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Numerical study on the effect of uncinectomy on airflow modification and ventilation characteristics of the maxillary sinus

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ABSTRACT

In this study, we examined the effect of uncinectomy on the alteration in local airflows and on the resulting effect on gas exchange in the maxillary sinus, by using computational fluid dynamics in two nasal cavity models: one with a preserved uncinate process, and the other with the uncinate process removed virtually. Uncinectomy distinctively changed the local flow topology by triggering the formation of counter-rotating vortices in the ostiomeatal complex, except for the instants with relatively low airflow rate when the respiration phase changed, ultimately leading to a change in the velocity field inside the ostium and maxillary sinus. Despite a significant increase in the maximum air velocity through the maxillary ostium, ventilation was found to increase only slightly when the uncinate process was removed. Furthermore, the degree of maxillary sinus ventilation by inhaled air was comparable to that by exhaled air. This was true to both models and was independent of the presence of the uncinate process.

1. Introduction

Since functional endoscopic sinus surgery (FESS) was suggested as an effective replacement for more radical sinus procedures in the 1970s (Messerklinger, 1978), the technique has been widely used to treat nasal obstruction resulting from refractory chronic rhinosinusitis (Kennedy, 1985; Schaefer et al., 1989). As noted by Stammberger and Posawetz (1990), the main physiological function of FESS is the re-establishment of sinus ventilation and drainage through the enlarged natural ostium. The technique often involves removal of the uncinate process, that is, uncinectomy. This procedure typically entails exposing the infundibulum for better visibility, excising some ethmoid cells, and performing a middle meatal antrostomy (MMA). The aim of the procedure is to achieve higher airflow into the ostiomeatal complex.

Because the posterior part of the uncinate process covers the openings of the neighboring paranasal sinuses, such as the maxillary sinus, removal of the uncinate process may increase maxillary sinus ventilation by allowing more airflow into the sinus during respiration (Kutluhan et al., 2011). Several recent computational fluid dynamics (CFD) studies have reported enhanced airflow into both the paranasal sinuses and the upper ethmoid and sphenoid sinus regions after FESS (Chen et al., 2012; Abouali et al., 2012; Xiong et al., 2011). However, these studies involved more extensive surgical interventions than uncinectomy alone.

Another important physiological concern is the conjecture that the uncinate process may play a protective role, such as preventing the deposition of foreign objects present in inhaled air (Hood et al., 2009; Nayak et al., 2001). It is therefore likely that while uncinectomy improves maxillary sinus ventilation, it interferes with the sanitary role of the uncinate process. Consideration of these two aspects, ventilation and protection, has led to controversy regarding the preservation versus removal of the uncinate process during the FESS procedure (Myller et al., 2011).

Until recently, CFD studies investigated uncinectomy only in combination with more extensive surgical interventions. These studies include those performed on a cadaveric head model (Xiong et al., 2011), simultaneous performance of MMA (Abouali et al., 2012; Chen et al., 2012), or those performed in the presence of an accessory ostium (Zhu et al., 2014). For this reason, to date, investigators have not been able to clearly isolate and describe the effect of uncinectomy alone in terms of ventilation and protection of the maxillary sinus. In addition, detailed information is still lacking regarding alterations to the local airflow field associated with uncinectomy. Such information would be physiologically impor-

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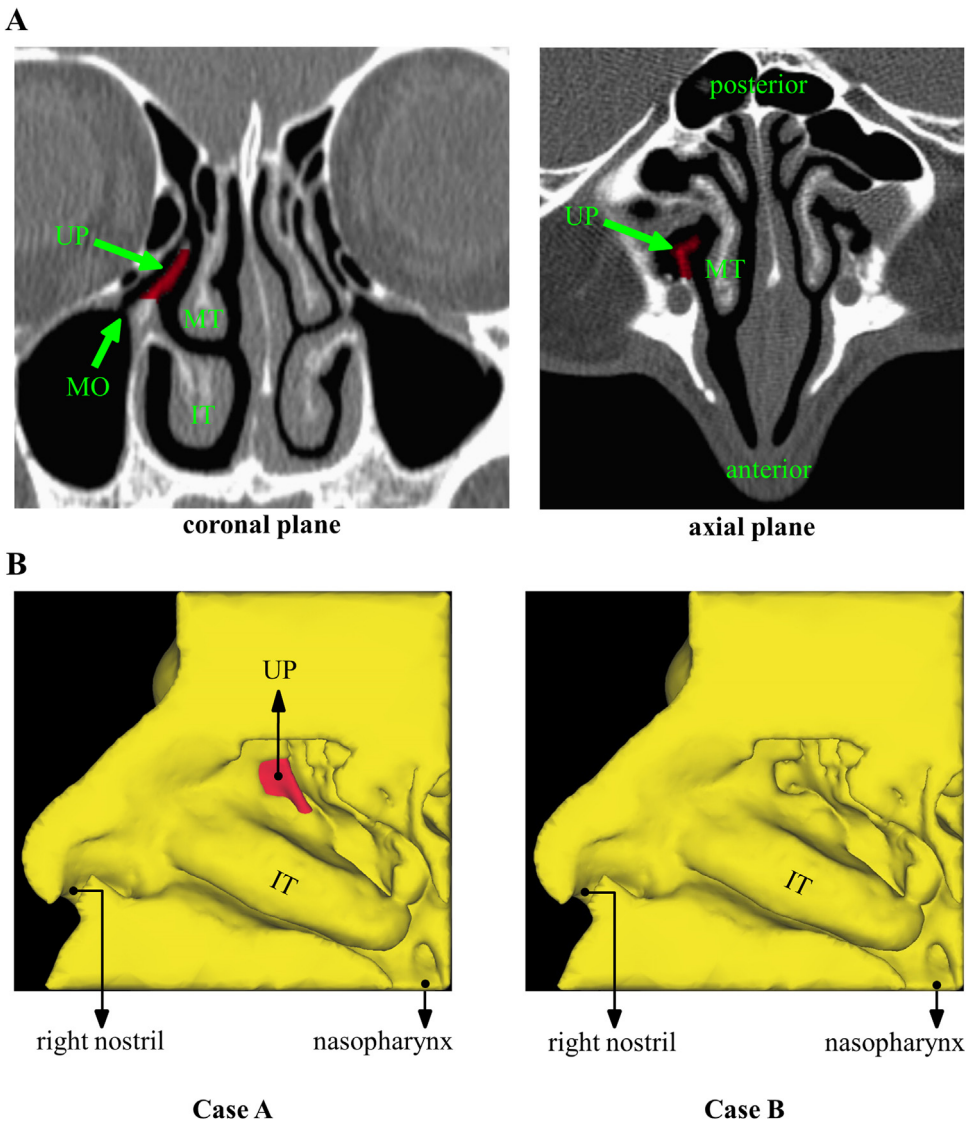

Fig. 1. CT images showing the uncinate process and the nasal cavity models with and without the uncinate process. (a) CT images used for the construction of the numerical model of Case A, with the uncinate process; (b) sagittal view of the nasal cavities in the medial-to-lateral direction, with the middle turbinate removed for visual convenience. MO, maxillary (natural) ostium; MT, middle turbinate; IT, inferior turbinate; UP, uncinate process.

tant in assessing the function of the uncinate process during both inspiration and expiration.

Therefore, the current study used CFD for in-depth analysis of variation in local airflow characteristics over time, both with and without the uncinate process, as well as the resulting gas exchange in the maxillary sinus, in order to better understand the function of the uncinate process during both phases of respiration. An anatomically correct numerical domain was constructed that accurately represented the nasal cavity, including the ethmoid infundibulum, which surrounds the uncinate process, and the natural ostium of the maxillary sinus.

2. Material and methods

2.1. Construction of numerical domains

To identify the physiological effect of the uncinate process, we prepared two different nasal cavity models: one with the uncinate process (Case A) and the other without (Case B). In case A, we created a surface-rendered computational model of the nasal cavity, including the maxillary sinus with the uncinate process. For this, we used data obtained from 0.65-mm-thick computed tomography (CT) slices from an adult patient with mild right-sided nasal obstruction due to common cold (Fig. 1a). The patient did not have any mucosal pathologies, polyps in the maxillary sinus, or a middle meatus. However, there was a mild septal deviation toward the left. The uncinate process did not have any medially or laterally bent portions. CT images were acquired at the Samsung Medical Center in Korea as part of a routine clinical procedure, and permission for this study was obtained from the Institutional Review Board of the Samsung Medical Center.

In order to create a computational model representing a normal anatomical configuration without the uncinate process, the computer-aided design software VWORKS v4.0 (CyberMed Inc., Seoul, Korea) was used to artificially remove the uncinate process from the Case A model. Thus, Case B represented the nasal cavity with only the uncinate process removed, without any concomitant surgical intervention such as MMA or ethmoidectomy. Case B is shown in Fig. 1b, which is the sagittal view in the medial-to-lateral direction displaying the right side of the nasal cavity. Note that the middle turbinate was artificially removed only in this figure for the purpose of visual convenience.