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Numerical study of the effect of the nasal cycle on unilateral nasal resistance

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ABSTRACT

We used computational fluid dynamics to study the effects of the nasal cycle on the modification of unilateral nasal resistance using nasal cavity models from 2 different patients with chronic rhinosinusitis. A steady airflow field with an inspiratory flow rate of 250 mL/s was simulated using ANSYS-FLUENT v14.5. The distribution of local unilateral nasal resistance showed different shapes of variation and magnitudes of resistance depending on the distribution of cross-sectional area in the nasal cavity models. The highest local resistance on the congested side was found near the nasal valve area in the first patient, whereas the highest value was found in the nasal vestibule for the second patient. The relative importance of nasal resistance in the turbinated air passage differed for the 2 patients. The unilateral resistance of the congested state was in the range of 0.0229–0.221 Pa s/mL. In the inferior meatus, greater flow rate was allowed during the congested state than during the decongested state if an extensive backflow developed.

1. Introduction

The term nasal cycle has been used to refer to the spontaneous and often reciprocal changes in human nasal airflow since Kayser (1985) first reported the cyclic repetition of congestion and decongestion states in the nasal cavities. According to an early study on 60 healthy volunteers by Heetderks (1927), a definite cycle of reaction was found in approximately 80% of cases. This was later consistently observed by both Stoksted (1953) and Hasegawa and Kern (1978). Several studies have reported that some patients exhibited reciprocal changes in unilateral nasal patency, leading to relatively constant total nasal patency, whereas others exhibited irregular changes (Hasegawa and Kern, 1978; Moore and Eccles, 2012). Thus, the nasal cycle may be revealed in various ways in terms of frequency, duration, alternating patterns, and the amplitude of the resistance. In fact, Moore and Eccles (2012), who reported a range of 0.01–2.4 Pa s/mL for unilateral nasal resistance in a non-decongested adult, pointed out that there is a great variation in both unilateral and total patency associated with the nasal cycle, depending on several factors, such as age, height, sex, breath rate, and the nasal shape and size related to climatic adaptation.

Our understanding of the physiologically relevant factors that may influence spontaneous changes associated with the nasal cycle is still incomplete (Moore and Eccles, 2012). However, the idea given by Eccles (2000), that the nasal cycle may act to share the burden of air conditioning between the 2 nasal passages so that the dominance of airflow alternates over the course of several hours, appears to be a useful hypothesis. In this context, investigation of the fluctuations in nasal patency associated with the nasal cycle has been the subject of previous clinical studies involving measurements of unilateral nasal resistance using rhinomanometry and acoustic rhinometry (Cole, 1997; Hasegawa and Kern, 1978; Knight et al., 1991; Lang et al., 2003; Stoksted, 1953).

On the other hand, the alteration of nasal resistance distribution associated with the nasal cycle has been explored in less depth. In addition to the quantitative data on the value of nasal resistance itself, information on the spatial variation of nasal resistance in the nasal cavity would be physiologically important in characterizing the nature of nasal resistance. Therefore, investigating the flow characteristics that influence the alteration of local unilateral nasal resistance could be useful in enhancing our understanding of the nasal cycle phenomenon. One of the few attempts to discuss flow physics is the experimental study conducted by Lang et al. (2003). They characterized the geometric configuration of the anterior cavum and the degree of increase in the cross-sectional area using acoustic rhinometry during each of the 2 phases of the nasal cycle. Due to the limitation of instrument, their description

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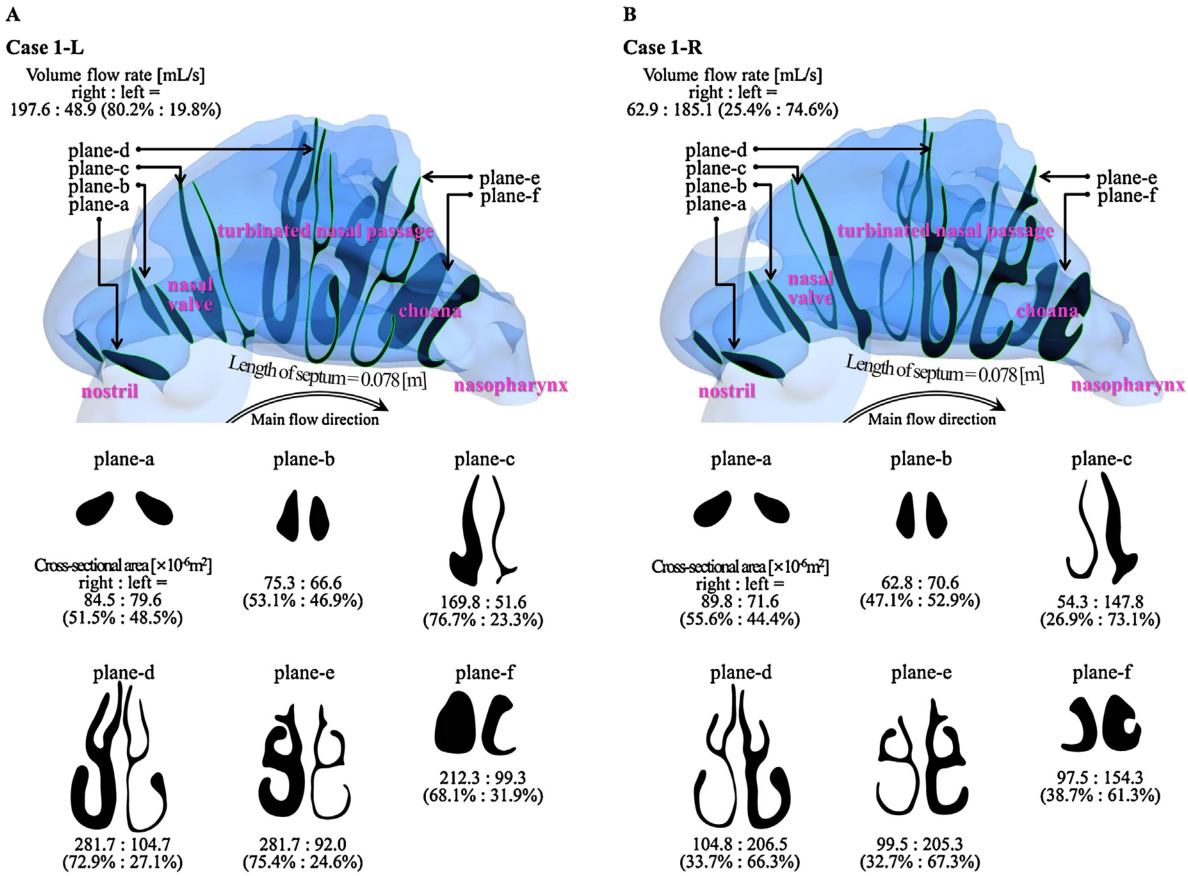

Fig. 1. Numerical geometry and 6 representative planes presenting computational results for Case 1. (a) Model Case 1-L with a congested left side. (b) Model Case 1-R with a congested right side.

of the detailed flow field was limited; they did, however, particularly assess the role of flow regime in the decongested phase in a systematic way. Patel et al. (2015) created preoperative and postoperative computational fluid dynamics (CFD) models for the first time by gradually changing the thickness of the inferior and the middle turbinates, as well as that of the septal swell body, to represent the nasal cycle. Since, they used postoperative CT scans to limit the congestion and decongestion of the turbinate in the preoperative nasal cycle model, the actual mucosal changes along the nasal floor, superior turbinate, and posterior septum might not have been well reflected in their model. As their CFD work focused on postoperative changes in the value of nasal resistance itself, the flow characteristics were discussed in less depth.

In the presence of a limited number of studies examining the variation of nasal resistance distribution in the nasal cavity during the nasal cycle, the CFD approach is expected to provide useful flow information for the study of the effect of nasal cycle on variations in nasal patency. In our study, anatomically correct numerical domains that represent both congested and decongested nasal cycle states, based on CT data from 2 patients, were analyzed using CFD to examine the spatial variation of nasal resistance associated with the nasal cycle. We assumed that a bilateral flow rate of 250 mL/s during inhalation would correspond to the resting breathing condition.

2. Numerical methodology

2.1. Construction of nasal cavity models

A cohort of 32 patients experiencing nasal obstruction was reviewed to select 2 patients (a 29-year-old male patient and a 34-year-old female patient), both of whom showed obvious reciprocal changes based on visual evidence from CT images obtained during a routine clinical procedure. Both patients suffered from chronic rhinosinusitis but did not have any history of surgical treatment for nasal obstruction. The geometric characteristics of the nasal cavities, showing both the congested and the decongested states of patient 1 (Case 1) and of patient 2 (Case 2) are displayed in Figs. 1 and 2. The model Case 1-L represents the nasal cavity of patient 1 with a congested state on the left side (Fig. 1a), whereas the model Case 1-R shows the nasal cavity with a congested state on the right side (Fig. 1b). Case 2-L and Case 2-R, shown in Fig. 2, also denote the congested states appearing in the left and the right sides of the cavity, respectively, of patient 2. Surface-rendered computational models of the nasal cavity from nostrils to nasopharynx, excluding the paranasal sinuses, were created using data from 0.65-mm CT scans of patients visiting the Samsung Medical Center, Seoul, Korea. Permission for this study was obtained from the Institutional Review Board of the Samsung Medical Center.

To present the simulation results, 6 representative 2-D planes were selected between the nostril and the choana, indicated in Figs. 1 and 2, for the examination of the local flow field. For the purpose of comparison in the presence of individual anatomical variation of the 2 patients, the distance along the airway from the nostril was normalized by the length of the septum of each nasal cavity. The 6 planes shown in Figs. 1 and 2 were selected in such a way that the corresponding planes of Cases 1 and 2 had the same normalized distance from the nostril.

Note too that these planes were selected so that they were approximately perpendicular to the local airflow, in order to facilitate a more effective investigation of the evolution of both flow and