Hyperpolarized Helium3 Phase-Contrast Velocimetry on Human Paranasal Sinus Ostial Patency

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Introduction: HP ^{3}He has been used to study gas exchange between the nasal cavity and the paranasal sinuses; recently HP ^{3}He was used to obtain flow patterns in the airways [1, 2]. Under normal conditions gas exchange between the nasal cavity and healthy sinuses is thought to be driven by the diffusion process [1]. During sinus surgery the natural openings between the nasal cavity and paranasal sinuses are enlarged. If these opening are made large enough air currently can be induced in the sinuses. This greatly increases the efficiency of gas exchange, but has the detrimental effect of increase allergen and pathogen exposure to the sinuses. This transition point is therefore of interest. HP ^{3}He Phase-Contrast (HP ^{3}He PC) MRI is well suited to study this phenomenon. We demonstrate this along this the transition between diffusion and air flow in a sinus phantom model.

Method: A plastic phantom simulating the human nasal cavity and the paranasal sinuses was developed. The MR acquisitions were performed on a 1.5 T whole-body scanner (Sonata, Siemens) with a birdcage coil tuned to ^{3}He frequency 48.4824 MHz. A 2D gradient echo (GRE) sequence with a bipolar gradient was combined to a PC velocity technique for image acquisition with the following parameters: TR/TE: 12/7.4; slice thickness 200; FOV 200; resolution 64; flip angle: 5; 2 images were acquired in three velocity components of b values 0 and 0.334. The hyperpolarized helium was generated via the spin exchange optical pumping method, using a commercial polarizer (GE Health, Durham, NC). For each experiment, 10 cc per second of pure HP ^{3}He was injected into the phantom via dedicated administrating system. The sequence was triggered at the initiation of the HP flow, and a projection image sensitized to velocity in one direction was obtained. The velocity components were assessed from the images by the phase difference with the reference image. The HP ^{3}He technique was quantitatively validated by creating velocity maps in a coronal projection image of a straight tube with known flow patterns. These velocity maps were then applied to the paranasal sinus phantom.

Results and Discussion

In the straight tube validating phantom, the x- and y-velocity components were measured in the MRI by the HP ^{3}He PC technique and verified with computational fluid dynamics (CFD) analysis. The same symmetrical flow pattern and the corresponding mean velocity value of 48 cm per second was observed for the MR and CFD images, as seen in Figure 1(b and c). The MR image is less precise around the tube edges due to partial volume and inflow effects.

The paranasal phantom consisted of several cavities attached to a straight tube by pores with varying diameters (2 mm, 3 mm, 6 mm, 8.33 mm, 9.99 mm, and 12.7 mm) that correspond to reasonable estimates of the sinus ostial size before, 2mm and 3mm and after, all other sizes, surgery. The HP ^{3}He PC MR images were obtained in the x- and y-velocity component and compared to the CFD analysis. When the pore size is relatively small (less then 3 mm), the gas exchange process is primarily a diffusive process. When the pore size is larger (>6 mm) a circular flow pattern appears in the gas exchange process. This change in the gas exchange process displayed in the MR and CFD images (Figure 2). The velocity component values of the MR images correspond to the CFD analysis of the same flow pattern (spherical flow at the pore shown in the close-up images of Figure 2c & 2e): velocity values in the larger pores are between 1.2 and 1.4 m per second while the smaller pores give values in the range of 0.1 to 0.2 m per second. The CFD analysis shows an observable diffusion process that occurs throughout the top of the cavities.

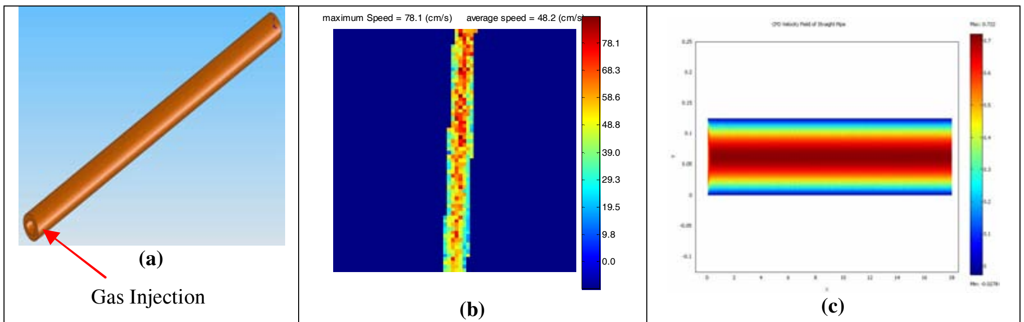

Figure 1: Straight Tube with a 1/8 inch inner diameter (b and c) Experimental Results numerical results that gives a mean velocity of 48 cm per second

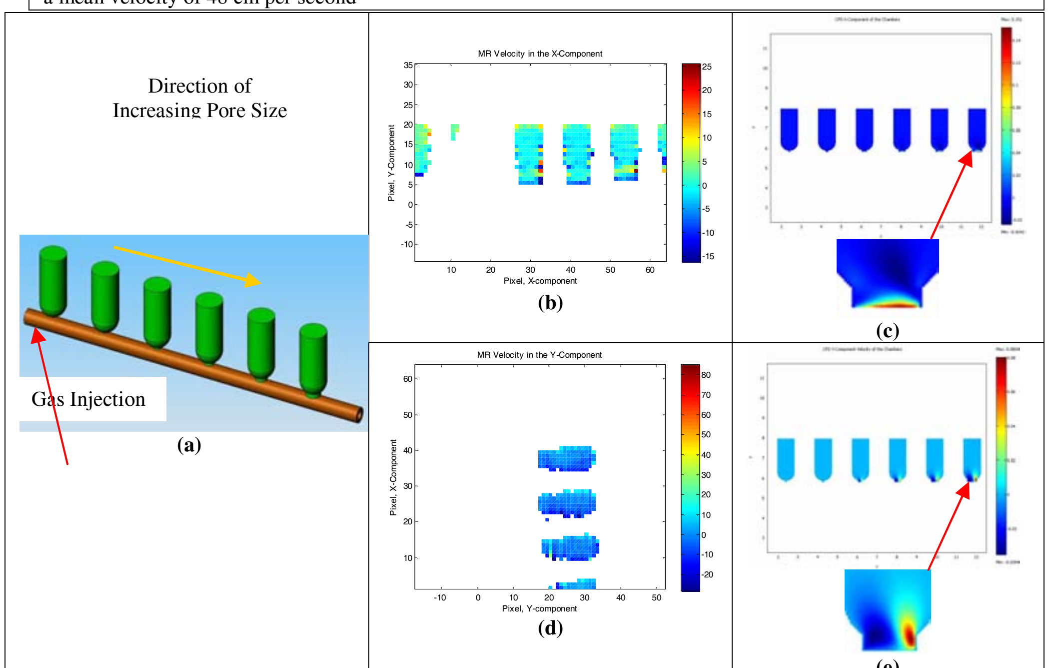

Figure 2: Paranasal Sinus Phantom with varying pore sizes (2 mm, 3 mm, 6 mm, 8.33 mm, 9.99 mm, 12.7 mm)
(b and c) Velocity in the x-component of the Phantom for the MR and the CFD, the close up image of the CFD shows the circular pattern of the flow (bright red and dark blue area)
(d and e) Velocity in the y-component of the Phantom for the MR and the CFD

Conclusion: This study's results suggest that HP ^{3}He PC MRI can be used to study the gas exchange process between the nasal cavity and the paranasal sinuses. Gas transport in multi-chambers exhibits a spherical flow pattern at the entrance of chamber that is dependant on pore size. Furthermore, the HP ^{3}He PC MRI could lead to new tests for sinus ostial patency and a diagnostic tool for sinus disease. It also has implications for the study of surgical methods designed to minimize the efficient transfer of allergens into the paranasal sinuses.

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References

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