FEM analysis of aspirated air flow in three-dimensional vocal tract during fricative consonant phonation.

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ABSTRACT

This paper deals with estimations of aspirated air flow in a three-dimensional vocal tract during fricative consonant phonation using the Finite Element Method (FEM). The shape of the 3-D vocal tract during phonation of fricative consonant /s/ is reconstructed from 32 coronal Magnetic Resonance (MR) images. MR images of the dental crown that contains a small amount of water were obtained using a dental crown plate. A 3-D FEM vocal tract model is formed so that the number of elements is 28686, the number of nodes is 7010, and a rigid wall constitutes the vocal tract wall. Results showed that the flow rate was high at the narrow space made between the upper central incisors and the tongue surface. An electric equivalent circuit for fricative consonant phonation was designed in consideration of the location of the noise source.

1. INTRODUCTION

Three-dimensional (3-D) data on vocal tract shapes are essential to the construction of an articulatory model. Several techniques for investigating human speech production have been reported in speech science literature focusing on the vocal tract as a fundamental articulatory organ. In addition, attempts have been made to model the vocal tract and estimate its characteristics.

Magnetic Resonance Imaging (MRI) is a powerful tool for investigating the geometry of the 3-D vocal tract shape and does not involve any known radiation risks.[1][2] However, most previous MRI studies have been limited to investigation of vowels. The reason for this is that, it is difficult to obtain profiles of dental crown shapes that contain a small amount of water using conventional MRI techniques. Thus there is insufficient data on the 3-D shapes of the vocal tract during the phonation of consonants that are produced using the teeth in a steady state.

In response to this problem, we have developed a method that uses a dental crown plate to enable simultaneous MR imaging of the dental crown and the vocal tract .[3]

The purpose of the present study is to apply this method, the Finite Element Method (FEM), to estimation of aspirated air flow in the 3-D vocal tract during fricative consonant /s/ phonation. We describe a method of reconstructing 3-D vocal tract shapes from 3-D MR images, and demonstrate an FEM analysis of the 3-D vocal tract model. Aspirated air flows in the 3-D vocal tract models are also illustrated. In the final section, the transfer characteristics are computed from an electric equivalent circuit based on an fricative consonant phonation model.

2. METHODS

2.1. Measurement of 3-D MR images.

All of the MR images in this study were collected using a 1.0 Tesla superconductive MR system (MAGNEX100HP, Shimadzu Corp., Japan).[3]

The mid-sagittal MR images were measured by the single-slice flip-back spin-echo imaging method at high speed. Each image was acquired with the repetition time TR=200 ms and the echo time TE=15 ms using an image matrix of 256×256 over a field of view of 25 cm. The section thickness of the excited plane was 5 mm. The measurement time was 25 s. The coronal MR images were measured by a multi-slice T1-weighted spin-echo imaging method and were acquired with TR=200 ms and TE=15 ms using an image matrix of 256×256 over a field of view of 25 cm.

3-D MR images consisting of MR images of 32 coronal sections, at intervals of 4 mm, from the tip of the nose to the atlas were obtained. The measurement time was 142 s. The section thickness of the excited plane was 3.5 mm.

Data on dental crown shapes are required in order to analyze the speech production and precisely estimate the acoustical characteristics of the vocal tract. In this study, these data are obtained by means of a dental crown plate, 0.6 mm thick, that is tightly attached to the subject's dental crown by thermoforming and that contains a contrast medium for MR imaging. By attaching the dental crown plate to the subject's upper and lower teeth, profiles of the vocal tract and dental crown can be obtained simultaneously using MRI.

The experiments were performed on a Japanese adult male subject. MR images and the sound uttered by a supine subject in the MR chamber were obtained. The subject's voice was recorded using a high sensitivity condenser microphone.

Figure 1 shows a sample MR image. As can be seen, the dental crown plate allows a clear profile of the dental crown.