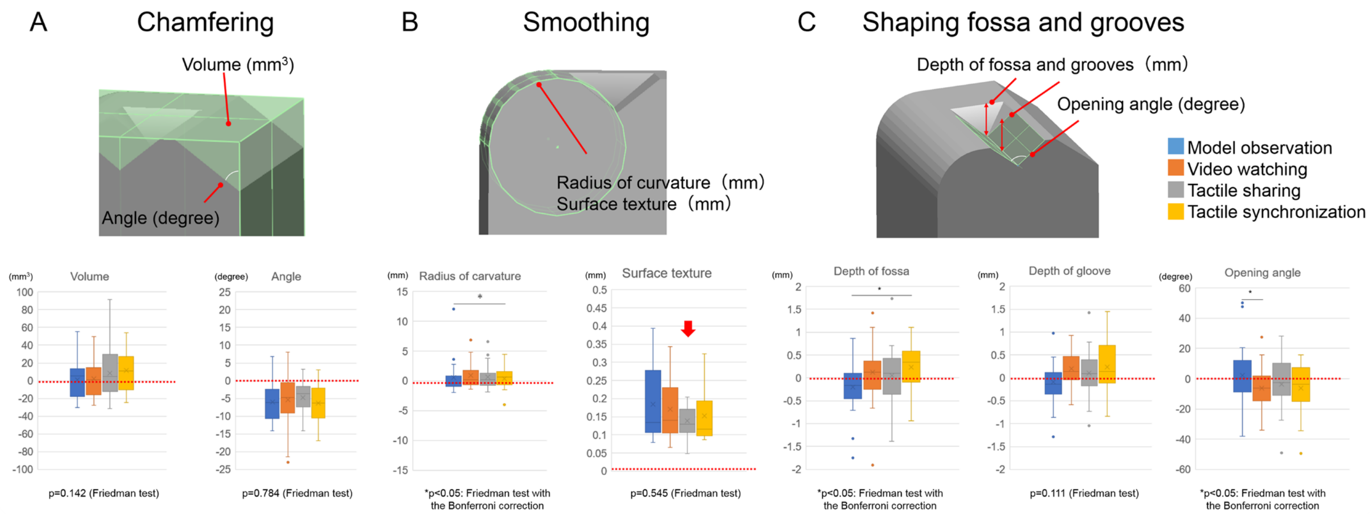


**Figure 4:** Results of the wax carving works for each approach. (A) Volume and angle of chamfering; (B) Radius of curvature and surface texture of smoothing; (C) Depth and opening angle of shaping the fossa and grooves.

For smoothing, a significant difference in the radius of curvature was observed between the tactile synchronization and the model observation approaches (p<0.05). Surface texture was improved in the tactile sharing approach. Especially, for first- to third-year students, the tactile sharing approach showed improved surface texture compared to the other approaches. As shown in the individual line graphs (*Figure 6*), most of the values for the tactile sharing approach were lower than those for the other approaches, indicating smoother surface texture. On the other hand, for fourth-year students, the surface texture was smoother than that of first- to third-year students across all approaches. Among these, the carvings produced using the tactile synchronization approach exhibited greater variability in surface texture.

For shaping the fossa and grooves, the median depth value in the model observation approach was negative, indicating shallower carving compared to the ideal carving model (*Figure 4*). In contrast, the median values for all other approaches were positive, reflecting deeper carving of the fossa and grooves.

The depth of the fossa with the model observation approach was significantly deeper than that of the tactile synchronization approach (p<0.05). The opening angle in the model observation approach showed greater variability compared to other approaches. A significant difference was observed between the model observation and video watching approaches (p<0.05). The individual results for the fossa by academic year are presented in Figure 7. In fourth-year students, the tactile synchronization approach led to reduced error relative to the ideal carving model and decreased variability.

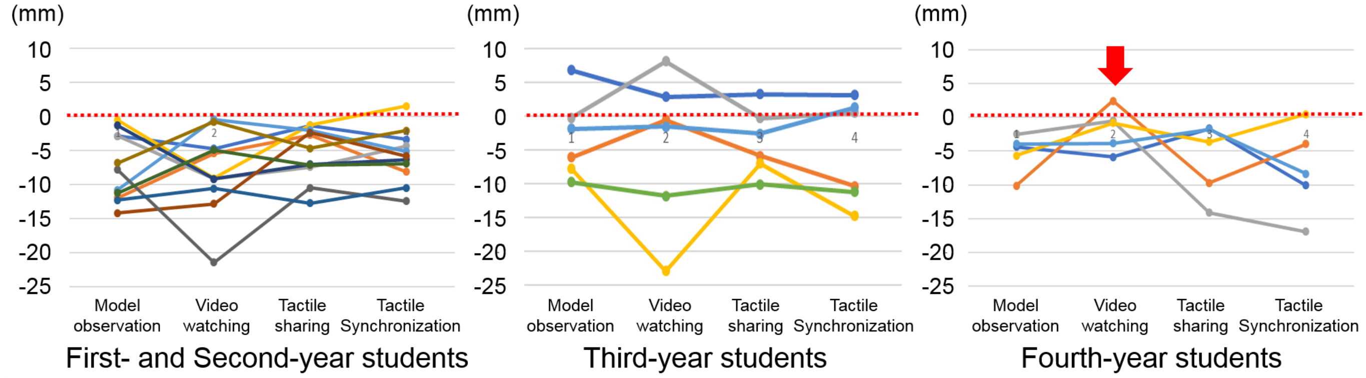


**Figure 5:** Angle of chamfering in the wax carving works for each approach by academic year.

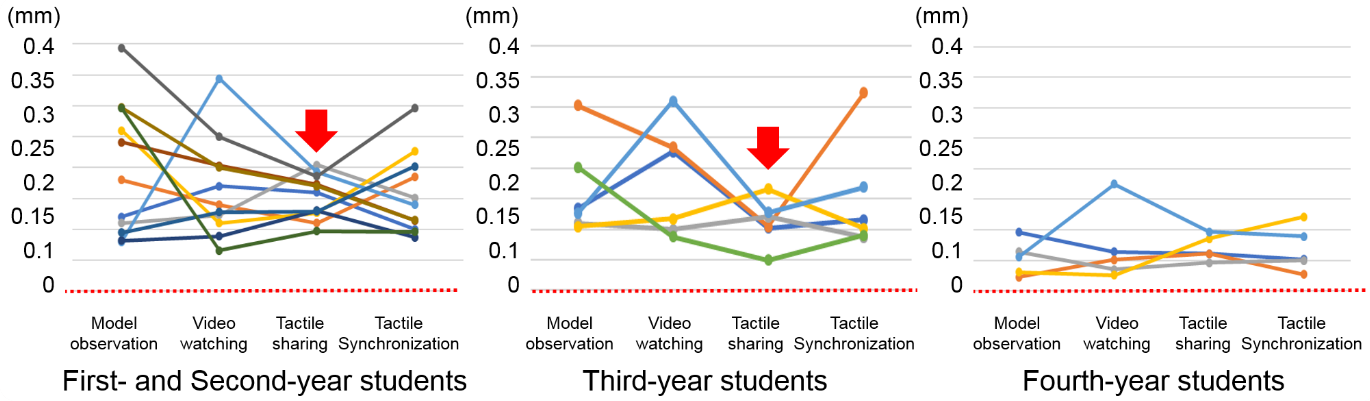


**Figure 6:** Surface texture of smoothing in the wax carving works for each approach by each grade student.

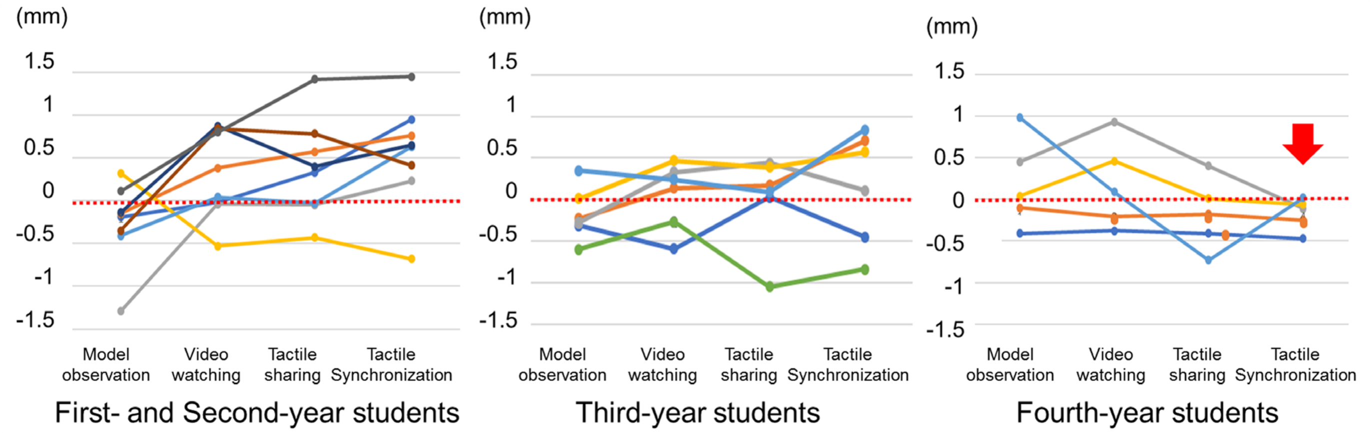


**Figure 7:** Depth of the fossa in the wax carving works for each approach by each grade student.

## QUALITATIVE METRICS

According to the questionnaire results regarding wax carving, significantly more participants felt that video watching, tactile sharing, and tactile synchronization approaches were more effective than the model observation approach in terms of understanding three-dimensional morphology, selecting appropriate instruments, the proper grip on instruments, and the correct way to move instruments ($p<0.05$) (*Figure 8*). In the model observation approach, more than half of the participants reported difficulty understanding or only somewhat understanding these aspects. In contrast, in the other approaches, more than half of the participants reported a clear understanding. For the carving force and the surface texture of the wax, a significantly higher number of participants found the tactile sharing and tactile synchronization approaches to be more effective compared to the other approaches ($p<0.05$). In the model observation and video watching approaches, more than half of the participants reported difficulty in understanding or only somewhat understanding these aspects, whereas in the tactile sharing and tactile synchronization approaches, more than half of the participants reported a clear understanding.

The average SEQ scores for those without the tactile sharing system and with the system were 2.57±1.44 and 3.39±1.59, respectively. The SEQ score of using the tactile sharing system was significantly higher than that of without the system ($p<0.05$). The average SUS score for the tactile sensation system (Tactile sharing and tactile synchronization approaches) averaged 47.50±20.40, with a maximum of 82.5 and a minimum of 15.

# DISCUSSION

Educational methods for dental students encompass visual, aural, reading/writing, kinesthetic, and demonstrative approaches.[20] In tooth carving education, visual methods involve observing tooth models, with the advantage of facilitating the imagination of the ideal tooth morphology. Reading/writing methods entail studying texts to learn the detailed features of tooth morphology, allowing for a comprehensive understanding of the intricate characteristics of teeth. Kinesthetic methods involve carving teeth out of materials like wax, which is beneficial for learning the techniques necessary to replicate tooth morphology required in clinical practice.[8] Demonstrative methods, where instructors show how to use instruments and carve, offer efficient learning opportunities by allowing students to observe the procedures directly, via screen-displayed cameras, or through instructional videos. Viewing demonstrations on a display can reach many students at once. However, lacks the immediacy and engagement of observing up close.

Various simulators equipped with haptic interfaces have been developed and utilized to improve clinical dental skills.[21] In contrast, a technology to transmit tactile and force sensations between the sender and the receiver has not been applied to the dental field. However, to pass down the techniques of skilled dentists/dental technicians, it is necessary to apply tactile sharing system, rather than relying solely on simulations with haptic interfaces in virtual environments.

Human skin has tactile receptors for force, vibration, and temperature, which are referred to as "haptic primaries".[22] In this study, the goal was to capture and transmit a very subtle sense of touch required when carving wax with a small knife. It was considered that vibration is more favorable compared to the other modalities because it is similar to the actual sensation of carving.

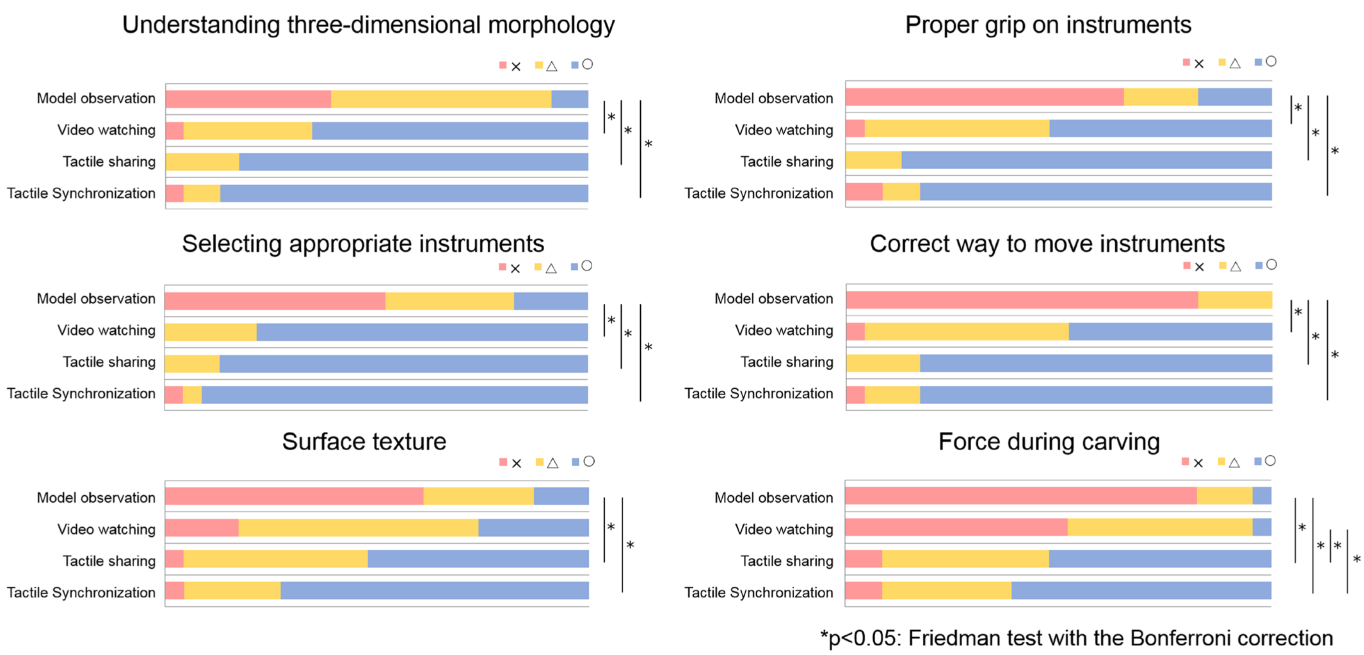


**Figure 8:** Questionnaire results regarding wax carving for each approach.

Tactile feedback can potentially expand educational methods in dentistry. By not only observing but also feeling the instructor's demonstrations, students can gain a more realistic understanding of the speed, timing, and force required to manipulate carving instruments. It has been shown that the bigger and more complementary the variety of educational resources, the more likely it is to reach the educational goals and develop the abilities required.[23] In this study, an education system for tooth carving in shared tactile perception was developed for educational effectiveness.

The tactile sense is often affected by the visual sense, and illusions and interactions occur between them. The most representative illusion is "Rubber hand illusion".[24] The interaction between them was reported by Kanamori *et al.* in 2018.[25] They revealed that the proposed stereoscopic projection can manipulate the haptic perception of shape. Furthermore, it has been reported that visual stimuli in a virtual reality environment can influence how vibrotactile feedback is perceived.[26] Therefore, we tried to match the sender's visual information with the receiver's environment as closely as possible using the camera and monitor.

The education system for tooth carving skills in shared tactile perception allowed learners in different locations to connect online and receive real-time skill training through both visual and tactile information. This system was designed to be bidirectional, allowing not only the transmission of tactile feedback from the instructor to the learner but also from the learner to the instructor. Consequently, instructors could feel the tactile sensations of learners, enabling them to assess whether the learner's actions were correct. In the evaluation phase of this study, a pre-recorded demonstration video was used to ensure consistency in the visual and tactile information presented to all participants. To maintain standardized conditions, no live demonstrations were conducted via remote platforms.

Some approaches are being developed to enhance the learning of tooth morphology, with DVDs, programs, and software yielding promising outcomes by incorporating interactivity and fostering independent learning.[23,27,28] These methods offer several advantages, including the ability to access information anytime and anywhere, allowing students to study at their own pace without relying on a teacher. These digital tools for teaching dental anatomy and tooth carving have been utilized either as supplementary teaching aids or as substitutes for traditional laboratory instructions and demonstrations. They have demonstrated the potential to either replace traditional methods or significantly improve students' understanding, engagement, and performance in their courses.

Similar to creating instructional videos, incorporating tactile data into these videos would allow learners to repeatedly train at any time while experiencing both the visual and tactile aspects of the instruction. This approach ensures that learners can repeatedly experience the precise sensations and movements demonstrated by the instructor, thus enhancing their understanding and proficiency through consistent and realistic practice sessions.

In the evaluation of the feasibility of the tactile sharing system in tooth carving, a video was used for the feasibility evaluation of this system because the instructor's explanations remained consistent for all learners and allowed them to repeatedly view the demonstrations. Wax carving in this study was focused on basic shapes (chamfering, smoothing, shaping fossa and grooves) rather than tooth morphology to evaluate motor skills independently of knowledge of dental anatomical morphology.

Conventional virtual reality haptic simulation systems produce force feedback for learners by generating pseudo-forces based on the collision parameters of virtual objects, including tools and teeth.[29,30] The present system, however, introduces a novel approach: actual tactile sensations from skilled practitioners are converted into digital signals and subsequently transmitted as vibrations to learners. This pilot study was therefore conducted to investigate the potential of this approach, specifically to identify which tasks and subjects it could most effectively address. We recruited students with diverse learning preferences and experience levels,[31-33] and their personal reactions were meticulously examined, in addition to trends observed in each academic grade.

Regarding the chamfering, the fourth-year students showed improvement in chamfering angle with the video watching approach. Visual materials include detailed information such as the movement and the angle of the instrument at which it is applied. Therefore, learners with experience in tooth carving may have been able to adjust the instrument angle based on these visual cues, leading to improvement. Regarding the surface texture in smoothing, first- to third-year students showed improvement with the tactile sharing approach, indicating that tactile feedback may aid less experienced learners in improving surface texture. Previous reports indicate that vibration is advantageous for conveying texture,[34] and our results align with this, showing that methods utilizing vibration were effective in improving surface texture related to texture perception. Regarding the depth of the fossa and grooves, the model observation approach tended to result in shallower carving. Similar to the angle of chamfering, observing the angle of the instrument through video could lead to improving the depth of the fossa and groove. Fourth-year students showed an improvement in depth of the fossa via the tactile synchronization approach (*Figure 7*). It is hypothesized that with increased experience, tactile feedback can supplement visual information for elements that are difficult to grasp visually. Tactile somatosensory information is encoded by sensory receptors and transmitted to the brain for processing, and it contributes to motor control.[35,36] Therefore, it was considered that the carving experience may affect how the transmitted tactile information is received. There are reports suggesting that tactile information obtained through vibrations and visual information influence each other positively, enhancing the transmission of perception.[26] This effect is particularly pronounced in more experienced individuals.

This study's primary objective was to compare learner responses across four different approaches. Consequently, all participants underwent exposure to each approach in a fixed order: (1) model observation, (2) video watching, (3) tactile sharing, and (4) tactile synchronization. Given concerns about the influence of repeated carving practice or cumulative effects on subjects' responses, inter-individual variability for each learning approach was analyzed using line graphs, presented according to the specified sequence. The observed data did not exhibit a consistent upward trend, emphasizing the presence of considerable individual variation. This result underscores the importance of tailoring learning approaches to individual subjects for enhancing carving skill, extending beyond mere repetitive practice. This consideration will be crucial for future large-scale investigations.

Video watching, tactile sharing, and tactile synchronization approaches are all methods of learning through video, and this visual information had a positive effect on the understanding of three-dimensional morphology, the selecting appropriate instruments, the proper grip on instruments, and the correct way to move instruments. The results of the quantitative evaluation, which showed improvements in an angle of chamfering, a depth of groove and fossa, and an opening angle due to the video, were considered to be related to this qualitative assessment. It was found that visual information from models and videos alone made it difficult to understand the force applied during carving and the surface texture. For these two aspects, many participants felt that the tactile sharing and tactile synchronization approaches were effective, indicating that tactile information might provide learners with more feedback.

Clinicians continually draw upon past sensory experiences to adjust operation force and inform palpation diagnoses during current procedures. Thus, developing a robust internal model is crucial for enhancing clinical skill. Our system generates high-quality sensory signals, derived directly from skilled practitioners, which may facilitate the construction of such an internal model in learners. For future research, this consideration will be vital for demonstrating our system's efficacy in long-term skill retention.

The SEQ results indicated that wax carving with the tactile sharing system (Tactile sharing and tactile synchronization approaches) was perceived as easier than wax carving without the system (Model observation and video watching approach).

The SUS score for the tactile sensation system (Tactile sharing and tactile synchronization approaches) ranged from a maximum of 80 to a minimum of 15, indicating a significant disparity between learners who found it useful and those who did not. Learners who found the system useful were able to effectively incorporate tactile information into their learning and improve their carving skills. Conversely, learners who did not find the system useful likely felt overwhelmed by the amount of information. This might be also related to the increased errors observed in tooth carving through the tactile synchronization approach in the quantitative evaluation.

The usefulness of the tooth carving education system using tactile sharing system can be attributed to its ability to enhance interest in dental carving education, facilitate the acquisition of basic skills, and improve tactile sensation. Results from both quantitative and qualitative evaluations indicated that tactile information could be effective for the carving skills related to surface texture, depth of fossa and groove, force of carving, and significantly improved learners' understanding. It could be worked as a complementary teaching approach, instead of a substitute for traditional teaching methods.

Conventional haptic simulations predominantly deliver force sensations. However, this system differentiates itself by using vibration, specifically targeting Pacinian corpuscles rather than the Merkel disks, Meissner corpuscles, or Ruffini corpuscles typically engaged by prior systems. Given that clinicians utilize vibrations from devices like turbines or scalers to guide preparation force and detect calculus, this system demonstrates potential for application in tooth preparation and scaling.

One of the practical advantages of the tactile sharing system developed in this study is its relatively low cost and ease of implementation. The system hardware can be assembled from commercially available components at a total cost of approximately 90,000 JPY (equivalent to about 525 EUR or 600 USD, based on the exchange rate as of July 2025). The system operates using common online platforms or recording software. This design allows for flexible use across various institutions. Its accessibility may facilitate wider adoption for dental skill training.

This system can be utilized in real-time not only in person settings but also remotely by digitizing tactile sensations, broadening its applicability in education. Another significant advantage of this system is that it can preserve skills that are difficult to hand down by recording the exceptional skills of experts.

To elucidate the factors contributing to participant responsiveness and to identify optimal tasks for our system, we recruited individuals from diverse academic grades, encompassing varied learning preferences and experience levels. However, given the exploratory nature of this investigation, the sample size was insufficient for robust statistical analysis. This study, therefore, serves as a pilot designed to achieve the aforementioned objective. Building upon these preliminary findings, we intend to conduct larger-scale studies to further evaluate the practical applicability of this system within dental education.

## CONCLUSION

In this study, an education system for tooth carving skills was developed by digitizing the tactile sensations of an instructor's dental skills using tactile sharing system with the wearable skin vibration sensor. The tactile sharing and tactile synchronization approaches have the potential to support more efficient skill training in tooth carving. The tactile sensation provided were considered helpful for skills related to surface smoothing, shaping depth of fossa and groove, and force of carving. The findings suggest that this system can enhance the traditional methods of tooth carving education by integrating and sharing visual and tactile information, thereby potentially facilitating the acquisition of the motor skills necessary for tooth carving.

# ACKNOWLEDGMENTS

The authors would like to thank the Japanese Association for Dental Science for their support through Sponsored Research [grant numbers 2022-B-4].

## CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

# REFERENCES


1. Shaheena, K.P., Sanjeev, R., Shyamaladevi, M.P., Palathingal, P., Varghese, M., Musthafa, N. and Razak, R.P. Role of tactile sensitivity in dentistry. *JSPIK* 2020; **12**:164-170.
2. El-Kishawi, M., Khalaf, K. and Winning, T. How to improve fine motor skill learning in dentistry. *Int J Dent* 2021; 6674213.
3. Overskott, H.L., Markholm, C.E., Sehic, A. and Khan, Q. Different methods of teaching and learning dental morphology. *Dent J (Basel)* 2024; **12**:114.
4. Abu Eid, R., Ewan, K., Foley, J., Oweis, Y. and Jayasinghe, J. Self-directed study and carving tooth models for learning tooth morphology: perceptions of students at the University of Aberdeen, Scotland. *J Dent Educ* 2013; **77**:1147-1153.
5. Goodacre, C.J., Younan, R., Kearbey, V. and Fitzpatrick, M. An educational experiment resulting from COVID-19: the use of at-home waxing and webinars for teaching a 3-week intensive course in tooth morphology to first-year dental students. *J Prosthodont* 2021; **30**:202-209.
6. Rishikesan, M., Krishnan, R.P. and Sundar, S. Knowledge, perception and attitude regarding tooth carving among dental students. *Nat Volatiles Essent Oils* 2021; **8**:8644-8656.
7. Nayak, A. and Tamgadge, S. Tooth carving exercise as a foundation for future dental career – a review. *J Acad Dent Educ* 2022; **8**:42-44.
8. Conte, D.B., Zancanaro, M., Guollo, A., Schneider, L.R. and Lund, R.G. and Rodrigues-Junior, S.A. Educational interventions to improve dental anatomy carving ability of dental students: a systematic review. *Anat Sci Educ* 2021; **14**:99-109.
9. Bilir, H. and Aygüzen, C. Live-video versus video demonstration methods: dental students' learning preferences during the COVID-19 pandemic. *Sağlık Bilimlerinde Değer* 2021; **11**:250-256.
10. Alzer, H., Ismail, N.H. and Alsoleihat, F. Blended learning with video demonstrations enhances dental students' achievements in tooth carving. *Adv Med Educ Pract* 2023; **15**:1425-1431.
11. Tanaka, Y., Horita, Y. and Sano, A. Tactile sensing utilizing human tactile perception. In: *Proc IEEE World Haptics Conf* 2011; p.621-626.
12. Tanaka, Y., Horita, Y. and Sano, A. Finger-mounted skin vibration sensor for active touch. In: *Proc Int Conf Haptics: Percept Devices Mobility Commun. Vol. II EuroHaptics* 2012; p.169-174.
13. Suzuki, T., Tanaka, Y., Niwa, K. and Saito, T. Contracture diagnosis system using wearable tactile sensor. In: *Proc IEEE Haptics Symp (HAPTICS)* 2020; p.955-960.
14. Imran, E., Adanir, N. and Khurshid, Z. Significance of haptic and virtual reality simulation (VRS) in dental education: a review of literature. *Appl Sci* 2021; **11**:10196.
15. Kasoju, C., Kadam, M. and Devishree, C.P. Haptics – The science of touch in dental training. *Int J Innov Sci Res Technol* 2022; **7**:175-180.
16. Hsu, M.H. and Chang, Y.C. Haptic and force feedback technology in dental education: a bibliometric analysis. *Int J Environ Res Public Health* 2023; **20**:1-17.
17. Ohnishi, K. and Mizoguchi, T. Real haptics and its applications. *IEEJ Trans* 2017; **12**:803-808.
18. Sauro, J. and Dumas, J.S. Comparison of three one-question, post-task usability questionnaires. *Proc SIGCHI Conf Hum Factor Comput Syst CHI* 2009; 1599-1608.
19. Brooke, J. SUS: a 'quick and dirty' usability scale. In Patrick W.J., Bruce T., Weerdmeester A. and Ian M.L. *(Eds): Usability Evaluation in Industry.* London: Taylor & Francis, 1996; p.189-204.
20. Asiry, M.A. Learning styles of dental students. *Saudi J Dent Res* 2016; **7**:13–17.
21. Bakr, M.M., Massey, W.L. and Alexander, H. Can virtual simulators replace traditional preclinical teaching methods: a students' perspective? *Int J Dent Oral Health* 2015; **2**:149.
22. Kato, F., Inoue, Y. and Tachi, S. Haptic display glove capable of force/vibration/temperature. In: *Proc IEEE Int Symp Meas Control Robot (ISMCR)* 2019.
23. de Azevedo, R.A., da Rosa, W.L., da Silva, A.F., Correa, M.B., Torriani, M.A. and Lund, R.G. Comparative effectiveness of dental anatomy carving pedagogy: a systematic review. *J Dent Educ* 2015; **79**:914-921.
24. Botvinick, M. and Cohen, J. Rubber hands 'feel' touch that eyes see. *Nature* 1998; **391**:756.
25. Kanamori, T., Iwai, D. and Sato, K. Pseudo-shape sensation by stereoscopic projection mapping. *IEEE* 2018; **6**:40649-40655.
26. Rosa, N., Hürst, W., Vos, W. and Werkhoven, P. The influence of visual cues on passive tactile sensations in a multimodal immersive virtual environment. In: *Proc ACM Int Conf Multimodal Interact ICMI* 2015; p.327-334.
27. Mitov, G., Dillschneider, T., Abed, M.R. and Hohenberg, G. Introducing and evaluating Morphodent, a web-based learning program in dental morphology. *J Dent Educ* 2010; **74**:1133-1139.
28. Bogacki, R.E., Best, A. and Abbey, L.M. Equivalence study of a dental anatomy computer-assisted learning program. *J Dent Educ* 2004; **68**:867-871.
29. Bandiaky, O.N., Lopez, S., Hamon, L., Clouet, R., Soueidan, A., Le Guehennec, L. Impact of haptic simulators in preclinical dental education: A systematic review. *J Dent Educ* 2024; **88**:366-379.
30. Serrano, C.M., Bakker, D.R., Zamani, M., de Boer, I.R., Koopman, P., Wesselink, P.R. *et al.* Virtual reality and haptics in dental education: Implementation progress and lessons learned after a decade. *Eur J Dent Educ* 2023; **27**:833-840.
31. Shrestha, A., Sharma, R. Learning preferences of undergraduate dental students using VARK analysis. *J Kathmandu Med Coll* 2021; **9**:207-212.
32. Chaudhry, N.A., Ashar, A. and Ahmad, S.A. Association of Visual, Aural, Read/Write, and Kinesthetic (VARK) Learning Styles and Academic Performances of Dental Students. *J Pak Med Assoc* 2020; **70**(Suppl-1):S1-S5.
33. Ferrer-Valdivia, N., Herrera-Barraza, V. and Garrido-Urrutia, C. Learning styles in undergraduate dentistry students: A systematic review. *Jpn Dent Sci Rev* 2025; **61**:79–89.
34. Kurogi, T., Nakayama, M., Sato, K., Kamuro, S., Fernando, C.L., Furukawa, M. *et al.* Haptic transmission system to recognize differences in surface textures of objects for telexistence. *IEEE Virtual Reality* 2013; 16-20.
35. Ackerley, R. and Kavounoudias, A. The role of tactile afference in shaping motor behaviour and implications for prosthetic innovation. *Neuropsychologia* 2015; **79**:192-205.
36. Kobayashi, R., Sakurai, N., Nagasaka, K., Kasai, S. and Kodama, N. Relationship between tactile sensation, motor activity, and differential brain activity in young individuals. *Brain Sci* 2022; **12**:924.