Two-Dimensional Geometric Morphometric Analysis of Nasopharyngeal Shape

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INTRODUCTION

The nasopharynx is an important anatomical structure of the upper respiratory tract, which functions in respiration, vocalization, and deglutition. Understanding variations in nasopharyngeal anatomy is essential for otorhinolaryngologists, as alterations in its shape have severe clinical implications. For instance, a reduction in nasopharynx transverse diameter can affect upper respiratory airway patency increasing the risk of developing sleep disorders (Rodenstein et al., 1990). Schellenberg et al. evaluated 420 patients and found that narrowing of the airway by the lateral pharyngeal walls is associated with an increased likelihood of obstructive sleep apnea (OSA) (2000). The prognathic and vertically short faces of chimpanzees contain airways that are anteroposteriorly elongated, vertically short, and more anteriorly opened nostrils which mean reduced airway diameters leading to higher velocity and lower pressure than in the taller and shorter airways in humans (Bastir et al., 2021). The evolution and development of the nasopharynx have been associated with the developmental influence of the large *Homo* brain (Bastir & Rosas, 2016; Lieberman et al., 2000). However, there is limited research on the adaptive changes in the structure of the nasopharynx and its influence on physiological processes. This study aims to assess the shape variation of the nasopharynx and its relationship to nasopharyngeal size to understand adaptive changes better.

METHODS

We collected two-dimensional coordinate data on 10 to 15 transverse CT slices from 69 Rhesus macaques from the California National Primate Research Center. We used ImageJ to collect landmark coordinates of clearly identifiable hard tissues demarcating the maximum anteroposterior and transverse breadths of the nasopharynx (Figure 1) (Schneider et al., 2012). We analyzed the trajectory of shape change along the nasopharyngeal tract using geometric morphometrics methods and assessed the relationship of size to shape using linear regression. Homologous landmarks were standardized with Procrustes superimposition to a common orientation. Principal Component Analysis (PCA) was used to assess variation in shape space for the dataset using MorphoJ (Klingenberg, 2011).

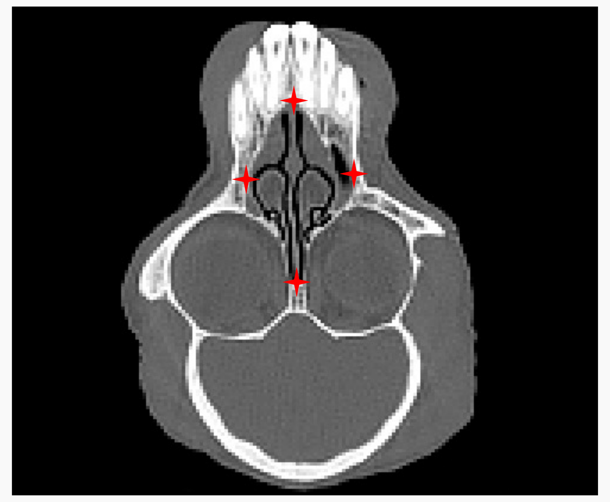

Figure 1 demonstrates the landmark coordinates used to measure the maximum anteroposterior and transverse breadths of the nasopharynx. Each CT image had the same number of landmarks placed in the same order. If hard tissue was not visible, landmarks would be placed in an estimated position.

RESULTS

The nasopharyngeal airway of Rhesus macaques tends to increase transversely in size caudally, changing from narrow diamond-shaped to triangular-shaped (Figures 2-4). Individuals vary in the location of the shape change of the nasopharynx. Shape is significantly associated with size in the nasopharynx but only in the upper regions of the tract ($p < 0.001$ upper, versus $p=0.198$-0.579 lower) (Figures 5-6).

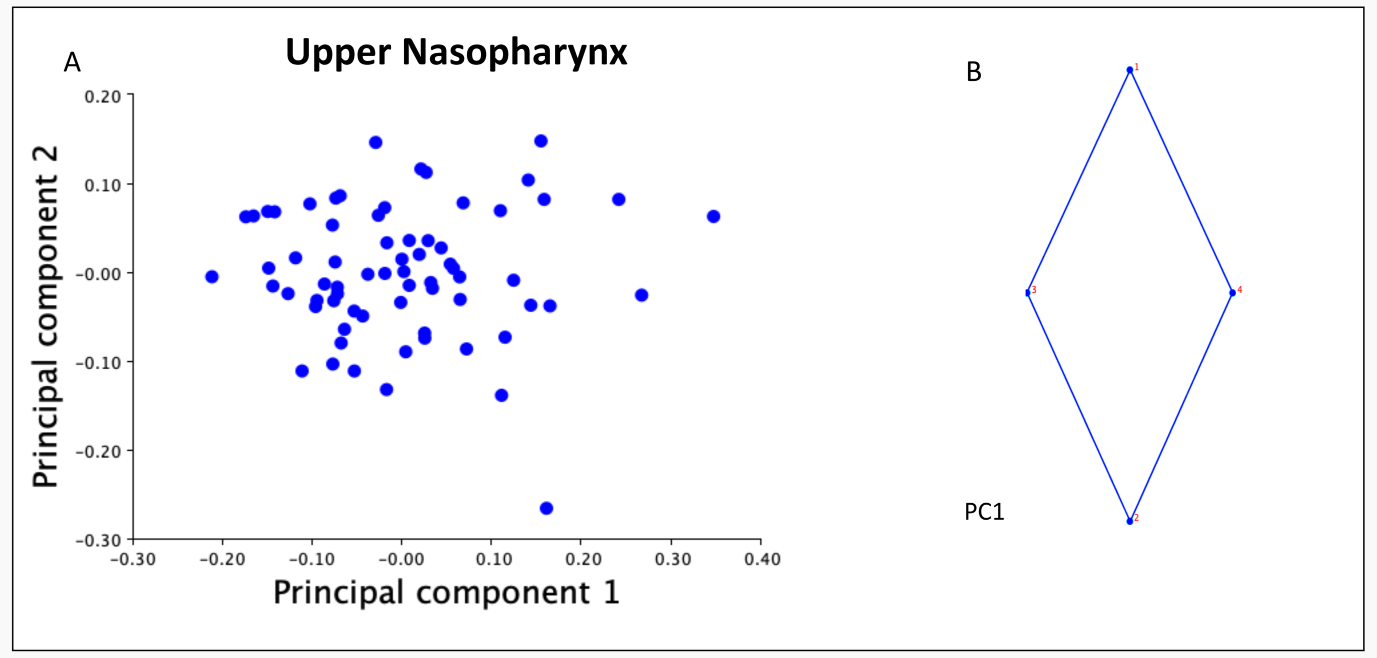

Figure 2 PCA plot of PC1 (69% variance) and PC2 (31% variance) assessing shape at the upper part of the nasopharynx. Each dot represents the shape of a single individual from our data set (A). The wireframe graph represents the mean shape of nasopharynx at the upper part of the nasopharynx (B).

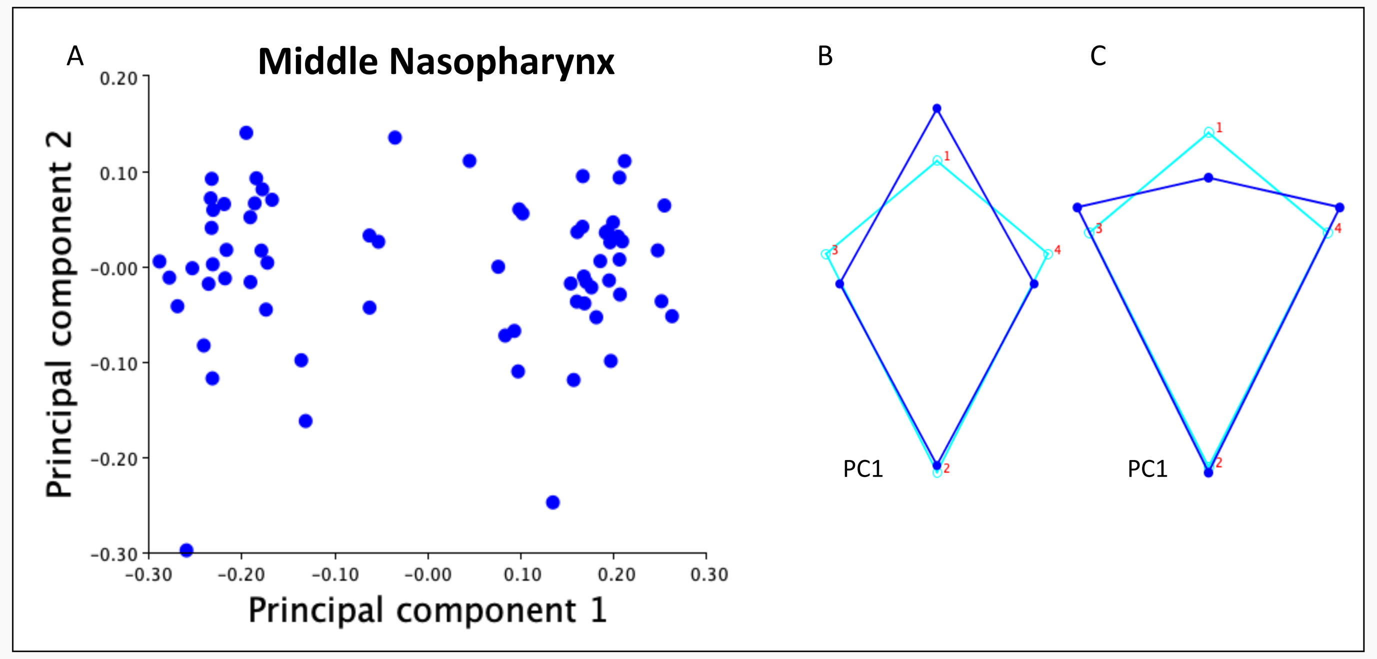

Figure 3 PCA plot of PC1 (85% variance) and PC2 (15% variance) assessing shape at the middle part of the nasopharynx. Each dot represents the shape of a single individual from our data set (A). The wireframe graphs represent the mean shape of middle part of the nasopharynx at scale factor -0.25 (B) and at scale factor 0.2 (C).

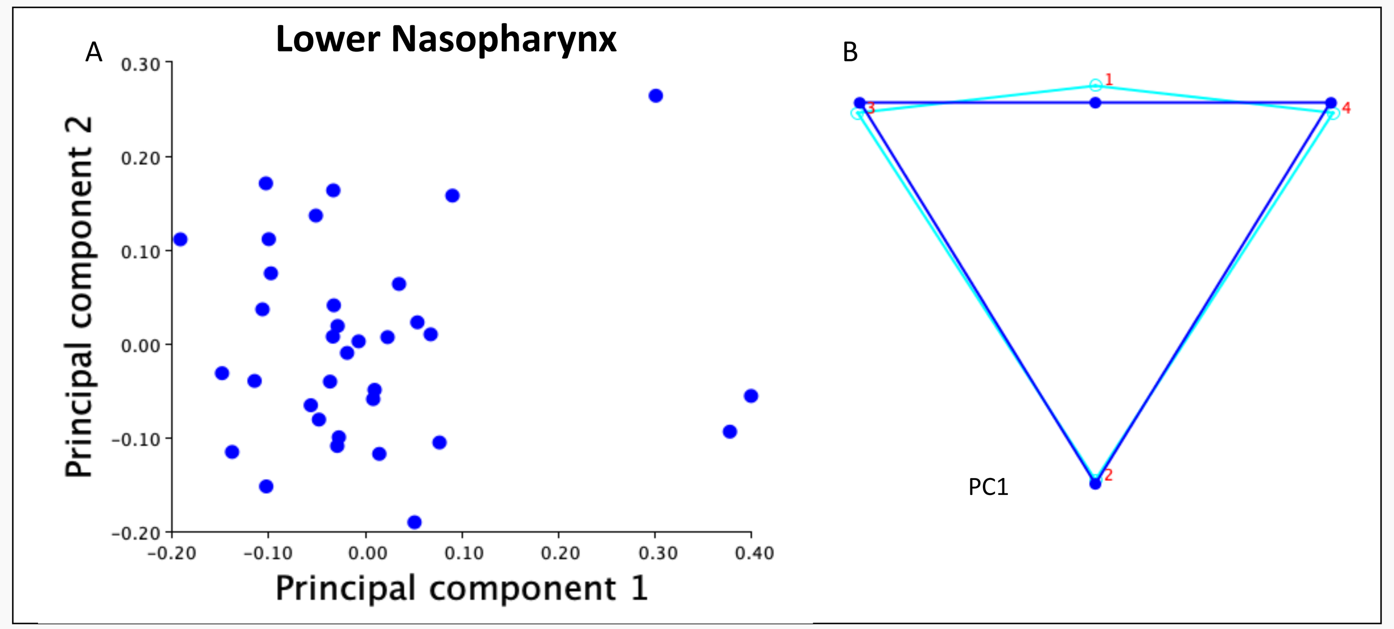

Figure 4 PCA plot of PC1 (62% variance) and PC2 (38% variance) at the lower part of the nasopharynx. Each dot represents the shape of a single individual from our data set (A). The wireframe graph represents mean shape of the lower part of the nasopharynx (B).

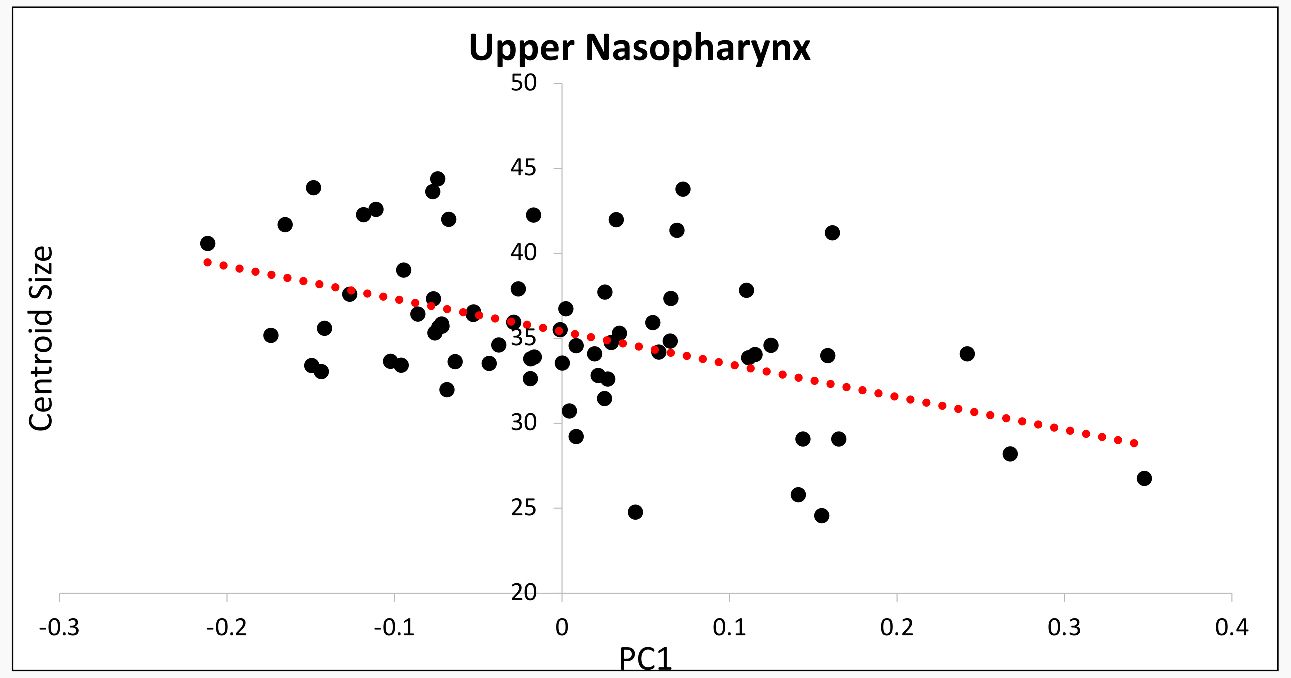

Figure 5 Linear regression of PC1 vs Centroid Size at the upper part of the nasopharynx. We found a significant relationship ($p<0.001$) between PC1 and centroid size ($R^2=0.215$).

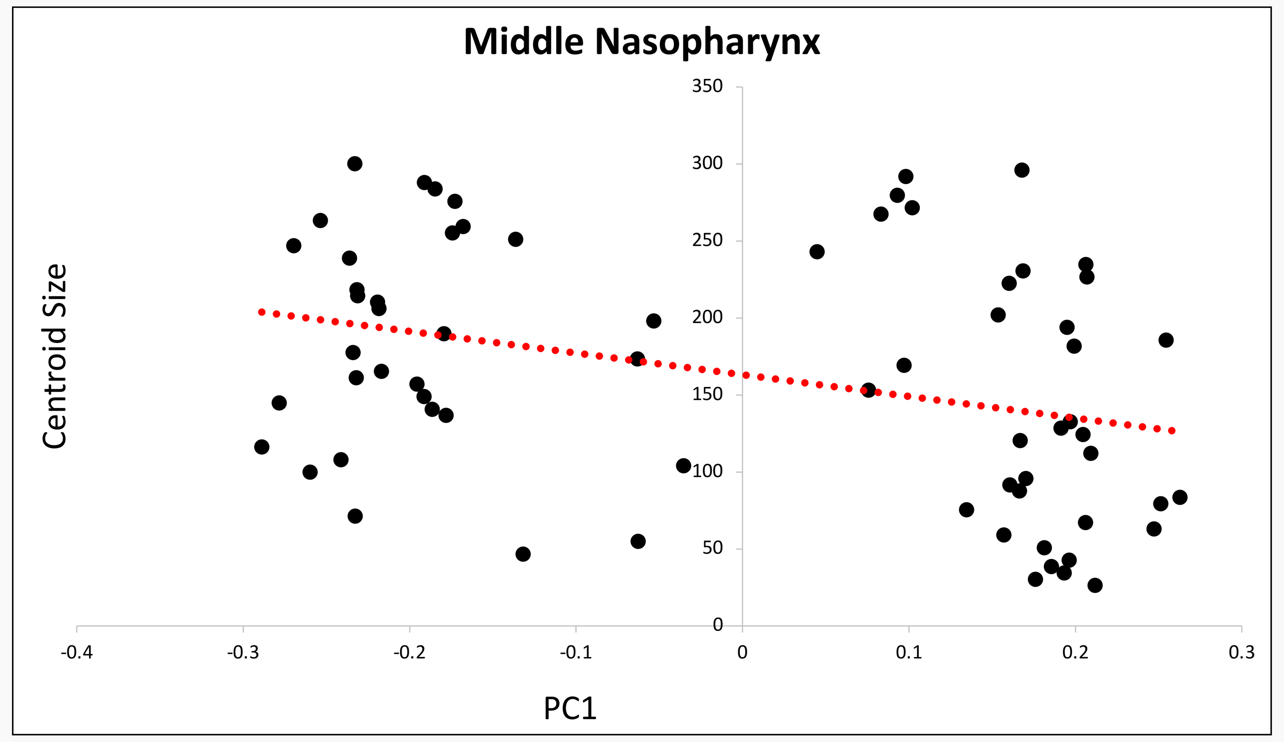

Figure 6 Linear regression of PC1 vs centroid size at the middle part of the nasopharynx. We found a significant relationship ($p<0.05$) between PC1 and centroid size ($R^2=0.112$).

CONCLUSION

Our results suggest that there is a significant relationship between shape and size only in the cranial end of the nasopharynx. We observed that the maximal transverse breadth changes caudally and the location of shape change of the nasopharynx varies. The variation in transverse breadth may translate to altered respiratory functions. In humans, individuals with OSA have smaller pharyngeal size than those without (Walsh et al., 2008). In Apert syndrome patients, a reduced nasopharyngeal space in three dimensions presents as stridor and sleep apnea, which reflects a functional problem (Peterson-falzone et al., n.d.). By recognizing this relationship, clinicians can be on the look-out for potential upper respiratory pathologies arising from morphological variations in the cranial aspects of the nasopharynx. Early recognition can lead to better prognosis and therapeutic options in these patient populations.

FUTURE DIRECTIONS

We aim to conduct a three-dimensional geometric morphometric analysis of the nasopharynx in Rhesus macaques to further assess volume and area variation of the nasopharynx and its clinical implications.

ACKNOWLEDGEMENTS

We would like to thank the California National Primate Research Center for providing access to their CT data.

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