Evaluation of Airway After Maxillary Skeletal Expansion in Adults Via Computational Fluid Dynamics

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Introduction: Transverse maxillary arch deficiencies commonly complicate treatment in orthodontics.1-6 In the adult patient, a problem arises as to how to expand the maxilla when the mid-palatal suture has already fused without the usage of surgery.7-16 Traditional expanders would not correct the skeletal deficiency as the resulting movement would be dental tipping.17 Therefore, for adult patients, mini-implant assisted maxillary skeletal expansion (MSE) is ideal. MSE uses four temporary anchorage devices (TADs) to transmit shear forces from a jackscrew to the hard palate via shear force, ultimately forcing the mid-palatal suture open in patients for which the suture has already fused.1,18-22 Progressive changes in patients who undergo MSE expansion and successfully split may shed light on an incidental finding suggesting that breathing can improve after treatment.7,23-29 As expansion occurs, the boney housing of the naso-pharynx expands, potentially allowing for more air input and less resistance.7, 23-25, 30-31 To gain more insight into these changes, a computational fluid dynamic (CFD) model could be made for MSE patients to examine exactly how the flow rate of air changed post treatment as well as to examine changes to pressure, velocity, and turbulence. Previous studies have modeled patient airways post orthodontic treatment using CFD, however, these models are non-physiologic and have not shown how flow rate of air changes after MSE treatment.26, 32-41 For this study, our team analyzed the CBCTs of thirty patients to understand the effects of MSE treatment on airway.

Materials and Methods: Overall, thirty adult UCLA Orthodontic patients were analyzed retrospectively, fifteen who were successfully treated with MSE and fifteen who served as controls. The patients received two cone-beam computed tomography scans (CBCTs) during treatment. CBCTs were segmented using Avizo in order to isolate the airway.42-43 Segmentation boundaries were chosen to allow for propagation of airflow and development of velocity profiles in the CFD simulations. Once segmented, the volumes were exported as surface meshes using STL file format. The CFD simulations used a clinical simulation platform that integrates all aspects of CFD model pre-processing, solution, and post-processing into a single platform. The vertical application is based on ANSYS Fluent. The platform was used to create computational grids for the flow analyses using the STL files as a starting point for generating the volumetric grid. The flow was assumed laminar and steady-state. Two separate simulations are required to model inhalation and exhalation since the flow is assumed steady. The pressure-based coupled solver was used to speed convergence and second-order upwinding was used to minimize the impact of numerical diffusion on the results. In addition, a mass flow rate boundary condition was applied at the oro-pharyngeal surface, which allows for the differences in airway resistance between the left and right nostrils to ultimately dictate the amount of air flowing into each side of the nose.

Results: Overall, the MSE groups’ total volume of the airway increased by 23% when compared to the control group. When each section of the airway was examined in the MSE group, it was determined that the volume of the nasal airway increased, the volume of the naso-pharynx increased, and the volume of the oro-pharynx increased. CFD simulations corroborate the findings seen in the volumetric changes. Pressure drop (∆P) was measured as the average pressure at the inlets minus the average pressure at the outlets. These roles are reversed for inhalation compared to exhalation. Overall, for both exhalation and inhalation, the pressure change of the airway was reduced post treatment by two-fold. Velocity profiles and speed contours also demonstrate marked improvement of airflow velocity at the outlets for both inhalation and exhalation.

Conclusion: In this study, marked volumetric gain and significant changes to airflow were examined via segmentation and CFD simulation, respectively. With a refined and tested workflow, airflow segmentation and CFD analysis can shed light on the overall effects of MSE on the patient’s improved ability to breathe.

Disclosure: There is no conflict of interest in this study as ANSYS engineers served as technical advisors using the Fluent Software.