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

<table>
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<tr>
<th>Shape of the human nasal cavity and paranasal sinuses</th>
<th>Lack of studies on the acoustic properties of the cavities</th>
<th>Acoustic analyses on the basis of the 3D shape of the cavities are needed to understand more about their acoustic effects on speech sounds</th>
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<td>• Complex</td>
<td>• Dang &amp; Honda (1996)</td>
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<td>• Individual variance</td>
<td>• Kagawa et al. (1996)</td>
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<td>• Stable during speech</td>
<td>• 3D BEM</td>
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<td>→ Speaker individualities</td>
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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 reconstruction of the 3D shape of the cavities

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/m³
- Normal sound absorption coefficient: 0.008 (12-layer PML)

For details of the simulation method, refer Takemoto et al. (2010).
Results and discussion

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

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

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