Journal of Dental Sciences 17 (2022) 589–591

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.e-jds.com

Journal of Dental Sciences

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Pediatric obstructive sleep apnea: Computational fluid dynamics analysis of upper airway

KEYWORDS
Obstructive sleep apnea;
Computational fluid dynamics;
Polysomnography;
Upper airway

Recently, computational technologies and biomechanical theories have been applied in biomechanical analyses of the upper airway in patients with obstructive sleep apnea (OSA). Several researchers have used computational fluid dynamics[1] to simulate the human upper airway. Use of computational fluid dynamics has progressed from modeling the upper airway flow field to modeling patient-specific geometric characteristics obtained by medical imaging of the upper airway. These advances have improved the accuracy of computational fluid dynamics in assessing airflow characteristics.[1]

In a typical patient with OSA, relaxation of the pharyngeal muscles causes the pharynx to behave like a collapsible conduit. A pharynx that is hypotonic and highly compliant has a low luminal pressure, which decreases the cross-sectional area of the segments. During sleep, the narrowing process eventually results in a collapse of the airway in breathing.[2] Therefore, a high negative pressure detected in the pharyngeal airway by computational fluid dynamics may indicate a potential for pharyngeal-airway collapse during sleep.[3] Moreover, using computational fluid dynamics for functional evaluation of the upper airway may yield information unobtainable by morphologic evaluation alone.

A male pediatric patient (age 11 years and 3 months; BMI 20.8 kg/m^2) was referred to the OSA Dental Clinic at the Department of Oral Maxillofacial Surgery at Kaohsiung Medical University Hospital for evaluation and management of OSA. The sleep surgeon then referred the patient to the Ear-Nose-Throat and Orthodontic Departments for multi-disciplinary care. Symptoms included loud snoring, witnessed apnea and impaired school performance. Fiberscopy revealed a 60% airway obstruction caused by adenoid hypertrophy. Tonsil size was grade 2 in Friedman tonsil grading system.[4] The patient had a skeletal Class II with retrusive mandible and Class II subdivision malocclusion with large incisal overjet, anterior deep overbite and congenital missing premolars. The ENT surgeon performed adenotonsillectomy and uvulopalatopharyngoplasty to remove the upper airway obstructive tissue structure. After surgery, the patient underwent a 6-month orthodontic treatment starting with a twin-block appliance comprising a maxillary expansion (10 weeks) to stimulate mandibular growth and mandibular advancement to increase nasorespiratory airway volume.

In evaluations of treatment outcome, both polysomnography examination and computational fluid dynamics analysis revealed large improvements. The apnea-hypopnea index was decreased from 30.7 (evens/hour (e/h)) to 2.6. The lowest oxygen saturation level (SpO_2) improved from 82% to 87%. Pretreatment cone-beam computed tomography and computational fluid dynamics analysis (Soteria DcmRecons, version Alpha v0.7.0; Soteria Biotech Ltd., New Taipei City, Taiwan) revealed that constriction and air pressure were highest in the velopharynx (Fig. 1). The area most susceptible to collapse was the velopharynx, where aerodynamic forces may have important roles in OSA pathogenesis. At 6 months post-treatment, computational fluid dynamics analysis revealed that both air pressure during inspiration and velocity magnitude were significantly improved from baseline. The skeletal Class II condition improved to Class I jaw relation with normal incisal overjet and overbite. The objectives of the second stage of orthodontic treatment were providing prosthetic space for missing premolars and improving occlusion.

https://doi.org/10.1016/j.jds.2021.06.005

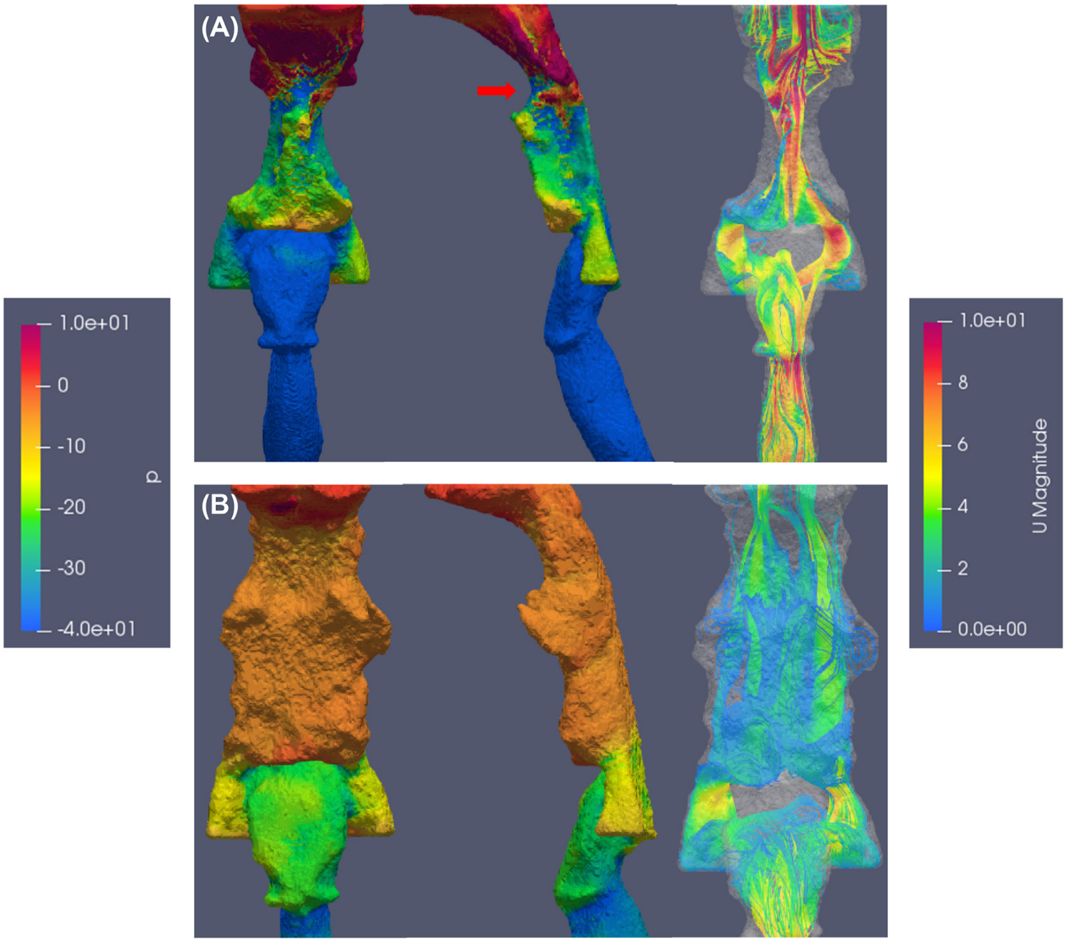

Figure 1 Upper airway ventilation conditions upon inspiration in a pediatric obstructive sleep apnea (OSA) patient. Pharyngeal airway pressure is depicted in ventral and left lateral views ((A) and (B) in left and center images). Airway velocity is depicted in ventral views ((A) and (B) in right images). (A) Before treatment, velopharyngeal airway velocity was high, and the site (red arrow) was considered an OSA causative site. At this site, negative pressure was high in the lower part of the upper airway. The high negative pressure in the pharyngeal airway was considered susceptible to collapse during sleep. (B) After treatment, velopharyngeal airway velocity decreased, the OSA causative site improved, and the large negative pressure in the pharyngeal airway decreased. The reduced negative pressure in the pharyngeal airway at inspiration decreased its susceptibility to collapse during sleep.

However, mild OSA was still noted (AHI 2.6 e/h; AHI <1.5 e/h are considered normal in children and adolescents[5]). The patient should be monitored for possible developing severe OSA. Early diagnosis of OSA during children and adolescent period with an effective intervention is crucial to prevent severe complications.

Regarding the reductions in AHI and improvements in symptoms achieved in this case, the contributing role of surgery versus that of the functional appliance could not be determined precisely. Our future works will use computational fluid dynamics to compare outcomes among several different surgeries (including adenotonsillectomy, uvulopalatopharyngoplasty, hypoid bone suspension) and different orthodontic interventions (e.g., mandibular advancement and rapid maxillary expansion). A detailed comparison of outcomes achieved by these treatments would increase the success rate and reduce surgical risks for pediatric OSA.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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Received 11 June 2021
Final revision received 15 June 2021
Available online 29 June 2021