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Development of Intelligent Oral Appliance Systems for the Management of Snoring and Obstructive Sleep Apnea

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Introduction

Obstructive sleep apnea (OSA) is characterized by recurrent narrowing of the upper airway during sleep, resulting in snoring, breathing cessation, and sleep fragmentation. These events precipitate increased cardiovascular activity, marked by elevated heart rate, blood pressure variability, and sympathetic nervous system activation, which have been extensively documented to have strong associations with cardiovascular pathology.

One therapeutic intervention for patients presenting with snoring and OSA is the mandibular advancement device (MAD), which has demonstrated efficacy in reducing the apnea-hypopnea index (AHI) and enhancing quality of life through improvements in sleep architecture and attenuation of daytime somnolence [1]. While MADs have been observed to exert less pronounced or more heterogeneous effects on apnea amelioration compared to continuous positive airway pressure (CPAP) therapy, a growing body of evidence suggests comparable benefits in cardiovascular parameters such as blood pressure regulation and overall quality of life metrics.

Current clinical guidelines recommend MADs for patients with mild to moderate OSA and suggest consideration as an alternative therapeutic modality for patients with severe OSA who exhibit CPAP intolerance or inadequate response to CPAP intervention [2,3].

Mechanism of Action and Side Effects

MADs effectively address snoring and OSA through anterior displacement of the mandible during sleep, which concurrently advances the muscles of the mandible and base of the tongue, thereby elevating the flaccid soft palate and uvula. However, patients with OSA undergoing prolonged MAD therapy may experience adverse effects attributable to the protracted anterior positioning of the mandible. MAD therapy induces transient dental and skeletal alterations. Documented adverse effects encompass diminution of overjet and overbite, development of anterior crossbite, posterior open bite, and potential exacerbation of AHI severity with consequent reduction in treatment efficacy. Furthermore, MAD utilization may precipitate temporomandibular disorders (TMD) in a subset of patients, although these manifestations are frequently transient. Given the progressive nature of these adverse effects, patients receiving long-term MAD therapy require regular clinical monitoring and appropriate device adjustments [4].

Contraindications and Compliance Issues

Contraindications to MAD therapy include active temporomandibular joint (TMJ) dysfunction, insufficient dentition to provide adequate device support, moderate to severe periodontal disease, and restricted maximum mandibular protrusion (less than 6 mm). Additionally, reported adverse effects comprise pain in the TMJ and associated musculature, dental structures, and oral soft tissues, TMJ crepitus, and occlusal alterations. Clark documented that approximately 15% of patients utilizing MADs discontinued treatment due to orofacial pain [5]. Walker-Engström et al. [6] reported that approximately 62%–82% of patients using MADs experienced occlusal discomfort. According to Perez et al. [7], the baseline prevalence of TMD in patients receiving oral appliance therapy for OSA was 19.8%, though these symptoms were transient. Notably, in patients with pre-existing TMD symptomatology prior to oral appliance therapy, no significant increase in symptoms was observed following appliance use. They further reported posterior open bite in 17.9% of cases, with only 29.6% of these patients recognizing the occlusal alterations in the posterior dentition.

Technological Advancements

Recent technological innovations have been incorporated into MAD design and functionality [8,9]. These advancements have facilitated the development of diverse intelligent MADs with varying functionalities across different developmental stages, ranging from proof-of-concept prototypes to commercially available technologies. The majority of these devices monitor patient compliance, while some incorporate data-responsive mechanisms to adjust mandibular positioning. These intelligent MADs actively modulate mandibular protrusion in response to patient physiological parameters and health metrics. This capability has the potential to prevent unnecessary mandibular advancement and minimize adverse effects such as TMJ symptomatology.

Based on the anatomical and clinical mechanisms underlying oral and pharyngeal manifestations of snoring and OSA, technological applications have been developed to create wearable smart sensing diagnostic devices and novel therapeutic oral appliances. Sensor systems have been engineered to measure real-time oxygen saturation levels in patients. Additionally, smart sensing mouthpieces have been developed for individuals with respiratory difficulties. These devices can advance the mandible anteriorly to create patent space in the oropharynx, facilitating respiration. All systems incorporate state-of-the-art technology, including wireless rechargeable capabilities and Active Micro Driver technology. The diagnostic device, designed to monitor respiratory function, has a fingertip-like configuration through which it measures oxygen saturation levels. It utilizes Bluetooth Low Energy (BLE) for communication with monitoring systems and battery recharging. Whereas previous oral appliances were associated with discomfort and TMJ complications, the novel device developed through our research is designed to operate selectively only during episodes of snoring or apnea. This selective activation significantly reduces adverse effects and complications while substantially improving respiratory function [10].

Conclusion

In the foreseeable future, intelligent MADs hold considerable promise for enhancing the efficacy of OSA treatments and introducing innovative therapeutic approaches to the field of sleep medicine.

Author Contributions

Conceptualization: Seong Taek Kim. Data curation: Hyo-Jung Jung. Formal analysis: Hyo-Jung Jung. Funding acquisition: Seong Taek Kim. Investigation: Gyuhag Kim. Methodology: Seong Taek Kim. Project administration: Gyuhag Kim. Resources: Hyo-Jung Jung. Software: Gyuhag Kim. Supervision: Seong Taek Kim. Validation: Gyuhag Kim. Visualization: Hyo-Jung Jung. Writing—original draft: Hyo-Jung Jung. Writing—review & editing: Seong Taek Kim.

Conflicts of Interest

Seong Taek Kim, a contributing editor of the *Sleep Medicine Research*, was not involved in the editorial evaluation or decision to publish this article. All remaining authors have declared no conflicts of interest.

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