Computers in Biology and Medicine 100 (2018) 62–73

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/compbiomed

Numerical simulation of thermal water delivery in the human nasal cavity

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ARTICLE INFO

Keywords:
Thermal waters
Computational fluid dynamics
Large eddy simulation

ABSTRACT

This work describes an extensive numerical investigation of thermal water delivery for the treatment of inflammatory disorders in the human nasal cavity. The numerical simulation of the multiphase air-droplets flow is based upon the Large Eddy Simulation (LES) technique, with droplets of thermal water described via a Lagrangian approach. Droplet deposition is studied for different sizes of water droplets, corresponding to two different thermal treatments, i.e. aerosol and inhalation. Numerical simulations are conducted on a patient-specific anatomy, employing two different grid sizes, under steady inspiration at two breathing intensities.

The results are compared with published *in vivo* and *in vitro* data. The effectiveness of the various thermal treatments is then assessed qualitatively and quantitatively, by a detailed analysis of the deposition patterns of the droplets. Discretization effects on the deposition dynamics are addressed. The level of detail of the present work, together with the accuracy afforded by the LES approach, leads to an improved understanding of how the mixture of air-water droplets is distributed within the nose and the paranasal sinuses.

1. Introduction

Inflammatory disorders affecting the upper respiratory tract are among the most common conditions for which treatments with thermal waters are advised. Such treatments are typically administered as inhalations. Several thermal centers around the world offer inhalation therapy to patients, and propose natural thermal waters with different characteristics and composition. Sulfurous waters are one of the most popular choice in inhalation therapy [1,2].

Relatively recent laboratory tests have shown definite positive effects from sulfurous water, including mucolytic and trophic action on the respiratory mucosa and anti-oxidant and anti-elastase activity. Therefore, scientific evidence presently supports an anti-inflammatory action of thermal waters which effectively helps controlling the inflammatory processes of the upper respiratory tract [3–6]. Various techniques and devices have been developed to properly deliver differently fractionated thermal waters and their gaseous content to the respiratory tract: inhalations, aerosols (also in their more recent sonic/ionized variant), humages, nebulizations and nasal douches are the most common ones [1,2].

Among these, douche-based techniques, based on saline or different solutions, have a scientifically proven efficacy [7]. Irrigations and douches effectively wash the nasal cavity, although inhalations and nebulizations too do deliver water to the nasal cavity to some extent, thus providing a sort of nasal douching. It should also be noted that douches and irrigations are frequently performed in thermal centers where professional devices are available. Such devices have been demonstrated to provide a more effective delivery compared to douching performed by patients at home [8]. On the other hand, aerosols and humages do not provide douching at all, since the water delivery to the nasal cavities is minimal, and the gaseous phase largely prevails.

Even though literature studies describing the clinical effectiveness of these techniques are available, an in-depth knowledge of their details, as for example the spatial pattern of deposition of thermal water droplets over the mucosal lining of the nasal cavities, the pharynx and, broadly speaking, the upper respiratory tract is still lacking. Such knowledge would for example enable tuning and optimizing the design of thermal water diffusors for active droplets distribution, capable to target a specific district of the airway depending on the specific clinical condition. Therefore, a better understanding of the deposition pattern, and how it depends on the particular technique, combined with the type of breathing, would be useful from a clinical as well as a scientific standpoint.

A large number of *in vivo* [9–11] and *in vitro* [12–15] studies have addreseed the problem during the recent years. The difficulties in carrying out *in vivo* studies are obvious. Significant recent advances in Computational Fluid Dynamics (CFD) techniques for the study of the nasal airflow are improving the general picture, by providing a quantitative analysis tool with unprecedented analytic power. Such advances are briefly reviewed in the next section, with specific reference

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https://doi.org/10.1016/j.compbiomed.2018.06.029
Received 5 March 2018; Received in revised form 24 June 2018; Accepted 25 June 2018