A Virtual Reality Ear Ossicle Surgery Simulator Using Three-dimensional Computer Tomography

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Abstract

This paper describes a virtual reality simulator for middle ear ossicle surgery. An automatic segmentation method has been developed to segment tiny ear ossicles at transverse computer tomography (CT) slices. Surgeons can therefore easily observe the three-dimensional (3D) geometry of the segmented ossicles by the volume reconstruction and the spatial relation with the temporal bone to diagnose middle ear disease. Surgeons can use a virtual reality round cutting bur to cut the temporal bone for opening the 3D tympanic cavity, and a virtual reality round polishing bur to cut for separating ear ossicles from other bones or to polish the adhered tissue sclerosis on the ear ossicles. These burring simulations can achieve real-time visual and haptic responses based on our reported volume manipulation methods. A technique is developed to judge if a separation among the ossicles or from the temporal bone occurs during the burring simulations so that repositioning simulations can be followed to align the ear ossicles. A simulation example of a real ear ossicle surgery demonstrates these simulation functions work well even for tiny ossicles and thus shows the effectiveness of the surgical simulator to rehearse the surgical procedures, confirm surgical plans and train interns and students.

Keywords: Middle ear surgery, Virtual reality surgery simulation, Ear ossicle, Volume visualization

1. Introduction

Surgeries for recovering functions of middle ear ossicles (malleus, incus and stapes) through bone ossicular replacements, alignment or cleaning are advanced surgical procedures for treating conductive hearing loss. However, the tiny sizes of these ossicles bring high surgical failure rates [1-5]. The X-ray based cephalogram is a standard procedure to evaluate geometry of the middle ear (tympanic) cavity and the inside ear ossicles, diagnose diseases and manage surgery. However, projection errors occur in using X-rays [6], which cannot provide correct spatial relations among the ear ossicles and with the temporal bone to make correct surgical plans. Meanwhile, computer tomography (CT) slices can provide interior information and avoid projection errors, and thus are considered as an excellent way to evaluate the tiny ear ossicles [7-10]. Three-dimensional (3D) reconstruction from a volume constituted by CT slices can be used to visualize pathologies of the ear ossicles [11] or simulate cutting operations on the 3D temporal bone [12,13].

However, the ear ossicles are too small to be distinguished from the neighboring temporal bone for visualization and then surgical simulation. This paper therefore proposes an automatic segmentation method to recognize the ear ossicles in the tympanic cavity on transverse CT slices. Using segmented ossicular areas on the two-dimensional (2D) CT slices, 3D ear ossicles can be highlighted from the temporal bone during the volume reconstruction. A surgeon can then easily zoom in on the tympanic cavity to simulate opening the tympanic cavity, polishing out tissue sclerosis on the ear ossicles and repositioning to align these ossicles. This paper also develops a volume-based simulation method that uses real-time visual and haptic burring simulation functions to open the tympanic cavity and polish the ear ossicles, checks whether the ossicles are separate or separated from the temporal bone and uses repositioning functions to align ossicles. In this preliminary study, we evaluated the usefulness of our method and the prototype system with a middle ear disease case.

2. Subjects and methods

2.1 Middle ear ossicle segmentation on transverse CT slices

The process of finding the middle ear ossicles on a transverse slice is described as follows.