学位論文

Development of a virtual reality training system for endoscope-assisted submandibular gland removal

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ABSTRACT

Purpose: Endoscope-assisted surgery has widely been adopted as a basic surgical procedure, with various training systems using virtual reality developed for this procedure. In the present study, a basic training system comprising virtual reality for the removal of submandibular glands under endoscope assistance was developed. The efficacy of the training system was verified in novice oral surgeons.
Material and methods: A virtual reality training system was developed using existing haptic devices. Virtual reality models were constructed from computed tomography data to ensure anatomical accuracy. Novice oral surgeons were trained using the developed virtual reality training system.
Results: The developed virtual reality training system included models of the submandibular gland and surrounding connective tissues and blood vessels entering the submandibular gland. Cutting or abrasion of the connective tissue and manipulations, such as elevation of blood vessels, were reproduced by the virtual reality system. A training program using the developed system was devised. Novice oral surgeons were trained in accordance with the devised training program.
Conclusions: Our virtual reality training system for endoscope-assisted removal of the submandibular gland is effective in the training of novice oral surgeons in endoscope-assisted surgery.

1. Introduction

Endoscope-assisted surgery has been established as a basic surgical procedure and has emerged as an important method in several medical fields (Castaldo et al., 1992; Sham et al., 2009; Ledesma et al., 2016). Surgeries using endoscopy have rapidly become the preferred approach in many medical fields because of their minimal invasiveness and efficacy in decreasing hospital recovery times (Banta, 1993). In oral surgery, the proportion of surgeries performed using endoscopy has increased year by year. Several studies have reported the efficacy of oral and maxillofacial endoscope-assisted surgery (Gonzalez-Garcia, 2012), including surgeries for soft tissue diseases (Matsui et al., 2008; Iwai et al., 2010; Rosa et al., 2013). Minimally invasive surgery has also been shown to increase patient satisfaction regarding esthetic outcomes. Endoscope-assisted surgery is generally conducted delicately while viewing images displayed on a camera. Therefore, virtual reality (VR) surgical training simulators have been developed and have been put to practical use in many procedures, such as arthroscopic or laparoscopic surgeries (Tarcoveanu et al., 2011). However, a VR training simulator for endoscopic surgery of supporting soft tissues has yet to be developed for oral and maxillofacial surgery.

The removal of the submandibular gland is a representative example of such a soft tissue surgery in the oral and maxillofacial

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region. During this procedure, damage to the mandibular branch of the facial nerve should be avoided while approaching the submandibular gland from beneath the nerve via a small incision in the skin. This technique provides excellent cosmetic outcomes postoperatively. However, surgeons are required to have advanced knowledge and special skills, particularly during detection and handling of Wharton's duct, the lingual nerve, and vessels, such as the facial artery and veins, as these maneuvers are performed while watching images captured by the endoscope. Technical training prior to the performance of surgery is mandatory for novice oral surgeons and trainees. The main training systems for endoscope-assisted soft tissue surgery are phantom training (Munz et al., 2004) and animal training (Jiga et al., 2008). Phantom training, however, fails to accurately simulate the elasticity of soft tissues, and animal training cannot be undertaken repeatedly due to associated costs and lack of facilities.

Training systems using VR have rapidly progressed in medical fields in which the operative procedure can be repeatedly simulated. Various training curricula have been established to facilitate their application (Baumann et al., 1996). Furthermore, VR training systems for hard tissue surgery in the oral and maxillofacial region, such as implant treatments (Kusumoto et al., 2006) and apicoectomy (von Sternberg et al., 2007), have been developed. However, few systems have been reported for soft tissue surgery because the characteristics of soft tissue are difficult to reproduce in VR.

The present study aimed to develop a VR system that included the submandibular gland, vessel, and layered connective tissue. With a computational dynamic model, the visualized component was designed to simulate physiological deformation by external forces. The developed system may be a useful tool for trainees who want to master the basic skills of endoscope-assisted surgery on the soft tissues of the oral and maxillofacial region because it can simulate various operative steps used during the surgery in addition to facilitating the removal of the submandibular gland.

In the present study, we developed for the first time a training simulation of endoscope-assisted removal of the submandibular gland using VR, and evaluated the utility of the developed training system in novice oral surgeons.

2. Material and methods

2.1. Design of a VR endoscopic simulator

The VR simulator consisted of a computing system (operation system; Windows 7 Professional SP3 32bit, Memory; 4GB DDR-2 SDRAM, Graphics, NVIDIA Quadro FX1800 768MB), a 23-inch display, and two Geomagic Touch (Geomagic Technologies, Wilmington, MA, USA) (Fig. 1) haptic devices. Geomagic Touch uses Geomagic Freeform software and can operate with a VR force feedback device. The specifications of the device are as follows: nominal position resolution: >450 dpi (0.055 mm); range of motion: hand movement pivoting at the wrist; maximum force sensed: 3.3 N; force feedback: x, y, z 3-axis; and interface, IEEE-1394 FireWire.

The system simulates the motion of forceps on the monitor when the haptic device is handled. The VR images were composed of several structures as follows: three layers of connective tissue, a globe imitating the submandibular gland, and a blood vessel (Fig. 2). The latter two structures were under the connective tissue. Each structure was built from data obtained from actual surgeries performed at our institution. Structures were projected using OpenGL onto the VR image constructed as virtual objects, with each virtual object assigned a value for elasticity and hardness. In this manner, the motion and elasticity of the virtual tissues could be tuned to simulate various clinical situations. Several virtual tools for touching and abrasion, essential skills required for endoscope-

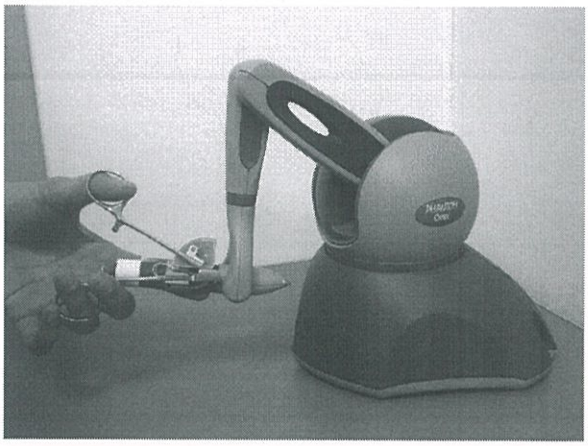

Fig. 1. Geomagic Touch. The Geomagic Touch device allows 3D spatial position (x, y, and z coordinates) and stylus pen direction (pitch, roll, and yaw) to be accurately measured. The device uses a motor to generate a force against the user's hand, allowing simulation of touch and interactions with virtual objects.

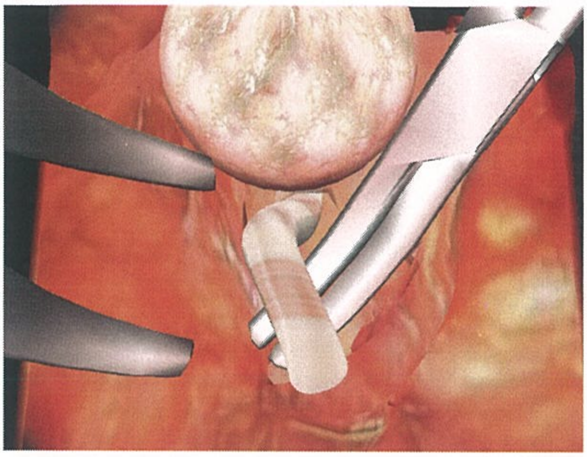

Fig. 2. Virtual reality image. It is possible to exfoliate the submandibular gland and vessel under the layers of connective tissue using two Pean forceps.

assisted surgery, were available in Geomagic Freeform software; thus, we were able to manipulate virtual objects using the forceps on the device handle.

The operation of the forceps in VR, as performed by the original device handle, simulated the opening and closing of Pean forceps by pressing a button on the handle. This surgery is different from the actual surgical surgery. To represent reality as accurately as possible, the Pean forceps to be used in the actual surgery were fitted to the original device handle. The Pean forceps were modified to send signals via a magnetic reed switch. This allowed the rendering of experiences similar to the actual surgical environment.

The haptic device used in the present study is able to exert up to 3.3 N of force by adjusting the coefficient of friction and tensile strength between the spheres constituting tissues in virtual reality. Within this range, we adjusted the force such that the sensation of device operation was approximate to that of actual surgery. The force generated was measured using the following equation:

$$\text{force generated when spheres come in contact } (F) = -k\Delta x$$

where F represents force (N; kg m s^{-2}), k represents the proportionality constant (spring constant; N/m), and Δx represents the elongation of the spring (m).

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As multiple spheres may be in contact at any time, their cumulative force was used as the force obtained in virtual reality. One oral surgeon performed the same operation 10 times, and the mean of the forces measured was used. The mean force on tissues was found to be 1.30 N, while the action of peeling tissues requires the application of 1.39 N of force, and the force required to lift a blood vessel was 1.04 N. These values are higher than the 0.9 N reported by Choi et al. for the force applied during suture simulation in virtual reality using the same device (Choi et al., 2012). These findings are likely attributable to Pean forceps being more blunt than needles, and puncturing and peeling tissues with a pair of Pean forceps requires a larger contact area. We further asked 13 oral surgeons to fill out a questionnaire during the production process with subjects reporting that they felt a force of approximately 80% of the force felt during actual surgery. We therefore used the above-mentioned values as the initial values in the present study.

2.2. Training program

Initially, two tasks were repeated 10 times on VR simulations by novice surgeons who had not experienced an endoscope-assisted surgery within 1 week. The first task was the abrasion of a connective tissue membrane around the submandibular gland and blood vessel, and the second task was to lift a blood vessel. The time required for each surgery and the level of device operation skill were evaluated. The skill was evaluated at the following four levels: (1) touching the membrane with the non-dominant hand, (2) pushing the membrane with the non-dominant hand, (3) assisting the dominant hand with the non-dominant hand, and (4) abrasion, cutting, and grasping the membrane with the non-dominant hand. Based on these results, a training program was devised.

2.3. Evaluation of our VR training system program

In total, 14 oral surgeons who had not experienced endoscope-assisted surgery participated in evaluation tests. Subjects in this study had different years of experience, but none of them had experience with endoscopic surgery, and were randomly selected. Initially, all subjects were trained in the vessel extraction task using a surgical training model (Limbs & Things Ltd, Bristol, UK; Fig. 3) composed of blood vessels and connective tissue (Bath et al., 2011). A surgical model was fixed to the frame and video-taped by camera. Surgeons were able to perform the surgical training procedure while viewing the image projected on a display in real time. The surgery duration and number of strokes required to exfoliate the connective tissue and lift the vessel were measured, and the smoothness of the task was evaluated.

Subsequently, 10 subjects were further trained in the use of the developed VR training program. Finally, all subjects performed a second training surgery using the surgical model. The efficacy of the VR training was evaluated by comparing surgery durations and number of strokes performed during each surgery. All data were processed and analyzed using IBM SPSS Ver. 20.0. Difference in performances was compared using the Mann–Whitney *U* test. A P value < 0.05 was considered statistically significant.

3. Results

3.1. Training program using VR simulation

To investigate the effectiveness of the VR simulation, two tasks were evaluated according to the time taken and level of device use by novice surgeons. When the VR surgery was performed 10 times, the time and number of errors during surgeries were seen to significantly decrease after seventh repetition (Fig. 4). In addition,

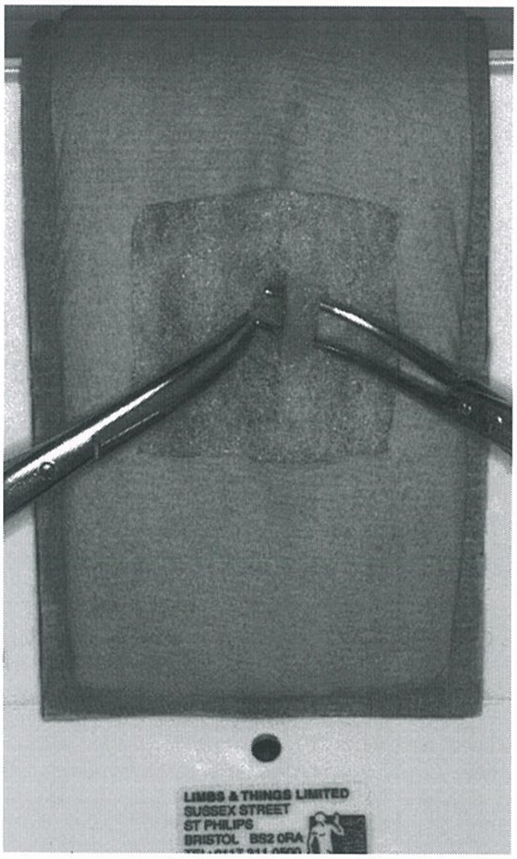

Fig. 3. The vessel extraction task was performed using a surgical training model (Limbs & Things Ltd, Bristol, UK). The surgical procedure was performed while viewing the image projected on the display in real time.

the highest level of device use was achieved after the fifth repetition in both groups of surgeons. From the seventh time on, the values did not decrease compared to the seventh operation; therefore, we assumed that seven repetitions were sufficient to obtain stable improvement in technique.

This result indicates that more than seven repetitions of VR training are required to decrease the duration of actual surgeries, and that it is possible to improve the ability of novice surgeons to use Pean forceps. Based on the above observations, an original training program was devised such that surgery tasks were performed seven times within 1 week using the VR training simulator for oral surgery (Fig. 5).

3.2. Final evaluation

The vessel extraction task was evaluated using a surgical training model. In the VR training group, when comparing the difference between surgery durations before and after VR training, it was found that operating times were significantly decreased after the first trial ($P = 0.00036$; $P < 0.01$) (Fig. 6A). Furthermore, the number of strokes with Pean forceps required during surgeries before and after VR training was significantly decreased in the VR group ($P = 0.00020$, $P < 0.01$) (Fig. 7A). In the non-VR group, no significant differences were observed for either measure. In addition, there was a statistically significant difference between the average time taken between the VR and non-VR trained groups (VR, 86.5 s vs. non-VR, 28.7 s; $P = 0.0069$; $P < 0.01$; Fig. 6B) and the

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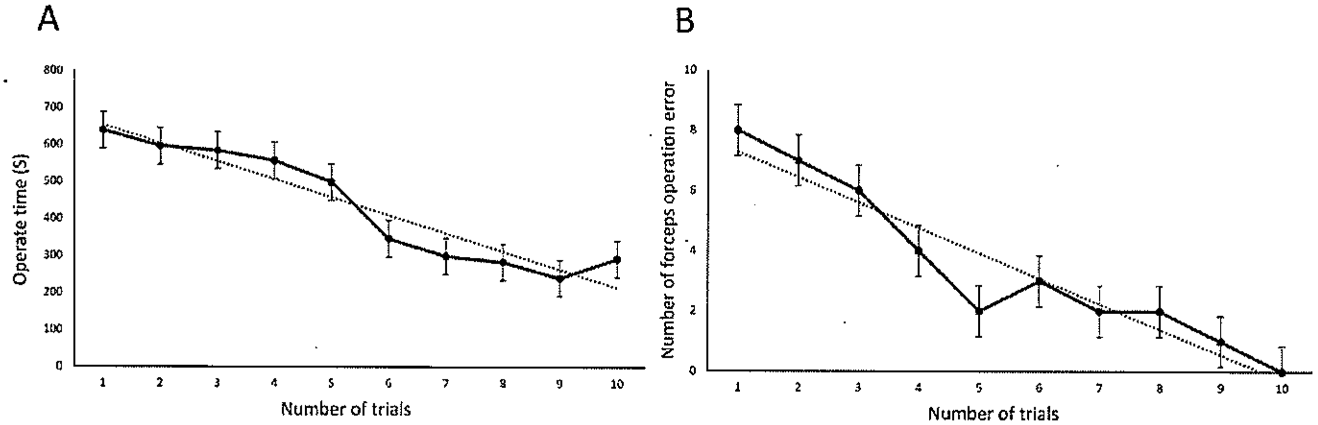

Fig. 4. (A) Consistent decreases in surgery duration on virtual reality (VR) over seven sessions. (B) Decreased number of errors on VR, with all errors eliminated after 10 sessions.

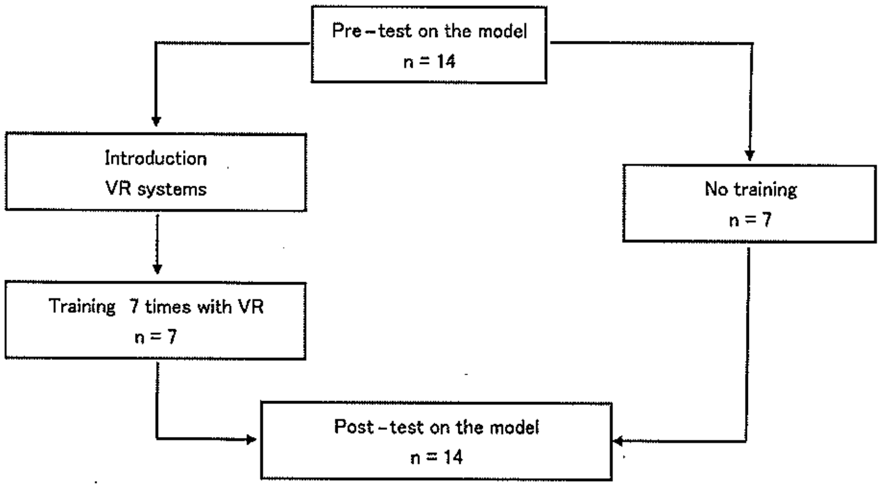

Fig. 5. Study protocol. A total of 14 novice surgeons who had not experienced endoscope-assisted surgeries were included. One group practiced with virtual reality simulation, whereas the other did not.

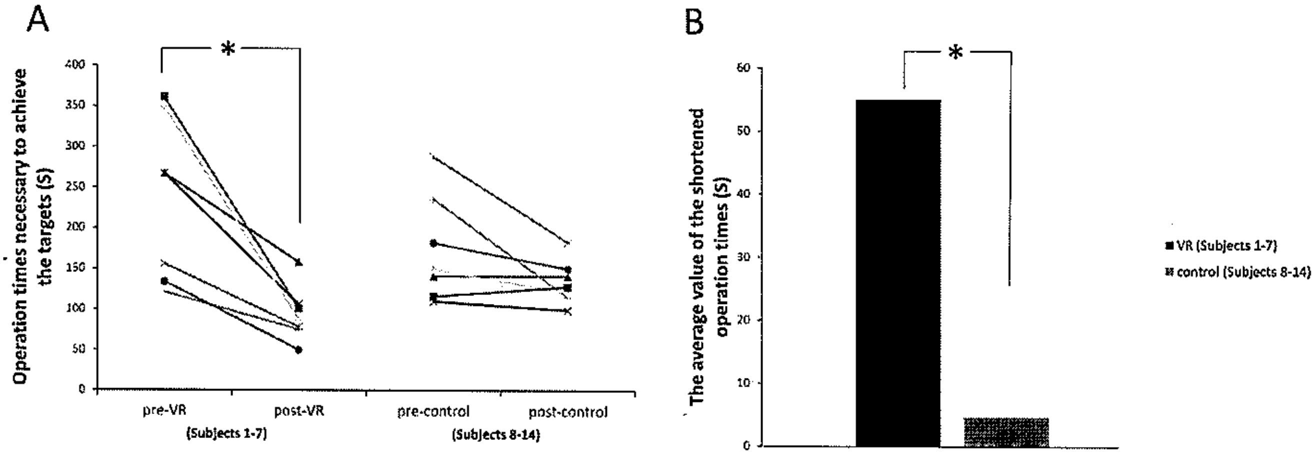

Fig. 6. (A, B) Operation times decreased in the virtual reality group after training compared with the control group. *P < 0.05, Mann–Whitney *U* test.

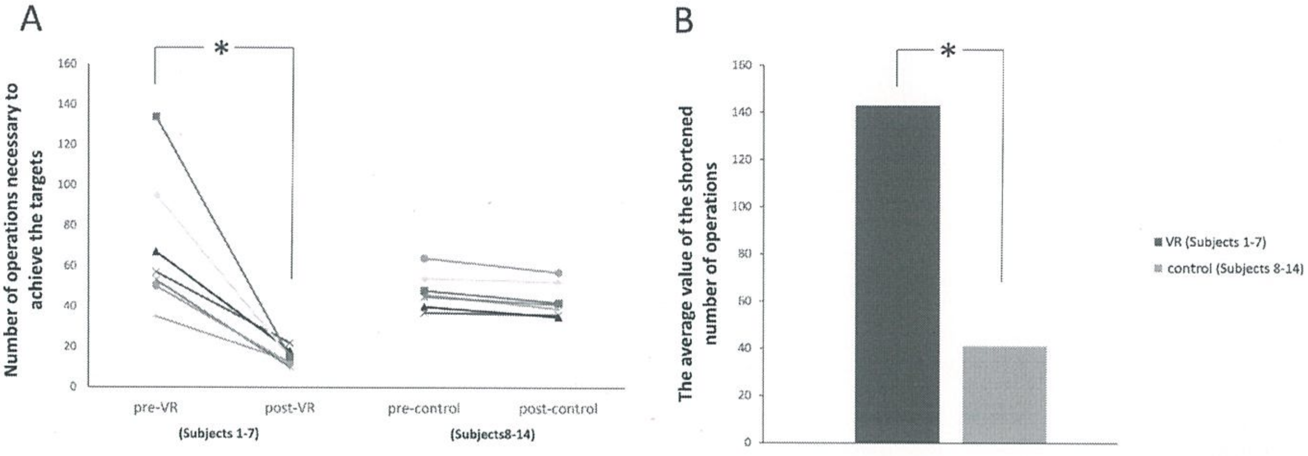

Fig. 7. (A, B) Number of strokes decreased in the group with virtual reality after training compared to the control group. *P < 0.05, Mann–Whitney *U* test.

number of strokes required for the task (VR, 31.9 strokes vs. non-VR, 3.4 strokes; P = 0.0069; P < 0.01) (Fig. 7B).

4. Discussion

Since their development in 1992 (Castaldo et al., 1992), virtual reality training simulators of surgical surgeries have been developed for various training equipment (Ayodeji et al., 2006; Lucas et al., 2008), with accompanying training programs devised (Aggarwal et al., 2006; Kossi and Luostarinen, 2009). In the area of oral and maxillofacial surgery, VR simulation has been developed for oral implant surgery (Kusumoto et al., 2006) and apicoectomy (von Sternberg et al., 2007). However, VR simulation representing an endoscope-assisted surgery in this area has not yet been developed. In recent years, oral surgery using endoscopes has been reported (Gonzalez-Garcia, 2012; Matsui et al., 2008; Iwai et al., 2010; Rosa et al., 2013), and their utility has become widely recognized. With the rapid development of minimally invasive surgery, acquiring the specific skills required to perform endoscope-assisted surgery is now inevitable for all oral surgeons. The practice of endoscope-assisted surgery requires new psychomotor skills that are counterintuitive to open surgery and are thus difficult to learn. Such observations have validated the need for virtual reality operative training with endoscope-assisted surgical simulators.

At present, there are several VR-based endoscope surgery simulators available, including some commercial products such as LAP Mentor (Wilson et al., 2010) and LapSim (Munz et al., 2004). These simulators focus primarily on surgeries in which there are only small deformations and movements of soft tissues, such as cholecystectomy (da Cruz et al., 2010). However, these simulator representations of force are insufficient, and therefore, subjects are unable to experience an accurate representation of actual surgery. Therefore, the computation of realistic deformations and haptic responses represents a substantial technical challenge. Recently, VR simulations of various small field-procedures have been developed, such as the technique of suturing (Choi et al., 2012). These were constructed using common haptic devices. Subjects are able to experience the force applied during surgical tasks by operating this device. Training simulators of submandibular gland removal under endoscopic assistance have been developed using haptic devices. Representation of soft tissue surgeries is substantially different because of substantial soft tissue movement and deformation. Therefore, our VR model was built on the physiological deformation model developed by Jianwu Dang et al. (Fujita et al., 2007). Moreover, as the submandibular gland and adjacent soft tissues frequently self-collide and collide with the abdominal cavity during surgery, an efficient collision detection algorithm is essential to robustly detect collisions in real time. The force required for submandibular gland resection was modeled in our simulator. Force values measured were similar to data obtained from previous reports and were considered to be appropriate for VR simulation (Panait et al., 2009; Sowerby et al., 2010; Karadogan et al., 2010). However, because modeled forces in VR systems are currently subjectively determined, future animal studies are required to identify the most realistic representations of forces encountered during surgery.

In the present study, the development of a training program using VR simulation of submandibular gland removal under endoscopic assistance was demonstrated. By performing VR training more than seven times, the technique of novice oral surgeons statistically significantly improved in terms of device use and surgery durations. A recent study demonstrated improvement in VR technique after seven or more repetitions (Aggarwal et al., 2006). Therefore, our developed training program demonstrated utility in improving VR technique. Improvements in VR technology have been reported in many previous VR training studies. However, previous studies evaluating actual surgical technique have reported limited improvements with the use of VR training. We observed significant differences in model laboratory performance between the VR and non-VR groups in terms of surgery duration and the number of strokes using Pean forceps. We concluded that conducting nonparametric testing was appropriate, as subjects were randomly selected and distributed, the amount of obtained data was small, and it was difficult to assume the distribution of the data. The results demonstrated that random, less skilled individuals included in the virtual reality training group exhibited substantial improvements, and this finding was likely for the statistically significant difference observed. Thus, these findings indicate that the proposed training system allows students who are complete novices in medicine and beginner surgeons to practice smooth handling of instruments. However, as a training system that improves the actual technique, the content and expression of this system are insufficient; thus, the range of operations and visual effects of bleeding need to be improved. To that end, instead of increasing the number of spheres that constitute tissues in virtual reality and superimposing two-dimensional layers, tissues should be created as three-dimensional structures from the beginning. Therefore, a high-capacity and high-performance computer that is capable of faster calculations than the present one is imperative. It is also necessary to ensure that the sensation of force being applied is as close to the actual force of surgery. In other words, it is important to measure the actual force generated during procedures on actual tissues through animal experiments in order to allow appropriate adjustment of the force modeled in virtual reality.

These results indicate that surgery durations and the number of strokes required for blood vessel extraction decrease following VR training, with the effectiveness or individual strokes improved and ineffective strokes eliminated. Moreover, surgery durations were shortened, indicating that exacting, precise procedures were more smoothly performed. In addition, VR simulator may represent a more realistic environment using handle-type forceps rather than pen-type forceps. In a previous study, the utility of a VR training system was demonstrated in novices; however, the reported utility may not extend to professional practice (Wu et al., 2014). Recently, training times for novices have decreased, as simulations can be performed in a single session. The effectiveness of the proposed training system was evaluated through an imitated surgical operation using a simulation model. As such, neither actual surgical procedures nor animal-based experiments were used in the present study. The proposed system is low cost and was designed as a portable training device that could be used anywhere. Therefore, we performed the most thorough evaluations possible under the constraint of limiting costs. We hope to perform further evaluations to increase the effectiveness of this system. Moreover, as this is the first training system reported to improve the skill levels of beginners, we intend to create a simulation in which multiple systems can be set up with relatively low cost compared to current high-cost simulations. The development of a training system involving the technique of performing surgery while looking at a screen represents significant progress. Endoscopy represents a basic and inexpensive technique, with small-scale training systems shown to be highly effective for beginners. Based on currently available virtual reality simulations, it may be possible to reproduce other soft tissue surgeries in the oral cavity region, with simulation of tongue resection likely representing the first step.

5. Conclusion

Our training program using VR simulation of submandibular gland removal under endoscopic assistance demonstrated efficacy in shortening surgery durations, decreasing the number of Pean forcep strokes required, and improving the performance of endoscope-assisted surgery. The findings of the present study indicate that it is required to aim at the exact representations of haptic feedback so that more accurately model textures may be feasible in addition to improved VR simulator utility.

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References

Aggarwal R, Grantcharov TP, Eriksen JR, Blirup D, Kristiansen VB, Funch-Jensen P, et al: An evidence-based virtual reality training program for novice laparoscopic surgeons. Ann Surg 244: 310–314, 2006

Ayodeji ID, Schijven MP, Jakimowicz JJ: Determination of face validity for the Simbionix LAP mentor virtual reality training module. Stud Health Technol Inform 119: 28–30, 2006

Banta HD: Minimally invasive surgery. Implications for hospitals, health workers, and patients. BMJ 307: 1546–1549, 1993

Bath J, Lawrence P, Chandra A, O'Connell J, Uijtdehaage S, Jimenez JC, et al: Standardization is superior to traditional methods of teaching open vascular simulation. J Vasc Surg 53: 229–235, 2011

Baumann R, Glauser D, Tappy D, Baur C, Clavel R: Force feedback for virtual reality based minimally invasive surgery simulator. Stud Health Technol Inform 29: 564–579, 1996

Castaldo P, Chiavellati L, Di Giulio E, Schiffino L, Stipa F, Ziparo V, et al: Laparoscopic cholecystectomy. The beginning of a new era. Recenti Prog Med 83: 429–436, 1992

Choi KS, Chan SH, Pang WM: Virtual suturing simulation based on commodity physics engine for medical learning. J Med Syst 36: 1781–1793, 2012

da Cruz JA, Sandy NS, Passerotti CC, Nguyen H, Antunes AA, Dos Reis ST, et al: Does training laparoscopic skills in a virtual reality simulator improve surgical performance? J Endourol 24: 1845–1849, 2010

Fujita Satoru, Dang Jianwu, Suzuki Noriko: A computational tongue model and its clinical application. Oral Sci Int 4(2): 97–109, 2007

Gonzalez-Garcia R: Endoscopically-assisted subcondylar and vertical ramus osteotomies for the treatment of symmetrical mandibular prognathism. J Craniomaxillofac Surg 40: 393–395, 2012

Iwai T, Matsui Y, Tohnai I, Mikami T, Maegawa J: Three-dimensional visualization of the relationship between cervical cystic lesions and related vessels using CT angiography for endoscopically-assisted neck surgery. J Plast Reconstr Aesthet Surg 63: 82–83, 2010

Jiga LP, Cristian H, Blidisel A, Sandra F, Nistor A, Hoinoiu B, et al: Thoracoscopic approach of the internal mammary artery (IMA): a training model in pigs. Microsurgery 28: 375–379, 2008

Karadogan E, Williams 2nd RL, Howell JN, Conatser Jr RR: A stiffness discrimination experiment including analysis of palpation forces and velocities. Simul Healthc 5: 279–288, 2010

Kossi J, Luostarinen M: Virtual reality laparoscopic simulator as an aid in surgical resident education: two years' experience. Scand J Surg 98: 48–54, 2009

Kusumoto N, Sohmura T, Yamada S, Wakabayashi K, Nakamura T, Yatani H: Application of virtual reality force feedback haptic device for oral implant surgery. Clin Oral Implants Res 17: 708–713, 2006

Ledesma JB, Wang T, Desmond E, Imrie M, Gamble JG, Rinsky LA: Endoscopic-assisted epiphysiodesis: technique and 20-year experience. J Pediatr Orthop B 25: 24–30, 2016

Lucas SM, Zeltser IS, Bensalah K, Tuncel A, Jenkins A, Pearle MS, et al: Training on a virtual reality laparoscopic simulator improves performance of an unfamiliar live laparoscopic procedure. J Urol 180: 2588–2591, 2008

Matsui Y, Iwai T, Tohnai I, Maegawa J: Endoscopically-assisted resection of a brachial cyst. Br J Oral Maxillofac Surg 46: 336–337, 2008

Munz Y, Kumar BD, Moorthy K, Bann S, Darzi A: Laparoscopic virtual reality and box trainers: is one superior to the other? Surg Endosc 18: 485–494, 2004

Panait L, Akkary E, Bell RL, Roberts KE, Dudrick SJ, Duffy AJ: The role of haptic feedback in laparoscopic simulation training. J Surg Res 156: 312–316, 2009

Rosa M, Usai P, Miano R, Kim FJ, Finazzi Agrò E, Bove P, et al, International Translational Research in Uro-Sciences Team (ITRUST): Recent finding and new technologies in nephrolitiasis: a review of the recent literature. BMC Urol 13: 10, 2013

Sham CL, Woo JK, van Hasselt CA, Tong MC: Treatment results of sinonasal inverted papilloma: an 18-year study. Am J Rhinol Allergy 23: 203–211, 2009

Sowerby LJ, Rehal G, Husein M, Doyle PC, Agrawal S, Ladak HM: Development and face validity testing of a three-dimensional myringotomy simulator with haptic feedback. J Otolaryngol Head Neck Surg 39: 122–129, 2010

Tàrcoveanu E, Moldovanu R, Bradea C, Dimofte G, Lupascu C, Georgescu S, et al: Laparoscopic surgical education–the experience of the first surgical unit Iasi. Chirurgia (Bucur) 106: 67–76, 2011

von Sternberg, Bartsch MS, Petersik A, Wiltfang J, Sibbersen W, Grindel T, et al: Learning by doing virtually. Int J Oral Maxillofac Surg 36: 386–390, 2007

Wilson M, McGrath J, Vine S, Brewer J, Defriend D, Masters R: Psychomotor control in a virtual laparoscopic surgery training environment: gaze control parameters differentiate novices from experts. Surg Endosc 24: 2458–2464, 2010

Wu F, Chen X, Lin Y, Wang C, Wang X, Shen G, et al: A virtual training system for maxillofacial surgery using advanced haptic feedback and immersive workbench. Int J Med Robot 10: 78–87, 2014

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