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

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A B S T R A C T

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

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.

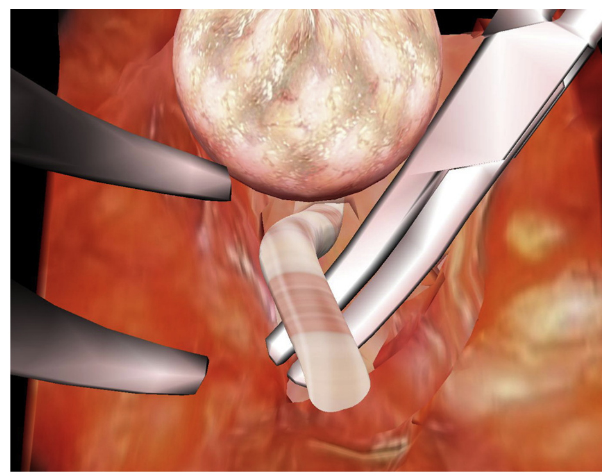

Fig. 2. Virtual reality image. It is possible to exfoliate the submandibular gland and vessel under the layers of connective tissue using two Pean forceps.

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).