Three-dimensional analysis of the upper airway in obstructive sleep apnea patients

Chen, H.

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Chapter 11

Summary

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Obstructive sleep apnea (OSA) is a sleep-related breathing disorder, often associated with oxygen desaturations and arousals from sleep. OSA is a major public health problem, affecting a significant portion of the population, approximately 3-7% of adult men and 2-5% of adult women. The critical factors that play a role in the pathogenesis of OSA and the treatment outcome of OSA are still not completely clear. The aim of this thesis, therefore, was to determine the role of the upper airway in the pathogenesis of OSA, as well as in the treatment outcome of OSA.

Three-dimensional upper airway measurements could be used to further investigate the role of the upper airway in the pathogenesis of OSA. However, the upper airway measurements must be reliable and accurate. For this reason we have carried out an investigation into the reliability and accuracy of the procedures of upper airway measurements. The methodology of landmark localization and upper airway measurements used in our study showed an excellent reliability and can thus be recommended for the upper airway analysis (**Chapter 2**). With regard to the accuracy of different CT scanners, we found that cone beam computed tomography (CBCT) and multi-detector row computed tomography (MDCT) scanners generally underestimated the upper airway dimensions, which is most probably due to the partial volume effect of the segmentation process. This underestimation, however, is small and probably not of clinical relevance. CBCT scanners can offer adequate clinical accuracy for the assessment of the upper airway (**Chapter 3**). To determine the accuracy of different software programs, we developed an anthropomorphic phantom of the upper airway as the gold standard. Three software programs (Amira®, Ondemand3D®, 3Diagnosis®) were used to perform upper airway measurements and all of them underestimated the upper airway dimensions by 2.1 - 10.8% (**Chapter 4**).

The above procedures of upper airway analysis investigated in the previous chapters **(Chapters 2-4)** have been applied to clinical research. In a systematic review, we found that the most relevant anatomical characteristic of the upper airway related to the pathogenesis of OSA is a small minimum cross-sectional area. Upper airway with a small cross-sectional area has an increased tendency toward obstruction of the upper airway (**Chapter 5**).

In addition to the anatomical characteristics of the OSA patients, we have investigated the aerodynamic characteristics of the upper airway in OSA patients. Using computational fluid dynamics (CFD), we found that the airway resistance during expiration is the most relevant aerodynamic characteristic of the upper airway related to the pathogenesis of OSA (**Chapter 6**).We also compared the craniofacial anatomy between responders and non-responders to mandibular advancement device (MAD) therapy and found that OSA patients with a short length of the maxilla and a small maxillomandibular enclosure size may respond better to MAD than patients with a large maxillary length and a large maxillomandibular enclosure size (**Chapter 7**).

Based on a systematic review, we concluded that maxillomandibular advancement (MMA) surgery and MAD may improve several aerodynamic characteristics (viz. airway resistance, velocity, and wall static pressure) of the upper airway (**Chapter 8**). Using particle imaging velocimetry (PIV), we found that the ventilation of the upper airway of an OSA patient improved most with the MAD in situ at 50% protrusion position (**Chapter 9**). These findings help us further understand the role of the upper airway in the pathogenesis of OSA, and its effects on the treatment outcome in OSA patients from the perspectives of both anatomy and aerodynamics (**Chapter 5-9**).

In the general discussion (**Chapter 10**), we present the limitations of the various studies and make suggestions for future research.

The conclusions of this thesis can be summarized as follows:

1. **The methodology of upper airway measurements used in this study can be reliably used to perform upper airway analysis on CBCT images (Chapter 2)**.
2. CBCT scanners offer an alternative to MDCT scanners in the assessment of the upper airway morphology. All devices produced dimensions of the upper airway that are smaller than the real dimensions, although this difference is probably clinically irrelevant **(Chapter 3)**.
3. **All three software programs used in this study can offer reliable measurements of the upper airway, but underestimate the dimensions of the upper airway (Chapter 4).**

4. The minimum cross-sectional area of the upper airway is the most relevant anatomical characteristic in the occurrence of OSA **(Chapter 5).**
5. A higher airway resistance during expiration is the most relevant aerodynamic characteristic of the airflow in the pathogenesis of OSA **(Chapter 6).**
6. Before controlling for BMI, OSA patients with a shorter maxillary length, a smaller maxillomandibular enclose size, and a smaller tongue area may respond better to MAD treatment than patients with a longer maxillary length, a larger maxillomandibular enclosure size and a larger tongue area. After controlling for BMI, there was no longer a significant difference in the tongue area between responders and non-responders. **(Chapter 7).**
7. MMA surgery and MAD therapy can improve the aerodynamic characteristics of the upper airway in OSA patients **(Chapter 8).**
8. The effect of MAD therapy at different protrusion positions for an OSA patient can be analyzed by particle imaging velocimetry **(Chapter 9)**.