

Comparative investigations of anatomy and physiology in mammalian noses (Homo sapiens - Artiodactyla)*

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SUMMARY

Background: Knowledge of airflow in animal noses is sparse. Such knowledge could be important for selection of animal models used in environmental studies. From the phylogenetic and ontogenetic point of view, a comparison between the animal and human nose is interesting.

Method: Nose models of 5 even-toed ungulate species (he-goat, sheep, cow, roebuck, wild boar) and two humans (new born infant and adult) were examined. Anatomical and physiological features of the nasal cavities of all species were compared. All models were rinsed with water and the flow was visualized for observation. Geometric and rhinoresistometric measurements were then performed.

Results and Conclusions: Even-toed ungulates have two turbinates directly in the main part of the nasal airflow (respiratory turbinates) and a different number of turbinates in a so-called dead space of the nasal airflow above the nasopharyngeal duct (ethmoidal turbinates). The latter correspond with the upper and middle turbinate in analogy to the human nose. Respiratory turbinates of even-toed ungulates insert immediately behind the external nasal ostium. Thus, the whole nasal cavity acts as a functional area with the exception of a small area acting as dead space only detectable in ruminants, possibly indicating a small evolutionary progress from suinae to bovidae.

The shape of the animal nasal cavity is stretched and flat. The airflow runs nearly completely turbulent through the nose.

The nasal cavity in the adult human is relatively short and high. The area between the external nasal ostium and the head of the inferior turbinate is called inflow area. It distributes the airflow over the whole nasal cross section and generates a turbulent flow. So the airflow is prepared to contact the mucosa in the functional area (turbinate area). The morphology of the inflow area is approximately formed by the shape of the external nose.

The nasal cavity of a newborn child is also stretched and flat and more similar to the nasal shape of the investigated animals. The inflow area in the newborn nose is not yet developed and corresponds with the growing external newborn nose.

One can hypothesize that the inflow area in human noses is a morphological adaptation in the changed length-height-ratio of the nasal cavity.

Key words: nose, nasal flow, animal, respiratory function, anthropology, rhinoresistometry

INTRODUCTION

Investigations of airflow in the human nose were first performed over 100 years ago⁽¹⁾. In literature, the flow quality (laminar, semi-turbulent, and turbulent) is assessed differently⁽²⁻⁵⁾. With the exception of a few case studies, respiratory function of animal noses has not been investigated^(6,7). Such knowledge could help to improve understanding the concept of morphology and function in human noses. At the same time, this

knowledge would allow to select appropriate animal models for environmental medical investigations⁽⁷⁾.

During the evolution of the mammals, and especially the change to erect position of mankind, it is probable that changes in the anatomy and physiology of the nose have happened, which may be mirrored in the nasal functions as to olfaction, cleaning, humidifying and tempering the respiratory air.

The aim of the study was to compare nasal anatomy and some respiratory nasal functions of five selected even-toed ungulate species with the nose of a newborn infant and of an adult using their nasal models.

METHOD

Samples

To verify evolutionary changes of the nasal anatomy and function due to erect position in comparison to humans, we chose mammalian animals restricted to quadrupedal movement. Even-toed ungulate species were easily accessible due to their economic importance, thus enabling us to evaluate closely related families. We included the suborder ruminantia (he-goat, sheep, cow, roebuck) and suina (wild Boar) into our study. For comparison, nose models of two humans (new born infant and adult) were evaluated.

Model manufacturing

All noses underwent an endoscopic investigation to exclude significant endonasal pathology. Using silicone rubber (Otoform A®, Dreve Otoplastik, Unna, Germany), we took casts of the internal nose from the non-fixed animal and human corpses. The nose models were manufactured by a moulding technology from silicone into transparent resin from Weitur ST® (Johabbes Wethas, Lütjenburg, Germany).

The models were labelled according to the origin in the following way:

- I. Human (adult): the model corresponds to the nose of a 62 year old man (Caucasian population).
- II. Human (newborn infant): the model corresponds to the nose of a 12 day old infant (Caucasian population).
- III. Roebuck: the model corresponds to the nose of a 3 year old roebuck.
- IV. Sheep: the model corresponds to the nose of a 5 year old sheep.
- V. He-goat: the model corresponds to the nose of a 10 year old he-goat.
- VI. Cow: the model corresponds to the nose of a 18 year old cow.
- VII. Wild boar: the model corresponds to the nose of a 2 year old wild boar.

All models were measured geometrically and functionally. The geometrical measurement included at first the longest distance of the nose in the anterior-posterior direction, with the dorsal measure point being situated above the nasopharyngeal duct (nasal length). The second measured parameter was the longest distance between the nasal bottom and the roof (nasal height).

From both measured values, the length-height-ratio was calculated. The anatomical features of the seven models were described including some of their metric data (Table 1).

Stream observation

Water was run through the models of the nasal cavity in inspiratory direction. Flow velocity of air was calculated by the help of Reynolds law.

The observation of the stream behaviour was performed accordingly to an airflow-velocity of 50 to 500ml/s. Streamlines were visualized with the help of dye injection into the water. For all examinations, video documentation was employed. A detailed description of the method of these fluid dynamic experimentals can be found in Mlynski et al. ⁽⁸⁾.

Rhinoresistometry

For the functional diagnostic of the models, we used the rhinoresistometer Resi 1® (Stimotron, Wendelstein, Germany). Rhinoresistometry is an objective measurement method. Analogous to anterior rhinomanometry, it measures the pressure difference and the flow during respiration. Special software calculates additional parameters, such as: flow resistance depending on the flow, degree of turbulence depending on the flow, hydraulic diameter as a parameter of width and drag coefficient *l* describing the wall condition causing turbulence ⁽⁹⁾.

RESULTS

Anatomical considerations (Figure 1)

Several anatomical differences can be observed between human, ruminants and suiformes. The pig has a unique additional prenasal bone together with accordingly changed lateral cartilages, supporting the tip of the nose and giving it its unique configuration in comparison to ruminants and humans. Endonasally, we were unable to detect a nasal valve equivalent in all examined animals. In the infant, the nasal valve is much less pronounced in comparison to the adult nose. In all investigated artiodactyla species there are two turbinates in direct respiratory airflow (concha nasalis ventralis and dorsalis), as well as a different number of turbinates (ethmoidal turbinates) above the nasopharyngeal duct. The latter are predominantly covered with olfactory epithelium (regio olfactoria) and are parts of the ethmoidal bone. The ethmoidal turbinates correspond with the superior and middle turbinate of the human ^(10,11). In humans, there sometimes exists an additional concha nasalis suprema (concha Santorini).

The largest respiratory turbinate of the even-toed ungulate is the maxillary turbinate (concha nasalis ventralis). It inserts

Table 1. Morphometric data of animals and humans used for taking nasal models.

	Human			Ruminantia			Suina
	Adult	New born infant	Roebuck	Sheep	He-goat	Cow	Wild boar
Age (y)	62	0,03	3	5	10	18	2
Height /Shoulder height [cm]	177	54	69	76	75	138	62
Body weight [kg]	83	3.5	16.5	63	62.5	562	71
Body Mass Index	26	12	34.6	109	111.1	295.1	184.7

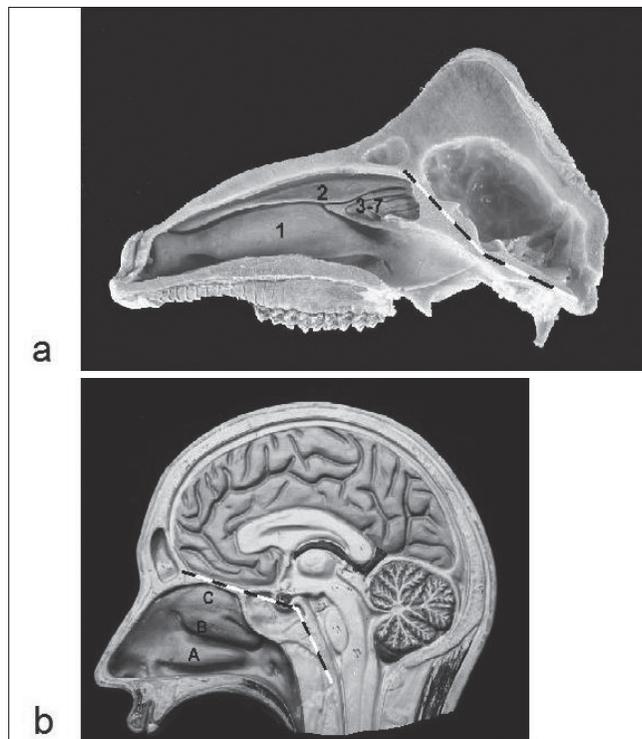


Figure 1. a) Paramedian section through a sheep head. 1- Concha nasalis ventralis ; 2- Concha nasalis dorsalis; 3-7- ethmoidal turbinates; Dotted line- angle of the cranial base (klinorhynch). b) Paramedian section through a human head. A- Concha nasalis inferior (inferior turbinate); B- Concha nasalis media (middle turbinate); C- Concha nasalis superior (superior turbinate); Dotted line- angle of the cranial base (klinorhynch).

directly in the lateral wall of the external nasal ostium. This turbinate has its own bone (os turbinale), similar to the inferior turbinate in the human nose. In suinae, the turbinates show a simple helical formation, whereas ruminants have additional cells embedded into the turbinate structure⁽¹²⁻¹⁴⁾.

The position of the lamina cribrosa as part of the skull base differs between humans and animals: in the animal species, the lamina goes in a more vertical direction, whilst in human the lamina goes in a more horizontal direction. The length-height-ratio of the nose is smallest in the human adult, and larger in the human infant and in all of the investigated animals (Table 2).

Table 2. Morphologic und rhinometric results.

Model	Morphologic results				Rhinoresistometry		
	Number of ethmoidal turbinates (regio olfactoria)	Length [mm]	Height [mm]	Length-height-ratio	Hydraulic diameter (dh) [mm]	Flow resistance (inspiratory) at 150 Pa [sPa/ml]	Lambda (inspiratory)
I	1	78	40	1.95	7.38	0.13	1.9
II	1	28	11	2.55	1.93	2.76	3.1
III	5	102	30	3.4	7.22	0.19	4.3
IV	5	184	78	2.36	9.17	0.13	2.9
V	5	145	51	2.84	9.58	0.11	1.5
VI	5	290	71	4.08	12.58	0.11	1.5
VII	8	230	40	5.75	5.35	0.13	1.5

Flow observations

I. Human (adult): At all flow-velocities, we observed a distribution of the airflow over the entire nasal cavum. For air flow velocities of 50 ml/s, the airflow was purely laminar. At a flow of 100 ml/s, a semiturbulent flow was found. A predominantly, turbulent airflow was observed at more than 300 ml/s (Figure 2).

II. Human (newborn infant): There is a distribution of airflow over the entire cavum. At a flow of 50 ml/s, the airflow was predominantly turbulent (Figure 3).

III. Roebuck: The flow is distributed over the complete nasal cross sectional area. The region above the nasopharyngeal duct is little ventilated. At a flow of 50 ml/s, semiturbulent flow is found. At 200 ml/s and more, the stream was recognised as predominantly turbulent (Figure 4).

IV.-VI. Sheep, he-goat, cow (Bovidae): In all models, we found an almost identical stream behaviour. There was a flow distribution over the complete nasal cross sectional area. The area above the nasopharyngeal duct was not directly ventilated. Sporadically, colour particles appeared in this area, suggesting this region as dead space according to flow physical nomenclature. At a flow velocity of 50 ml/s and more, airflow was predominantly turbulent.

VII. Wild boar (suinae): The whole cavum nasi showed flow without evidence for regions acting as dead space. In the cranial and dorsal region, there is minor ventilation (above the nasopharyngeal duct). At 50 ml/s, we found semiturbulent flow. At 100 ml/s and more, airflow was predominantly turbulent.

Rhinometric data

In animals, hydraulic diameter correlates with shoulder height (Pearson’s correlation coefficient: 0.844; $p < 0.048$), but not significantly with body mass index. The flow resistances at 150 Pa were nearly irrelevantly different in all models, with the exception of the newborn infant nose. Lambda, describing the nasal wall condition causing turbulence, was relatively small in noses showing large dimensions (cow and he-goat), whereas in small dimensional noses, lambda was relatively high (newborn infant, roebuck). Furthermore, we found a significant negative correlation for Lambda with body mass index (Pearson: -0.894; $p < 0.41$) for all models investigated.

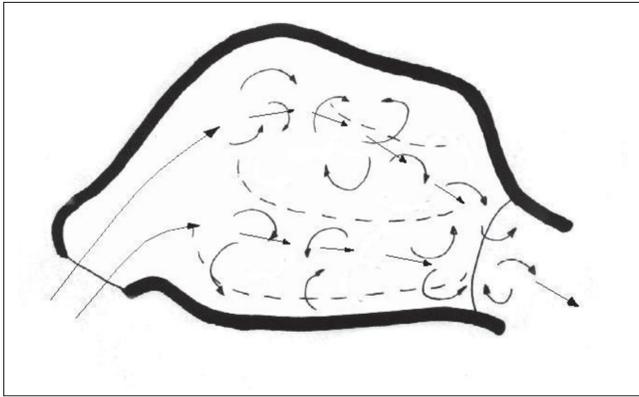


Figure 2. Flow pattern in model I (adult) at a flow of 100 ml/s. straight arrow: laminar flow; curved arrow: turbulent flow.

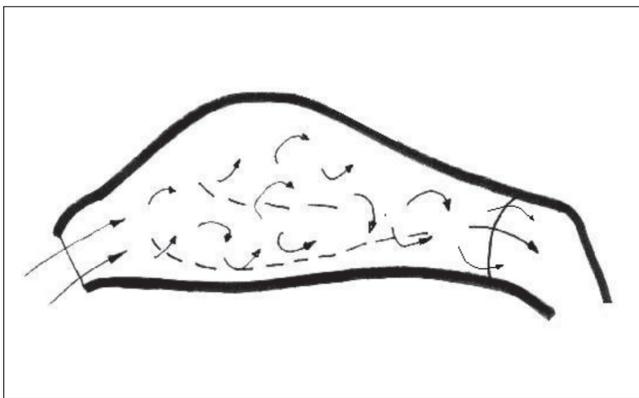


Figure 3. Flow pattern in model II (newborn) at a flow of 100 ml/s. straight arrow: laminar flow; curved arrow: turbulent flow.

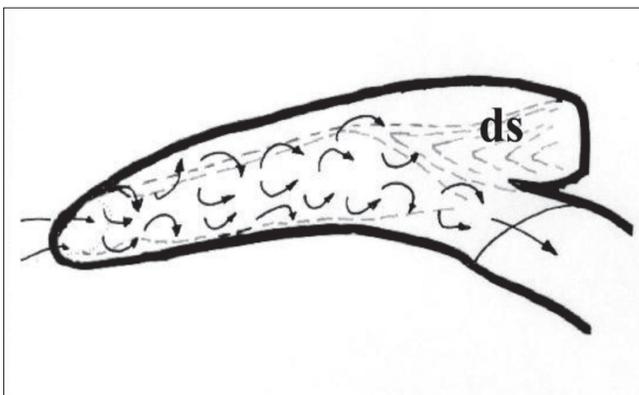


Figure 4. Flow pattern in model III (roebeck) at a flow of 100 ml/s. straight arrow: laminar flow; curved arrow: turbulent flow. ds-dead space.

DISCUSSION

As to the best of our knowledge, this is the first study to investigate the nasal flow in a human newborn and in five adult animals using a model of the respective noses and to compare these models with that of a human adult.

The investigated animal species belong to the order of even-toed ungulate or artiodactyla. These are subdivided into two underorders: nonruminantia (suiformes or pigs) and ruminantia⁽¹⁰⁾. Phylogenetically oldest are primitive representations of artiodactyla known as the nonruminantia. Anatomical evolu-

tionary differences of ruminantia and suiformes with respect to the nose include cells embedded into the turbinates and differences of the nasal tip.

The shape of the nasal cavity of artiodactyla, as in most other animals, seems to be stretched and flat. A prominent external nose, typical for humans, only exists rudimentary in the investigated animals. In correspondence, the nasal valve is lacking in the animals evaluated in comparison to the human adult nose and is not completely developed in the infant nose. The nasal length-height-ratio of the investigated species showed a wider variety. The biggest was found in the wild boar and the smallest in the adult human. The latter is also much smaller than the newborn infant.

Nasal proportions in human are obviously changing during ontogenesis. Only the adult human shows the typical short and high nasal cavity (Table 2). From our perspective, these anatomical observations led to the following hypothesis: to achieve distribution of air flow across the complete mucosal surface, evolutionary refinement of the inflow area has led to the development of the nasal valve.

The human cranial skull base shows a typical bending shape, caused by development of the erected walk and considerably increased size of the cerebrum. It has been described as a bending of the facial skeleton in relation to the cranial skull base towards the ventral side, also known as klinorhynch^(15,16). This leads to a ventral rotation of the lamina cribrosa. Thus, in the animal species the lamina goes in a more vertical direction, whilst in human the lamina goes in a more horizontal direction.

The olfactory sense is the phylogenetically oldest function of the nose⁽¹⁴⁾. Development of respiratory function came during the evolution to the foreground. So, it is to suppose, that the olfactory region in less evolved species needs a larger area than in highly evolved species. This can be reflected in the number of ethmoidal turbinates, carrying olfactory epithelium⁽¹⁰⁾. Pigs (wild-boar) have 8, ruminantia 5, and human 2 ethmoidal turbinates⁽⁶⁾. In this way, it seems possible to assess the stage of evolutionary development of the investigated species by counting the ethmoidal turbinates.

For the respiratory function of the nose, low nasal resistance is important to allow nasal breathing. Additionally, the nose works as pre-resistance for the lungs and prevents collapsing of the alveoles. This may explain why the flow resistances in the investigated nose models did not differ significantly, even though the dimensions of the nose models differed clearly. Due to its small size and its very small hydraulic diameter, the newborn infant nose is an exception. Sufficient contact between mucosa and respiratory air allows the exchange of substances and energy. This is a further property of the respiratory function of the nose. The whole respiratory epithelium should be ventilated and the air particles should come into contact with the mucosa. This is realised of course through a large mucosal

surface (turbinate region) and turbulent air flow⁽¹⁷⁾. In the investigated animals, the ventral turbinate inserts immediately at the external nasal ostium. The complete nasal cavity works as a functional area (turbinate area) in suinae, whereas in ruminants, only a small area above the nasopalatine duct was detected acting as dead space. In noses with this type of flow pattern, aspiration of air in its turbulent state makes sense to achieve optimal mucosal contact.

The difference in the flow pattern of suinae and ruminants, with development of dead space leads us to hypothesize that development of a dead space endonasally may be an indirect sign of evolutionary progress. Investigations of more animals of various orders are needed to verify this hypothesis.

In the human nose, the area from the external nasal ostium up to the head of the inferior turbinate is called the inflow area. This area distributes the air flow over the complete, relatively high nasal cross sectional area and generates a turbulent flow.

The inflow area is located in the external nose^(17,18). In animal noses, such an area is missing. Thus, it is to suppose, that the inflow area and the prominent external nose is the result of an adaptation to the short and high nasal cavity in human.

In the newborn infant nose, the flow was predominantly turbulent at 50 ml/s. The cavum nasi has a length-height-ratio of 2.55 and was stretched and flat. Also the newborn's external nose was very small and in this respect similar to the noses of the investigated animals. Thus, the newborn's nose mirrors the stage of an earlier evolution, but will reach a higher evolutionary stage after finishing its growth period and ending up in the adult's nose.

CONCLUSIONS

1. Conditions for the respiratory function of the nose are an intensive contact between breathing air and respiratory epithelium. In all investigated species this contact takes place in the functional area of the nose, i.e. the area of the turbinates.
2. The relation between nasal length and nasal height appears to have been reduced during evolution. This is also mirrored in human ontogenesis.
3. In the human, the area between the external nasal ostium and the head of the inferior turbinate is the inflow area. This area distributes the flow over the complete nasal cross sectional area and generates turbulent flow. The inflow area in the human nose is an adaptation to the relatively increased nasal height during evolution.
4. In the noses of the investigated animal species an inflow area does not exist. In these noses, the respiratory air is aspirated predominantly turbulent. The largest respiratory turbinate inserts directly in the lateral wall of the external nasal ostium. Thus, the whole nasal cavity is working as a functional area, with the exception of a small area acting as dead space. The existence of the dead space may be the result of an earlier evolutionary progress.
5. Depending on the stage of development in evolution a dif-

ferent number of ethmoidal turbinates is found. So we suppose that the smaller the number of ethmoidal turbinates, the higher the stage of development.

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