3pSC58

A Preliminary Acoustic Analysis of Three-Dimensional Shape of the Human Nasal Cavity and Paranasal Sinuses Extracted from Cone-Beam CT

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Background and Objective

Shape of the human nasal cavity and paranasal sinuses
- Complex
- Individual variance
- Stable during speech

→ Speaker individualities

Lack of studies on the acoustic properties of the cavities
- Dang & Honda (1996) 1D model
- Kagawa *et al*. (1996) 3D BEM

Acoustic analyses on the basis of the 3D shape of the cavities are needed to understand more about their acoustic effects on speech sounds.

Explore the acoustic characteristics of the 3D shape of the nasal cavities and paranasal sinuses using finite-difference time-domain simulation

Methods

Cone-Beam X-ray CT data

- Scanner: Hitachi medico MercuRay
- Subject: One female (18 years old)
- X-ray tube voltage: 100 kVp
- Pixel size: 0.377 mm × 0.377 mm × 0.377
- Image size: 512 × 512 pixels
- No. of slices: 512

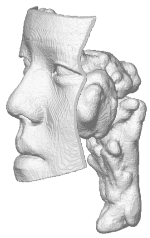
This research was approved by the ethical and safety committees of Showa University.

Extraction and reconstrunction of the 3D shape of the cavities

Original image
Concentric noise

Median smoothing

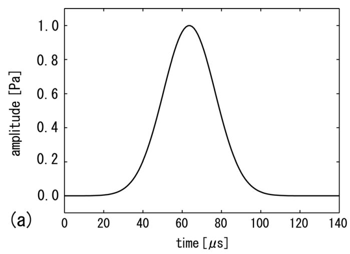
Segmentation
Trainable Weka segmentation



Reconstruction of 3D shape and adding wall
3-mm thickness

Acoustic simulation

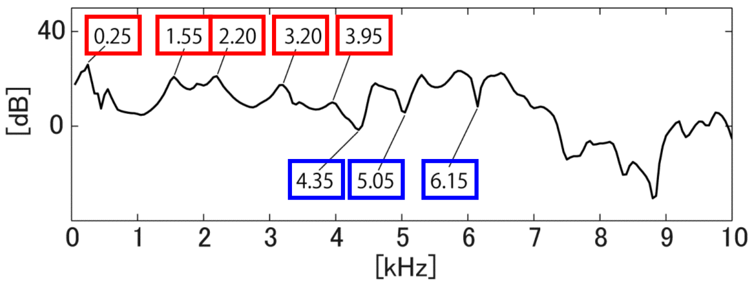
- Finite-difference time-domain method
- Input: Gaussian pulse was inputted from the glottis
- Observation point: 20 mm away from the nostril
- Spatial resolution: 0.5 mm × 0.5 mm × 0.5 mm
- Time resolution: 5.0×10^{-7} s
- Speed of sound: 346.7 m/s, Air density: 1.17 kg/m^3
- Normal sound absorption coefficient: 0.008 (12-layer PML)



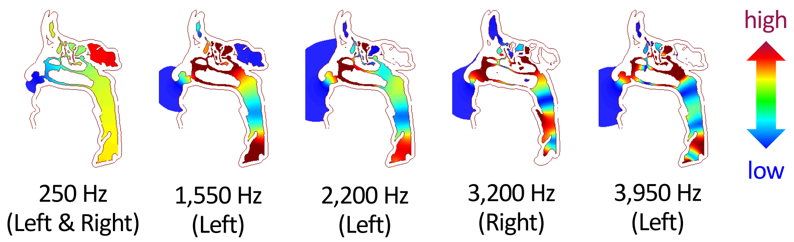
Input Gaussian pulse

For details of the simulation method, refer Takemoto *et al*. (2010).

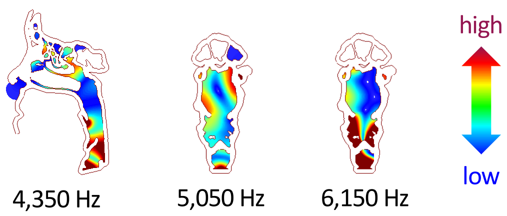
Results and discussion



Transfer function of the nasal and the paranasal cavities



Sound pressure distribution in the cavities for spectral peaks



Sound pressure distribution in the cavities for spectral dips

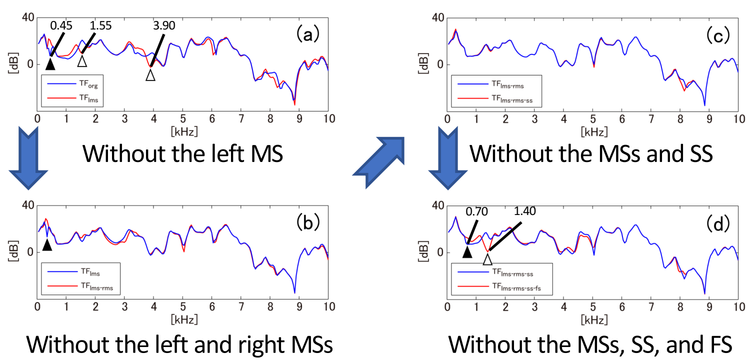
Sources of the spectral peaks

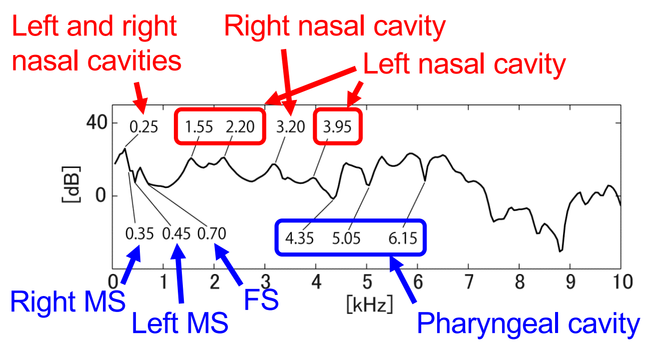
- 1st to 5th peaks → Resonances of a closed tube (closed end: the glottis, open end: the nostrils)
- The paranasal sinuses contributed to the resonances (not only to the anti-resonances).
- Unilateral resonance
  - 2nd, 3rd, and 5th peaks were generated in the left cavities.
  - 4th peak was generated in the right cavities.

Sources of the spectral dips

- Pharyngeal cavity contributed to the three deep dips.
- Dip at 4,350 Hz → 2nd resonance of the lower pharyngeal and the laryngeal cavities
- Dip at 5,050 Hz → 1st mode in the upper pharyngeal cavity (transverse direction)
- Dip at 6,150 Hz → 1st mode in the lower pharyngeal cavity (transverse direction)

Effects of the cavities





Transfer function of the nasal and the paranasal cavities

MS: Maxillary sinus, SS: Sphenoidal sinuses, FS: Frontal sinus

Conclusions

- The 3D acoustic analyses of the nasal cavity and paranasal sinuses of one female were performed using the FDTD method.
- The sources of the peaks and dips on the transfer function of the cavities were identified.
  - Left and right nasal cavities → the spectral peaks
  - Left and right MSs, FS, pharyngeal cavity → the spectral dips

References

[1] Dang and Honda, Morphological and acoustical analysis of the nasal and the paranasal cavities, JASA (1996).

[2] Kagawa, Ohtani, and Tsuchiya, Boundary element model of vocal tract including nasal branch in a head and its acoustic transmission characteristics, Proc. JSCES (1996).

[3] Takemoto, Mokhtari, and Kitamura, Acoustic analysis of the vocal tract during vowel production by finite-difference time-domain method, JASA (2010).

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