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| 論文題目 | Numerical Simulation of Flow and Air-conditioning in Anatomical Realistic Nasal Cavity Model of Chimpanzee<br>（チンパンジーの解剖学的にリアルな鼻腔モデル内の流れと空調の数値シミュレーション） | | | |
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**論文の内容の要旨**


Traditional research approaches into nasal airways have been critical due to their invasive nature. Recently, with the growth of medical imaging field, it became possible to reconstruct computer models from computed tomography (CT) scans to study the airflow within the nasal passages. Nasal cavity of primates and other animals has been reported in many research works. Lots of the previous studies focused on the nasal airflow but few of them considered the internal nasal air-conditioning phenomena. Furthermore, a proper study of the nasal topology, nasal airflow, and nasal air-conditioning of human's closest being, the chimpanzee, has never been reported.

Nowadays the chimpanzee is regarded as an endangered species which requires specific care and interest. The spread of respiratory infectious diseases is among the crucial dangers to chimpanzees. Addressing the nasal airways, which are the most superior organ of breathing system, is essential for pathologists involved in chimpanzee's medicine. The study of nasal cavity, nasal airflow patterns, and nasal air-conditioning distributions can be a prerequisite to understand chimpanzee's nasal physiology.

The aim of this research is to understand fundamentally the anatomy, inspiratory airflow, and air-conditioning physics of chimpanzee nasal passages. Because the lack of details on the chimpanzee nasal topology, we reconstructed a three-dimensional computer model of the chimpanzee nasal airways based on CT scans.

A detailed description of the nasal anatomy was given based on representative coronal cross-sections of the chimpanzee computer nasal model. An inhalation phase of the airflow was simulated and detailed analysis of the airflow structure within the chimpanzee nasal cavity was reported. The distribution of air-conditioning into the chimpanzee nasal cavity was investigated in distinct sections of the nasal passages, and a comparison of nasal air-conditioning performance between human and chimpanzee was considered.

The results of this study revealed a triangular shaped nasal geometry, as seen from side view, remarkably long and high enough for an efficient air-conditioning. The airflow structure inside the chimpanzee nasal cavity depended on the nasal topology. The inspiratory flow accelerated through the nasal valve, which displayed the smallest cross-sectional area. We noticed the existence of an anterior ventral vortex in the nasopalatine duct region and a dorsal vortex in the olfactory region. We attributed the appearance of both vortices to the increasing of the cross-section in the nasal valve area.

The protrusion of turbinates inside the nasal airways promotes a streamlined airflow in the central nasal passage. The horizontal nostrils and nasopharynx produced a horizontally straight airflow streamlines during inhalation. The computational fluid dynamics model revealed that the inhaled air flows at larger volume and higher rate in the middle airways of the nasal passage, while only small proportion reached the inferior meatus that was created following the protrusion of the inferior turbinate. The superior airways, where the olfactory epithelium is located, passes the least flow at lowest velocity. The minor airflow rate noticed in the dorsal upper part of the nasal cavity reflects a defense strategy that guards the sensitive olfactory nerves to be damaged. The observed vortex in the upper dorsal area of the nasal passage, near the olfactory region, appeared to distract airstreams at high velocity away from the olfactory epithelium.

Simulation of air-conditioning distribution showed that temperature and humidity were gradually adjusted in the middle part of the nasal passages, leading to a conditioned inhaled air at the nasopharynx region. Within the central nasal passages, the air-conditioning was quickly established and adjusted in the regions adjacent to and/or surrounded by the nasal lining such as the meatuses as the heat and water can be immediately exchanged between the tissue layer and the air stream via the epithelial layer, in contrast to the air flowing in the middle passage. No effective air-conditioning was observed within the frontal region of the nasal vestibule. We attributed this fact to the long horizontal nostrils of chimpanzee that are not highly vascular mucous lined airways, consequently cannot provide an ease exchange for heat and water transfer with the inspiratory flow stream. The Chimpanzee's nostrils luminal wall is lined by a squamous layer.

***Keywords:*** Numerical simulation, Chimpanzee nasal cavity, Computational fluid dynamics, Nasal airflow, Nasal air-conditioning.

## 論文審査の結果の要旨

本論文は、チンパンジーの頭部 CT 画像データを基に、チンパンジーの鼻腔の 3 次元形状モデルを構築し、これを元にした鼻腔内の気流、温度・湿度分布特性に関する数値流体力学的シミュレーションを行い、ヒトの特性との比較検討を詳細に与えた。特に高温地帯で生息するチンパン

ジーが鼻から吸気した高温の呼気を肺に到達するまでの間に鼻腔内で冷却するよう進化･適応させてきた ventilation system の特性について詳細に解析している。

鼻から吸気した呼気の温度を調節するには鼻腔内の湿度分布と経路長及び経路構造が重要になる。本論文はチンパンジーの頭部 CT 画像データを基にこれら 3 つの主要な要素に注目して、鼻腔内を流れる空気の温度がどのように変化するかを数値流体力学シミュレーションにより明らかにした。その特徴として、1）鼻腔内で呼気温度を下げるためには十分な経路長が必要となるが、頭部の限られたスペースに納めるために経路が大きく蛇行している。その構造は温暖なところで発達してきたヒトのものとは大きく異なっている、2）蛇行した鼻腔経路内で呼気は鼻腔壁の湿度により徐々に冷却されるが、蛇行経路特性により流速と方向が影響を受け、空気密度が一様ではない。このため温度分布も一様ではないが、鼻腔を進むにつれて蛇行した経路により空気が混ぜられ平滑化される、等の新しい知見を与えている。

チンパンジーは個体数が激減しており絶滅が危惧されている。これは人によりチンパンジーの生息域が奪われ、生存に適しない環境に追いやられていることが主因といわれている。樹木の伐採により食物の取得が困難になる上、より高温地帯あるいは低温地帯に追いやられると、それまで進化･適応してきたチンパンジーの生体特性が新たな環境に適応できなければ、絶滅は避けられない。このためチンパンジーの生体特性の解明が急務であり、本論文はこれに取り組む重要かつユニークなものである。

以上、本論文は CT 画像データを基にチンパンジーの鼻腔構造とこの中を流れる空気の温度及び湿度の特性を定量的に解析する新しいモデルを提案しており、学術に貢献するところが大きい。本モデルにより、個体、性別および地域毎の特性の差違を解析できるのでチンパンジーの保護に寄与するところが大きい。よって博士（情報科学）の学位論文として充分価値あるものと認めた。