The following individuals certify that they have read, and recommend to the Faculty of Graduate and Postdoctoral Studies for acceptance, a thesis entitled:

Mini-implant supported oral appliance for treatment of obstructive sleep apnea: a feasibility study

submitted by Matias Navarrete Grimminck in partial fulfillment of the requirements for the degree of Master of Science in Craniofacial Sciences

Examinining Committee:

Dr. Benjamin Pliska, Faculty of Dentistry

Supervisor

Dr. Fernanda Almeida, Faculty of Dentistry

Supervisory Committee Member

Dr. Sid Vora, Faculty of Dentistry

Supervisory Committee Member

Dr. Hugh Kim, Faculty of Dentistry

Additional Examiner
Abstract

Introduction: Obstructive sleep apnea (OSA) is a major sleep breathing disorder characterized by repetitive obstruction of the upper airway during sleep leading to sleep fragmentation and oxygen desaturation. Mandibular advancing oral appliances (OAm) are an effective treatment for OSA but cause long-term dental changes, resulting in some patients stopping treatment. We hypothesized that a novel OAm which interfaces with orthodontic mini-implants (OMIs), instead of teeth, can avoid dental changes. This study aims to evaluate the effectiveness of a novel device; to suggest future design improvements; and to advance the understanding of design and anatomical factors that may contribute to successful treatment.

Methods: The pilot trial included 3 non-obese adult OSA patients that were successfully treated with OAm. For each patient 4 OMIs were placed in the maxilla and 2 in the mandible, and an appliance was digitally designed and 3D printed based on patient anatomy. The appliance was tested on patients to evaluate viability of the design, retention, and patience experience. To evaluate the influence of anatomical factors, the dental records of 5 OSA patients were measured to determine the appliance design configurations at different amounts of titration and various OMI positions. Mathematical modelling was used to quantitatively approximate forces that would be exerted on the lower OMIs for different amounts of mandibular protrusion.

Results: The appliance retention was deficient under the initial design configuration. A total of 24 OMIs were inserted. The overall OMI failure rate was 50.0%; 38.5% in the maxilla, and 63.6% in mandible. Model analysis showed optimal sidebar angulation was only achieved in a sample Class II division 2 malocclusion/non-extraction case at maximum titration. Quantitative force analysis revealed forces of up to 32.5N could be generated on the lower OMIs with the existing design configurations.
Conclusion: Appliance design is limited by anatomical factors, OMI's location, and sidebar angulation. The overall appliance retention was deficient with a high OMI failure rate compared to previous orthodontic-based studies. Multiple individual OMI's may not be a suitable option to anchor the appliance. Conclusions should be taken with caution due to small sample size and high risk of bias.
Lay Summary

Mandibular advancement oral appliances (OAm) are an effective treatment option for obstructive sleep apnea. Conventional OAm cause teeth to shift over time. We hypothesized that a novel OAm combined with orthodontic mini implants (OMIs) can avoid dental side effects.

This study aimed to test this novel device and design, and to better understand the patient experience while using it. We also aimed to establish optimal OMI location, and to calculate the approximate force exerted on the lower OMI.

The novel OAm was tested in 3 patients, achieving poor retention. Half of the OMIs failed during the trial, a rate greater than reported in the literature. Optimal OMI location was limited by anatomical factors, and forces exerted on the lower OMI resulted in values larger than those found in previous studies. We concluded that multiple individual OMIs may not be a suitable option to anchor the novel appliance.
Preface

This thesis is based on the experimental work by Dr. Benjamin Pliska at UBC, Faculty of Dentistry, Vancouver, BC, Canada. The novel appliance was 3D printed and tested on a set of plastic models mounted on an articulator, achieving good retention. Dr. Pliska also designed the OMIs for the study to accommodate for appliance clearance and design requirements.

Dr. Pliska was the supervisor of this project and he guided me during OMIs placement and appliance insertion. This study complies with the Heath Information Protection Act (HIPA), and was approved by the Research Ethics Board at the University of British Columbia (UBC) H17-03108 on April 2018.

I was responsible for the study design by developing the methodology, clinical protocols and data collection. I was also responsible for patient recruitment, records, OMIs placement, intra-oral scans, STL files uploading, and device insertion. I also developed the methodology for the plaster model analysis, collected the cases, marked the OMI location, and measured the sidebar angulations.

Vivian Chung, Research Engineer at the Centre for Hip Health and Mobility was involved in transferring the mouth scan as STL file into SolidWorks™ software, sizing and modifying the novel appliance. She also participated in several appliance design meetings held after clinical delivery of each device, and designed the modified sidebars inserted in Patient #3. The force analysis in Chapter 3 was based on Vivian’s work.

This thesis is a novel research project and none of the text was taken directly from previously published papers.
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List of Abbreviations

AASM: American Association of Sleep Medicine
AHI: Apnea-Hypopnea Index
AOm: Mandibular Advancement Oral Appliance
BMI: Body Mass Index
BQ: Berlin Questionnaire
BP: Blood Pressure
CAD: Coronary Artery Disease
CEJ: Cementoenamel Junction
CI: Coefficient Interval
CPAP: Continuous Positive Airway Pressure
CSA: Central Sleep Apnea
CT: Computed Tomography
CVD: Cardiovascular Disease
ESS: Epworth Sleepiness Scale
FEA: Finite Element Analysis
HTN: Hypertension
ICSD-2: International Classification of Sleep Disorders Version 2
MARPE: Mimi-Implant-Assisted Maxillary Expander
MDA: Mean Disease Alleviation
MGJ: Mucogingival Junction
MMP: Maximum Mandibular Protrusion
NHP: Nottingham Health Profile
OCST: Out-of-Center Sleep Testing
ODI: Oxygen Desaturation Index
OMI: Orthodontic Mini-Implant
OSA: Obstructive Sleep Apnea
ODI: Oxygen Desaturation Index
PAP: Positive Airway Pressure
PRD: Portable Recording Device
PSG: Polysomnogram
QoL: Quality of Life
RDI: Respiratory Disturbance Index
REI: Respiratory Event Index
SBD: Sleep Breathing Disorders
SMMA: Surgical Maxillomandibular Advancement
TMD: Temporomandibular Disorders
TMJ: Temporomandibular joint
UBC: University of British Columbia
VAS: Visual Analog Scale
Acknowledgements

I would like to sincerely thank my supervisor Dr. Benjamin Pliska, and to committee members Dr. Fernanda Almeida, and Dr. Sid Vora for their mentorship, guidance, and support in improving my research skills and knowledge which has shaped my critical thinking as a Specialist in Orthodontics.

I would like to also acknowledge the UBC department of Oral Health Sciences for their generous funding this project through the UBC Faculty of Dentistry Pilot Project Award.
Dedication

I dedicate this thesis to my spouse Pablo Mochcovsky for his unconditional support and love, and to my family for their support and encouragement throughout my twelve years of university education.
Chapter 1: Introduction

1.1 Obstructive Sleep Apnea (OSA)

1.1.1 Definition

According to the second version of the International Classification of Sleep disorders (ICDS-2), by the American Association of Sleep Medicine (AASM), Obstructive Sleep Apnea (OSA) belongs to the major sleep disorder group within the category of sleep-related breathing disorders\(^1\). Defined as repetitive events of upper airway obstruction associated with apnea and/or hypopnea events during sleep, it is characterized by decrease of blood oxygen saturation as well as snoring. Interruption in breathing frequently causes arousal due to gasping or choking during the obstructive event\(^2\). OSA leads to intermittent hypoxia and sleep fragmentation\(^3\).

1.1.2 Epidemiology

The Wisconsin Cohort study, performed by Young et al, is the most cited reference related to OSA prevalence. The study evaluated polysomnograms (PSG) of 602 randomly selected subjects between the ages of 30 and 60 years and estimated the OSA prevalence to be 4% for men and 2% for women of working-class population in the USA. The percentage of subjects having an apnea/hypopnea index ≥5 (AHI ≥5) was 24% for men, and 9% for women. Furthermore, male sex and obesity were found to be related risk factors\(^4\). Similar results in a middle-age population were found in a Hong Kong based study of 150 subjects, although the prevalence for OSA (AHI ≥5) was less than the Wisconsin sample\(^5,6\). A two-phase cross-sectional study of 2150 Indian subjects, found an OSA prevalence (AHI≥5) of 4.9% in males and
2.1% in females. A study of Chinese subjects, concluded that the prevalence of OSA in the general population was approximately 3.6% to 4.8%.

A recent two-phase cross-sectional study of 555 subjects from a European/Caucasian population with a tentative diagnosis of OSA found that the subjects with oxygen saturation <90% for at least 30% of the time were associated with OSA. A higher prevalence of OSA was found in males compared with females when AHI ≥10. Snoring was found in 35% of the sample, daytime hypersomnolence in 18%, and breathing pauses in 6% of the subjects. When snoring was adjusted by sex, 45% of men and 25% of women snored. An increase in breathing pauses with age was also observed. No strong association between daytime hypersomnolence and OSA was found in this study. AHI was associated with hypertension after adjustment for age, sex, BMI, neck circumference, alcohol consumption, and smoking habits.

A prospective clinical study in the USA in the periods of 1988-1994 and 2007-2010, using data from the Wisconsin study, examined 1520 PGS of mostly non-Hispanic white population between age of 30 to 70 years. The results showed that the prevalence of sleep disorder breathing (SDB) was statistically significantly higher in men, older subjects, and subjects with higher BMI. Summarizing over age, sex, and BMI, the overall prevalence of mild to severe OSA (AHI ≥5) was 26% among people 30–70 years of age for the 2007–2010 time period. Specifically, the prevalence of mild to severe OSA in the 1988-2011 period was about 80% for males in the same age range, when BMI ≥40. On the other hand, the OSA prevalence in women was 43% in the 30-49-year-old group when BMI ≥40. The prevalence in women in the range of 50 to 70 years of age increased to 67.9% when BMI ≥ 40. The authors determined the overall prevalence of OSA at 17% of middle-aged men, and 9% of women in the group of 30 to 70 years of age.
Incidence of moderate to severe OSA (AHI ≥15) in the USA has been determined from a sample 286 subjects known as the Cleveland study. The study found an incidence of 15% for males and 8.2% for women\textsuperscript{10}.

The American Association of Sleep Medicine (AASM) included in its guidelines as high risk individuals those who suffer from obesity, cardiopathies, refractory and pulmonary hypertension, type 2 diabetes, stroke, nocturnal dysrhythmias, high risk driving population and candidates for bariatric surgery\textsuperscript{2}. According to Peppard et al, an individual who had 10% weight gain is expected to have an approximate 32% increase in risk of OSA\textsuperscript{11}. A study of 2968 moderately overweight subjects, in the range from middle-age to older age, that experienced weight gain, found that the incidence of sleep breathing disorders was present in 11.1% of men and 4.9% of woman, defined as a Respiratory Disturbance Index ≥15 (RDI≥15). The RDI is similar to AHI, but it also includes the respiratory-effort related arousal (RERAs)\textsuperscript{12}.

1.1.3 Diagnosis

Diagnosis of OSA is based on several criteria including signs and symptoms. The symptoms are subjective, and they are represented by the nocturnal respiratory disturbance, observed apnea, snoring, insomnia, or sleepiness also known as daytime hypersomnia. On the other hand, signs are objective and they are represented by AHI, RDI, RERAs, and oxygen saturation levels, among others\textsuperscript{1}. The obstructive events are defined by the AASM Manual as hypopneas, obstructive and mixed apneas, or respiratory effort-related arousal per hour of sleep during an overnight PSG. Related medical conditions such as hypertension (HTN), congestive heart failure, stroke, coronary artery disease, atrial fibrillation, type 2 diabetes, mood disorder, or congestive dysfunction, have all been associated to OSA. These conditions have to be associated
with an AHI≥5 for OSA diagnosis\(^2\). Having 15 or more obstructive respiratory events per hour is enough for OSA diagnosis, even in absent of symptoms or disorders\(^9\).

According to the AASM’s current clinical guidelines in adults, there is a consensus on parameters for the diagnosis of OSA\(^2\). Since OSA is a chronic disorder, the AASM requires that its diagnosis and follow-ups are done by a trained sleep physician. The follow-up can be done in conjunction with other health care providers such as primary care physician, qualified dentist, and ENT, among others\(^{13}\). The recommended start point is a proper sleep history. Questions should include history of snoring and daytime sleepiness, among others. A full physical exam should include evaluation of snoring, apneas, gasping/choking events, daytime sleepiness, total hours of sleep, headaches, sleep fragmentation, and decrease in concentration and memory. Assessment of associated conditions such as high blood pressure, stroke, myocardial infarction, cor pulmonale, decrease daytime alertness, motor vehicle accident, should also be gathered.

Obesity, signs of upper airway narrowing, as well as other contributing disorders should be also evaluated. Neck circumference and Body Mass Index (BMI) should be measured, as there is an increased risk of OSA when neck circumference is >17 inches in men and >16 inch in women with a BMI ≥ 30kg/m\(^2\). Previous studies have shown that BMI and age are significant predictors of sleep breathing disorders\(^{5,6}\). There is also consensus in the evaluation of retrognathia, lateral peritonsilar narrowing, macroglossia, tonsillar hypertrophy, size and position of the uvula, narrow palatal vault, and upper airway abnormalities and/or overjet\(^2\). A more recent prospective clinical study in 125 patients with HTN concluded that good predictors of OSA for this particular population are: Age>50, large neck circumference, and snoring\(^{14}\).

To help identify patients at high risk for OSA, and to identify snoring patients who are at risk of OSA, a questionnaire was develop in 1996 in Berlin, Germany, by a group of 120
American and local pulmonary and primary physicians, as well as several sleep researchers, in a
collection on sleep in primary care. It is commonly known as the Berlin Questionnaire (BQ). It is a self-reported survey that assesses risk factors for sleep apnea such as snoring behavior, waketime sleepiness or fatigue, and presence of obesity and/or hypertension. It was first used for this purpose almost 20 years ago in a study of 744 adults from a primary care population in Cleveland, Ohio, also known as the Cleveland study. As a criterion, when 2 of 3 symptoms category were present, the subject was considered to be at high risk of OSA. The study concluded that BQ provides means of identifying patients who are at high risk of OSA with a sensitivity of 86% for an RDI >515.

Current guidelines also require objective testing for clinical diagnosis of sleep related breathing disorders (SBDs). There are 2 accepted methodologies: full-night PSG (standard), and out-of-center sleep testing (OCST) or portable monitor devices which are indicated in patients in which full-night PSG is not possible due to cost, immobility, safety, critical illness, and to monitor response to non-CPAP therapies. OCST is not indicated in patients with other related serious conditions such as pulmonary disease, neuromuscular disease, or congenital heart failure2. Currently, ICSD-3 allows the use of OCST to obtain the Respiratory Event Index (REI)1. PSG provides data from a continuous polygraphic recording of encephalic, ocular, myographic and cardiac activity through noninvasive sensors located in the nose, oral cavity, over the chest, thorax, and abdomen4. The AASM states that a PSG study is indicated in high risk subjects with nocturnal symptoms of OSA. PSG is indicated as part of standard of care for those who are obese, and those with heart failure. The guidelines also include subjects with coronary artery disease, tachyarrhythmias or bradarrhythmias. PSG data allows for the calculation of the AHI and RDI that reports the frequency of obstructive events2. AHI is defined
as the average number of apneas plus hypopneas per hour of sleep, with apnea defined as a cessation of airflow and hypopneas defined as a ≥30% reduction in airflow or thoracoabdominal excursion for at least 10 seconds, both of which are accompanied by a ≥3% drop in oxyhemoglobin saturation\textsuperscript{16}. RDI is defined as the number of apneas and hypopneas divided by the total recording sleep time when OCST is used, whereas for a full-night PSG events are divided by the total sleep time. Therefore OSCT underestimate the severity of events since it only registers the recording time, rather than the total sleep time that is used to calculate the RDI\textsuperscript{2}. According to the AASM task force, AHI values ≥5-15 are considered mild OSA, AHI ≥15-30 moderate OSA, and AHI >30 severe OSA\textsuperscript{17}.

1.1.4 Associated Conditions in OSA

OSA has been recognized as a secondary cause of hypertension (HTN) since 2003, according to the Seventh Joint National Committee\textsuperscript{18}. A cross-sectional study of 1060 individuals, part of the Wisconsin sample, had found a dose-response relationship between AHI and blood pressure (BP), both at baseline and long-term\textsuperscript{19}. An independent association between Sleep Breathing Disorders (SBD) and HTN was found in a large community-based multicenter cross-sectional study, also known as a Sleep Heart Health study, performed between 1995 and 1998. The study involved 6132 patients ≥40 years of age across the USA, and it demonstrated that the prevalence of HTN increases at higher AHI. Furthermore, moderate-severe AHI values (≥ 15) were also observed in men that are ≥ 65 years, American aboriginal, smoker, and obese. Neck circumference was also increased in subjects with high AHI values\textsuperscript{16}. Moreover, there is current evidence supporting the fact that moderate-severe OSA (AHI >15) is the most common contributor to elevated BP in HTN patients from a sample of 125 patients in which 64% of them
had associated severe OSA\textsuperscript{14}. A later review sponsored by the American Heart Association (AHA), estimated that 50\% of patients with HTN have associated OSA, and found epidemiologic evidence to conclude that OSA is a modifiable and highly prevalent factor for HTN. Different mechanisms such as increase sympathetic activity, systemic inflammation, hemodynamic, aldosterone system, nocturnal fluid redistribution, drugs, and age, have been linked to HTN as contributors to poor BP control\textsuperscript{14,20}.

Long-term evidence linking HTN and OSA suggests an increased risk for cardiovascular morbidity and mortality for the population with hypertension. High risk factors for OSA should be evaluated and high-risk patients should be referred by a sleep physician for a PSG study for further assessment since an electrocardiogram (ECG) is also recorded during the study to assess heart rate and cardiac dysrhythmias events. High risk factors for OSA include obesity, male gender, large neck circumference, loud snoring, choking or gasping during sleep, daytime sleepiness, large tongue, and excess of soft palate tissue\textsuperscript{21}. A study of 60 consecutive patients with severe OSA, showed drops in mean BP by 10 mm/Hg after 9 weeks of CPAP use. The study concluded that BP reduction leads to a decrease in stroke risk by 56\% and cardiac event risk by 37\%\textsuperscript{22}. According to a review article in 2004, there is good evidence supporting the fact that OSA contributes to cardiac failure. This is explained by the relationship between OSA and HTN, and the latter as a risk factor for cardiac failure\textsuperscript{23}.

Coronary artery disease (CAD) has been also demonstrated to by linked to OSA. A prospective clinical study on 8 males with an AHI $\sim$50, showed that OSA promotes generalized arteriosclerosis by abnormal endothelial cell function due to repetitive episodes of hypoxemia, activating the sympathetic system and increasing BP. This was measured by changes in forearm blood flow (FBF). OSA subjects had significant blunting of FBF augmentation compared with
the control group. The study concluded that there is an abnormal endothelial mediated resistance vessel vasodilation in OSA subjects24.

A retrospective 7-year follow-up study in a sleep clinic population, with a sample of 182 patients (60 subjects with OSA and 122 subjects as control group), showed 4.9-fold greater chance of developing CVD in OSA subjects. This was independent of BMI, age, and BP. A 36.7% of the study group had at least one CVD observed compared to 6.6% of the subjects in the control group25. Moreover, risk of mortality increased 60% to 70% in patients with CVD and OSA after a 5-years follow-up study of 408 patients aged 70 years or younger. Incidence of cerebrovascular events were 3-fold higher in those patients with OSA26.

Mechanisms by which OSA leads to cardiac episodes such arrhythmias are recorded in a PSG as a vagal tone activity at the initial phase of the apnea event and sympathetic activity towards the end27. Bradycardia was also found in high frequency during the apnea event23. A recent PSG study in a sample of 72 mainland Chinese subjects with nocturnal heart block disease, concluded that OSA appears to be a “trigger” for heart block during sleep, and according to the authors this could be a potential mechanism for bradyarrhythmias8.

1.1.5 Treatment of OSA

OSA requires a multidisciplinary long-term management and it should be considered a chronic disease. The primary treatment options are behavioral, medical, and surgical. Secondary or adjunctive treatments such as positional therapy are indicated as needed2.

Behavioral intervention is the first approach for treatment of OSA. The strategies include weight loss to an ideal BMI of ≤ 25kg/m² by adjusting the diet and incorporating an exercise program, also known as a weight loss program. The positional therapy is another strategy in
which supine position during sleep is avoided, as well as the avoidance of sedatives or alcohol before bedtime. In a recent RCT, 60 obese patients with OSA (AHI ≥ 20, BMI >35 and <55) undergoing CPAP therapy, were randomized into two groups. The first group received bariatric surgery, while the second was subjected to a regular weight loss program. The study found a greater weight loss among the surgical group, but the improvement of OSA severity at 2-year follow-up was statistically similar for both groups. Only a small number of patients that received bariatric surgery were OSA free, leading the authors to suggest that weight loss is not a unique factor for treatment success, and factors such as sex and age are contributors, among other.

Positive Airway Pressure (PAP) therapy has been proven to be efficient in reducing the AHI, and is therefore the preferred treatment for OSA independent of its severity. PAP can be applied through a nasal, oral, or oronasal interface. Depending on how the air pressure is delivered, PAP is divided in 3 types: continuous delivery (CPAP), bi-level delivery (BPAP), and autotitrating delivery (APAP). PAP delivers pressurized air to the airway during sleep, opening the airway and preventing its collapse. CPAP is the most used in treatment of OSA. Titration for adequate PAP levels is typically determined by PSG or auto PAP trial results.

CPAP has been shown to contribute to the elimination of 80% of nocturnal bradycardia in a retrospective study of 72 subjects with OSA (AHI>5) after 3 consecutives days of therapy resulting in an immediate improvement of AHI and oxygen saturation values, as measured by a PSG and a 24-hour Holter monitor. While highly efficient as OSA therapy, CPAP compliance is low, decreasing the overall effectiveness of this therapy in treating OSA. The literature has shown that adherence was only 46% after 6 month, dropping to 17% after 5 years.

An alternative therapy to CPAP is the use of Oral Appliances (OAm). Currently, there are 2 types of oral appliances for the treatment of OSA: The Mandibular Advancing Oral Appliances

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(OAm), and the tongue retaining device (TRD). The OAm modifies the resting position of the lower jaw, anchors on the upper and lower teeth advancing and holding the mandible forward, leading to an enlargement of upper airway lumen. The TRD works similarly by holding the tongue in a forward position but without mandibular advancement. The OAm is not as efficient as CPAP in reducing AHI and improving oxygen desaturation. According to a recent systematic review and a meta-analysis of 14 trials comparing the outcomes of OAm versus CPAP in treatment of OSA, the authors found significant differences in favor of CPAP regarding AHI, arousal index, and partial oxygen saturation. Similar effects of both therapies were found related to change in ESS, quality of life, cognitive performance and blood pressure. At around the same time as the aforementioned review, another RCT measuring the health outcomes of CPAP versus OAm after 1 month of therapy in 126 mostly male patients (81%) with OSA (AHI >10) in Australia, found that CPAP was more efficient than OAm in reducing AHI, but the reported compliance was higher in the OAm group. The authors concluded that the outcome with both therapies are similar, since the greater efficacy of CPAP was offset by its inferior compliance compared to OAm, resulting in an overall similar effectiveness. Moreover, in a review article by the AASM in 2015, established that even though CPAP has better efficacy than OAm in terms of AHI reduction and prevention of obstructive events, when compliance is included the overall effectiveness is similar for both therapies.

In terms of the patient’s preferences, Almeida et al evaluated a sample of 22 patients with a mean age of 60 years. The sample was distributed in 3 groups: 3 subjects being treated with CPAP; 3 subjects with OAm; and 15 subjects with the two modalities. Patients underwent a qualitative analysis during 5 focus group sessions of 45 and 90 minutes long. The study’s
expectations were overall health and sleep improvement, cessation of apnea, reduction of fatigue and snoring, as well as bed partner benefits. A negative aspect of CPAP was reported as a discomfort by making the users feel too hot, face indentations from the mask, lack of mobility, and restriction of the sleep position. Noise was also highly reported, followed by poor fit that contributes to general discomfort and reduces compliance. Another negative aspect reported from CPAP users was claustrophobia from the mask, in form of panic attack. Maintenance and cleaning were also reported as negative.

For the OAm, frequent negative aspects were bite shifting, causing lip and cheeks biting, and chipping teeth. Another factor was poor durability of the appliance, having to replace it after 1.5 to 3 years. Minimal pain was reported immediately after delivery. On the other hand, bed partners were shown to benefit from OAm therapy, reporting better quality of life, described by improvement on rest, increase of happiness and willingness to sleep in the same space as the patient. The authors concluded that the factors influencing choice of treatment are effectiveness, device transportability, cost, bed partner, and power supply. This study may be a source of the characteristics to be used in future surveys which are needed to qualitatively measure patient preference, as well as to contribute to establish patients preferences\textsuperscript{38}.

Another approach for treatment of OSA is either hard or soft tissue surgery, including procedures such as tonsillectomy, adenoidectomy, craniofacial surgery, tracheotomy, and maxillomandibular advancement (MMA)\textsuperscript{34}. Even though they have proven to be highly effective in certain clinical situations, the topic is outside the scope of this literature review.
1.2 Mandibular Advancement Oral Appliance (OAm)

1.2.1 Definition

OAm is defined by the AASM as an intraoral removable appliance for treatment of OSA that anchors on the upper and lower dentition maintaining the mandible in a forward position. The rationale is that mandibular advancement enlarges the upper airway, improving its patency during sleep. Therefore, OAm diminishes the severity of the signs and improves symptoms of OSA\textsuperscript{33}. The AASM clinical guidelines indicate OAm in cases including OSA patients that are: intolerant to or prefer not to use CPAP; do not respond to CPAP; fail CPAP; are not appropriate candidates for CPAP; and in cases in which behavioral measures such as positional therapy or weight loss have been unsuccessful. OAm are also indicated in primary snoring cases in which behavioral therapy has also been unsuccessful\textsuperscript{34}. Since OAm is an intraoral appliance, candidates should have a complete clinical exam, including dental history and intraoral exam including: TMJ, periodontal, and occlusion evaluation, registering occlusal wear pattern in nocturnal bruxism, and soft tissue assessment. Dental records and radiographs including panoramic should be also evaluated. A cephalometric study is an option that might be included. Therefore, candidates should be free dental disease and restricted jaw motion. Patients need to be motivated and have enough motor skills to manage the insertion and removal of the appliance\textsuperscript{33}.

Current guidelines advise that OAm should be managed by a qualified dental practitioner with formal training in sleep medicine and/or breathing disorders with focus on diagnosis, treatment, and follow-up of OSA cases\textsuperscript{34}. 


\textsuperscript{34}Journal of Clinical Sleep Medicine. \textit{The Use of Mandibular Advancement Oral Appliance for Obstructive Sleep Apnea: A Literature Review}. 2019.
1.2.2 Classification

According to Chen et al by 2013, there were more than 100 different OAm designs in the market. They are grouped by fabrication material, location of the couple mechanism, titration capability, degree of customization, amount of vertical opening, and lateral mandibular movement. The AADSM current clinical guidelines describe 4 types of OAm: custom-made, non-custom-made, titratable and non-titratable. A titration mechanism allows customization of the amount of mandibular advancement.

1.2.3 Titration

According to Ferguson et al, titration is defined as the amount of initial advancement set at 70% of the maximum mandibular protrusion (MMP), increasing by a mean of 1.8mm over a period of 3 months until snoring ceases and symptoms improve, or until the patient cannot tolerate further advancement. An extensive review article by the same author mentions that the initial position is usually set between 50% to 75% of the MMP or less if the patient cannot tolerate a large amount of titration. Once the initial position is set, the rate of advancement should be customized until symptoms improve or are resolved, and confirmed by an overnight PSG. A recent 10-year retrospective study set the initial advancement at 75% of MMP, and later increments of 0.25mm until self-reporting resolution of snoring and daytime sleepiness, or until it became uncomfortable for the patient.

A common device used to set the initial amount of mandibular protrusion for an OAm and subsequent titration is the George-Gauge (H-Orthodontics, Michigan City, IN, USA), which allows the clinician to capture a protrusive bite and vertical opening to achieve proper
positioning without the patient’s cooperation. This device has been proven to be accurate and easy to use\textsuperscript{42}.

1.2.4 Efficacy

According to the AASM, efficacy of OAm refers to how well the appliance works in perfect conditions to prevent obstructive events during the intervention, and can be measured by the AHI\textsuperscript{30}. A systematic review of 131 articles identified 4 parameters that modify the efficacy of OAm: OSA severity; amount of mandibular advancement; presence of positional OSA, in which AHI increases in supine sleep position; and BMI. Low success rate has been observed in severe cases of OSA, whereas better success rate has been observed in patients with low AHI. The review also found generally that in most studies analyzed, that the higher the BMI, the lower the efficacy of OAm\textsuperscript{33}. In terms of amount of mandibular advancement as a contributor to efficacy, one of the prospective randomized studies found that the OAm set at 75\% reduces the AHI to < 10 in 52\% of patients, whereas set at 50\% reduces the AHI to < 10 in only 31\% of patients. This RCT supports the idea that the efficacy of OAm improves as the magnitude of mandibular advancement increases\textsuperscript{43}.

A recent retrospective long-term study, found that initial AHI was positively correlated with the magnitude of the overjet reduction, this is expected since mandibular advancement is often greater in severe cases of OSA with an increased AHI\textsuperscript{41}.

1.2.5 Effectiveness

Effectiveness of OAm is defined by the AASM as how well the appliance performs in real conditions\textsuperscript{30}. This definition is based on the concept of “disease alleviation”, which
combines compliance values and therapeutic efficacy\textsuperscript{44}. Compliance of OAm is measured both objectively and subjectively. The objective mean wearing time is obtained by calculating the objective mean rate of OAm use, by the number of hours of use per day, on a percentage of days of use per week. Patients are considered to have good or acceptable compliance when the objective mean wearing time is $\geq 4$h per day on at least 70\% of the week\textsuperscript{31}. Use of specific sensors to objectively assess compliance was demonstrated in a recent prospective clinical trial. The investigators used a temperature-sensitive micro sensor embedded in the OAm to successfully measure objective compliance in 51 OSA subjects with a mean age of 49.3 years, and a mean $\text{AHI} \sim 15$, in 1- and 3-months follow-ups. The study measured wearing time when the sensor recorded a temperature above 35\degree C. The median OAm use was 6.4 hours per night at 3-month follow-up\textsuperscript{45}.

The “Adjusted Compliance” is used as a way to objectively assess self-reported compliance by adjusting it with the total sleep time (TST), which is collected by recording daily during a 3-months period. In other words, the adjusted compliance is the result of the objective mean rate, expressed in hrs/day and \% day/week divided by TST\textsuperscript{46}. The overall therapeutic efficacy is obtained by the difference between the baseline $\text{AHI}$, and the $\text{AHI}$ after OAm use, expressed as a percentage. The Mean Disease Alleviation (MDA) is thus defined as the area expressed by the rectangle formed in a Cartesian graph when the therapeutic efficacy value, and the adjusted compliance value, are traced in the vertical and horizontal axis respectively\textsuperscript{46}(Figure 1). When $\text{AHI}$ is reduced by at least 50\% from baseline, the patient is said to respond to treatment. Treatment success is defined as a $\text{AHI} < 5$ events per hour on the follow-up PSG after
Another author has used the subjective measure of reduction of snoring expressed by a VAS $< 3$ as the success criteria$^{47}$.

**Figure 1 Mean disease alleviation.**

![Figure 1](image)

**Adapted from Vanderveken et al 2013$^{46}$**

1.2.6 **Efficacy of OAm vs CPAP**

A review of the literature of 131 articles over a 10-year search period, concluded that patients with mild to severe OSA have a 52% chance of controlling their sleep apnea with OAm. It also concluded that OAm is less effective than CPAP but may be better accepted by patients than nasal CPAP. OAm are not indicated as a first choice to treat patients with severe OSA (AHI $> 30$). On each of the cross-over studies CPAP reduced AHI to lower levels in almost all patients, whereas OAm only did so in 2/3 of the patients$^{33}$. Daytime sleepiness, measured through ESS has been shown to decrease after use of OAm, albeit only in short-term studies$^{43}$.

CPAP has also been effective in decreasing BP. A randomized clinical trial of 39 adults with OSA (RDI $> 15$), receiving weekly CPAP and non-titrated CPAP, found that BP decreased at daytime in both groups. The RDI also decreased for the CPAP group$^{48}$. 

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1.2.7 Qualitative Assessment

A Qualitative Assessment is obtained by subjective questionnaires regarding daytime sleepiness, snoring, and side effects. Daytime sleepiness is commonly assessed by the Epworth Sleepiness Scale (ESS), which is a self-administered survey that measures sleepiness by scoring the probability of falling asleep in 8 different scenarios. ESS total score range from 0 to 24, a score of ≥11 is considered excessive daytime sleepiness. ESS and Berlin Questionnaire (BQ) have been used in several studies to evaluate subjective treatment effectiveness of OSA treated with OAm. The ESS test has been validated by a prospective study of 87 adults as a simple, highly reliable and internally consistency method to assess daytime sleepiness.

A recent prospective clinical study of 128 adult patients, compared 3 questionnaires (BQ, Stop-Bang, and Sleep Apnea Clinical Score (SACS)), concluded that surveys alone cannot rule out the presence of OSA. It was also concluded that an objective PSG study is critical for diagnosis and exclusion of OSA.

Another tool for snoring assessment is the visual analog scale (VAS), which is a subjective report of snoring by the bed partner using a 10-point VAS from 0 to 10, in which 0 is no snoring and 10 is snoring that causes the bed partner to leave the room. VAD ≥ 7 is considered heavy snoring. A decrease in VAS post-treatment of at least 3 points is considered satisfactory. Ideally, snoring should be reduced to a level where it is no longer bothersome, defined as VAD ≤ 3. An RCT using OAm reported an 83% of 24 subjects with combined improvements in snoring, sleep quality, and daytime sleepiness. The majority (87.5%) tolerated well the appliance, suggesting that OAm is an effective treatment for snoring.

Quality of life relating to OSA has been evaluated by the Nottingham Health Profile (NHP), which includes 38 items assessing 6 dimensions: sleep, energy, physical mobility, pain,
social isolation, and emotional reactions. The answer for each item is closed (yes=1 or no=0), and a final score is calculated for each dimension by adding the weighted score for each item. The score for each dimension ranges from 0 (“excellent perception of health”) to 100 (“very poor perception of health”)\textsuperscript{57}. A prospective clinical study of 66 subjects has showed that NHP improved in 4 out of 6 dimensions after OAm use\textsuperscript{58}.

Patient preferences have been evaluated by Almeida et al in 22 patients through a qualitative analysis using a custom questionnaire during five focus group sessions of 45 and 90 minutes long. This study aimed to better understand patients’ preference for OAm or CPAP in areas such as expectations of treatment, side effects, overall health and sleep, cessation of apnea, reduction of fatigue and snoring, experience with the appliance, as well as the bed partner benefits were evaluated. The study found that the main reason for seeking treatment is improvement of the overall health, followed by apnea elimination and improvement of sleep. Among factors impacting the treatment choice, device effectiveness was the most mentioned. The study concluded that lifestyle and individual needs were found to be the main factors related to patients’ experience with OAm or CPAP\textsuperscript{38}.

1.2.8 Side Effects of OAm

According to Ferguson et al, side effects can be divided into minor or temporary, and moderate to severe. Minor side effects include TMJ pain, myofascial pain, tooth pain, salivation, TMJ sounds, dry mouth, gingival irritation and morning-after occlusal changes. More severe and continuous side effects included TMJ pain, myofascial pain, tooth pain, gingival pain, dry mouth and salivation\textsuperscript{33}. Side effects such as tooth sensitivity, tooth pain, hypersalivation, xerostomia, and TMJ pain, have been consistently reported in the literature\textsuperscript{45,58-61}. Among the short term side
effects, excess of salivation, mucosal dryness, and tooth pain have been reported to be present in about 40% of a sample of 66 patients treated with OAm\textsuperscript{58}. A randomized prospective cross-over study in 27 patients, showed minor side effects during the first month of treatment, including hypersalivation, and sore teeth and jaw. After 4 months, 36% of the patients had mild persistent side effects and 45% had no side effects at all. No TMD was developed among the sample\textsuperscript{35}. A later RCT study of 24 subjects showed that 50% had hypersalivation, 20% gingival irritation, and 12.5% tooth grinding, lasting less than 3 weeks\textsuperscript{56}.

OAm positions the mandible forwards anchoring on the dentition. According to a recent study, the force required to maintain this new position are in the magnitude of 13.6N or 1,387 gF. This force is transmitted to the teeth resulting in occlusal changes due to tooth movement. The study concluded that dental side effects associated with long-term use of OAm, can have a possible dose-dependent effect, meaning that the greater the forces received by the teeth, the more the occlusal changes\textsuperscript{62}.

A randomized controlled trial of 103 patients with a mean age of 49 years with severe OSA (AHI > 30), showed small but significant dental changes at ~2-year follow-up. Cephalometric analysis showed that overbite decreased by 1mm and overjet by 1.7mm, whereas the upper incisors retroclined by 2° and lower incisors proclined by 3.7°. The anterior facial height was significantly increased by 0.9mm. An association between the overbite reduction and the amount of mandibular protrusion was observed in the study\textsuperscript{42}. A later short-term retrospective study of 20 subjects showed similar results in dental and skeletal changes, although they claimed this change were clinically irrelevant\textsuperscript{63}.

 Longer-term dental changes can be expected to be more severe since the OAm is being worn for a longer time. Several cephalometric studies have confirmed larger changes in the
overjet and overbite as well as the incisor position and inclination. The first long-term follow-up study was published in 2006, evaluating 71 patients with a mean treatment length of 7.3 ± 2.1 years, found a significant reduction of overjet and overbite. The study found a mean overbite reduction of 2.8mm and a mean overjet reduction of 2.6mm. The upper incisors showed a significant retroclination of 3.1°, and the upper molar tipped distally by 2.3°. The lower incisors proclined 6.6°, the molars tipped mesially 3.4°, and the mandibular plane rotated downward 0.7°. The aforementioned sample was also analyzed in cast models, showing no occlusal changes in 14.3% of the casts, while 85.7% of them showed occlusal changes such as increase in mandibular arch length, mesial shift of the mandibular teeth, and decrease in overbite and overjet. As for changes in occlusion, a 44.3% of the sample had unfavorable changes, while 41.4% had favorable changes. The favorable group was, at the initial evaluation, class II malocclusion with a greater overbite and overjet than class I patients. Unfavorable changes in the occlusion such as anterior edge-to-edge or anterior or posterior cross-bite were observed in class I malocclusion patients.

A systematic review of 14 studies that involved a total of 389 patients with a mean follow-up of 39 months, showed that the overbite decreased 1.4mm and overjet decreased 1.3mm. A newer 5-year prospective study of dental side effects in 15 Spanish patients showed a mean reduction of overbite and overjet by 0.81 and 1.1mm respectively, as well as reduction in posterior occlusal contacts. No increase in TMD prevalence was found in this study. The longest long-term study to date was a recently published 10-year retrospective study of 77 OAm patients who were mostly mildly obese adult males, treated for primary snoring or mild to severe OSA. The study concluded that there are significant progressive changes in occlusion over time, such as an increase of incidence of anterior crossbite of at least one tooth in 62% of the sample,
and posterior open bite in 51% of the sample. Posterior open bite was caused by premature anterior contacts generated by the long-term use of the appliance. Other changes in the occlusion were observed as reduction in overbite and overjet of about 2mm on average, however with considerable individual variation. An expansion effect was observed in the lower arch as a decrease in crowding by 1.3mm, and an increase in the mandibular intercanine and intermolar widths by 0.7mm and 1.1mm respectively. The dental side effects associated with long-term use of the OAm in this study were found to be similar to the functional appliances for correction of class II malocclusion. A recent prospective observational long-term study of 41 consecutive patients showed significant changes in overjet (-1.8mm) and overbite (1.5mm) as well as an increase in class III molar occlusion and posterior open bite when casts were evaluated. They suggested class III subjects may not be candidates for treatment due to the mesial tip of the lower dentition caused by long-term use of OAm.

1.3 Orthodontic Mini-Implants (OMIs)

OMIs have been used in orthodontics with the purpose of obtaining absolute anchorage, allowing selective tooth movement, therefore facilitating mechanics and improving orthodontic outcomes. They are defined as: “a device that is temporally fixed to bone for the purpose of enhancing orthodontic anchorage either by supporting the teeth of the reactive unit or by obviating the need for the reactive unit altogether, and which is subsequently removed after use.”

1.3.1 Classification

Orthodontic mini-implants (OMI) are also known as a Temporary Anchorage Device (TAD) as they are temporarily placed into the jawbone for orthodontics purposes. On the other
hand, implanted support prosthesis is considered non-temporary device. OMIs are classified according their location related to the periosteum as: subperiosteal, transperiosteal, and endoperiosteal. They are also classified as mechanical or biomechanical according to their fixation to the bone. The mechanical fixation is obtained by cortical bone stability, and the biomechanical fixation is obtained by an osseous-integration process. OMIs are fixed mainly mechanically by cortical bone stability. They can also be classified according to their length, diameter, thread width, thread pitch, and head/end configuration. OMIs should be at least 1.5 mm in diameter and periodontal tissues should be in optimal conditions. They should ideally be easy to place, small, immobile, biocompatible, immediately loadable, and inexpensive, among other requirements\textsuperscript{68}.

\subsection{Initial Stability and Effects of Loading}

Initial or primary stability is the main goal for non-osseointegrated implants. The maximum load applied to OMIs has to be proportional to the surface of the bone contacting them\textsuperscript{68}. According to a bone mineral density study on 20 bovine pelvic bone sections, the cortical bone density plays a major role in the initial stability of the OMIs\textsuperscript{70}. A previous study in 32 patients with an average age of 24.4 years used CT images to measure cortical bone thickness for OMI planning location and the OMIs were placed by pre-drilling method. The OMIs used had 1.6mm diameter and 8mm length and were loaded immediately after insertion. The results showed that the cortical bone thickness was significantly thicker in OMIs later deemed successful. The authors concluded that cortical bone thickness should be at least 1mm\textsuperscript{71}. A later, similar study by the same author, evaluated a larger sample of 65 subjects with an average age of
24.8 years, having also concluded that cortical bone thickness ≥1mm improves the success rate of OMI\textsuperscript{72}.

Bone density in the mandible has been proposed as a contributing factor for OMIs failure compared to OMIs place in the maxilla. A systematic review by Papageorgious et al concluded that a greater bone density, particularly on the mandible, leads to higher torque forces causing bone overheating or microfracture during the insertion. According to the author, bone density is one of the main reasons for the increased failure rate in the mandible. Another factor mentioned is narrower vestibule, making the area difficult to access and clean\textsuperscript{73}.

Primary stability has also been related to the length of the OMI. In a short-term prospective clinical study, 27 women with an age range from 20 to 23 years, received 2 OMIs each of 6- or 8-mm length, in randomized mandibular quadrants, following the spilt-mouth model method. The OMIs were loaded after 2 weeks, in order to retract the lower anterior teeth with 100g to 150g force through a NiTi spring. After an average of 9 to 12 months, the authors concluded that 8mm length OMIs were significantly more stable than 6mm, with a 1-year stability of 81.5% and 66% respectively\textsuperscript{74}. These findings are in line with an earlier systematic review of 16 articles, which concluded that OMIs should be at least 6mm length, suggesting that the longer the screw the better the stability\textsuperscript{75}.

Regarding location of the OMIs insertion, a main factor is the root proximity, which has been reported by Kuroda et al to be one of the major risk factors for screw failure, after analyzing radiographs and 3-D CT scans of 216 screws in 110 patients\textsuperscript{76}.

A Systematic Review in 2012, involving 52 studies, 2281 patients, and 4987 OMIs, found that the overall OMIs success rate in orthodontics is 86.5%, and is dependent mainly in 2 factors: whether there is screw-root contact, or screw placement in the mandible\textsuperscript{73}.
In a later study, it was concluded that the OMI should be placed as apical as possible to avoid root proximity, since there is a wider interradicular space available. OMIs should also be placed in keratinized tissues to avoid soft tissue complications. It was also determined that an oblique insertion path decreases the possibility of root contact and increases the initial stability by cortical bone contact. This study concluded that the self-tapping method (pilot hole) and those which limit torque, also improve initial stability. Root proximity is related to the interradicular space available, which must be larger than 3mm\textsuperscript{77}.

A CT study published in 2009, evaluated the interradicular space in 30 maxillary and 30 mandibular teeth in a non-orthodontic adult sample with normal occlusion. The variables studied were bone thickness and interradicular distance at four different heights from the CEJ. Interradicular space ≥3mm was found at 8mm from the CEJ of maxillary incisors and premolars, and ≥4mm between second premolar and first molar. In the mandible, adequate interradicular space was found at ≥4mm between premolars, molars, and second premolar and first molar. Adequate height ≥4 mm was found in all intermolar regions, and between the second premolar and the first molar in all arches\textsuperscript{78}.

Cheng et al evaluated 140 OMIs in 44 patients, and found a cumulative survival rate of 89%, and a reported estimated relative risk failure of 1.101 at the posterior mandible. According to the authors, the risk of failure in the posterior mandible may be related to a narrow attached gingiva and a small vestibule, as well as access difficulty due to anatomic factors\textsuperscript{79}.

Another factor for OMI failure is loading timing. This was evaluated by a recent retrospective cross-sectional study of 570 consecutive, mostly female patients with a mean age of 42.7 years (range:12–73 years), during a 10–year period. The sample received OMIs as part of their orthodontic treatment, and they were immediately loaded, having an 89.10% success rate.
The study concluded that main factors for failure are the length of the screw and the jaw location. The short OMIs (5-6 mm) showed significant chance of failure (25.35%) compared to longer ones. A significant screw failure was also observed in the mandible (16.33%) compared to the maxilla (7.35%)\(^\text{80}\).

In-vitro studies have analyzed forces applied to OMIs by Finite Element Analysis (FEA) in a range of 2 to 6N in magnitude (Table 1)\(^\text{81-84}\). Lui et al applied forces of magnitude of 2, 4, and 6N on different types of OMIs that varies in diameter and length. They found that stress on the cortical bone increased as cortex thickness decrease under the same loading conditions. An increase in force magnitude resulted in higher stress on the cortical bone as 6N model had 3 times the stress in bone than the 2N model. No failure rate was reported\(^\text{81}\). Another study of 26 OMIs placed in alveolar block models loaded the OMIs with a linear force of 2N showing that most of the stress in bone is transmitted to the cortex, but again the failure rate was not reported\(^\text{82}\). A later study analyzing the stress distribution of OMI in cortex applying a force of 2N to OMIs of different lengths found that the stress levels increase as the OMI length outside the bone increased. No OMI failure rate was posted\(^\text{83}\). A recent study that aimed to evaluate the OMI angle of placement and direction of force applied on stability of OMI, used a 2N of force to test the OMIs by using FEA and found that a 90-degree angle provided better anchorage than the angle inserted OMI. No failure rate was reported\(^\text{84}\). A current study using FEA also applied a 2N force on OMIs placed at 4 insertion angles concluded that oblique inserted OMI provides enough anchorage for the force applied. No OMI failure rate was reported\(^\text{85}\).
Table 1 In-vitro OMI under heavy forces.

<table>
<thead>
<tr>
<th>Study</th>
<th>Description</th>
<th>Type of Force</th>
<th>Type of Appliance</th>
<th>Forge Magnitude</th>
<th>OMI Failure Rate</th>
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<td>Liu 2012</td>
<td>Finite Element Analysis</td>
<td>Shear</td>
<td>None</td>
<td>2, 4, 6 Newtons</td>
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<tr>
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<td>Finite Element Analysis 26 OMIs</td>
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<tr>
<td>Kuroda 2017</td>
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<td>Shear</td>
<td>None</td>
<td>2 Newtons</td>
<td>Not Reported</td>
</tr>
</tbody>
</table>

1.3.3 OMI for Mandibular Advancement

There is limited literature regarding the use of OMIs for mandibular advancement. A case report was published in 2010 by de Carlos et al, in which a 49-year-old edentulous patient having OSA (AHI 25) was treated with 4 OMIs. 2 OMIs were placed at the subanterior nasal spine region in the maxilla bilaterally, and 2 OMIs at the level of the external oblique ridge also bilaterally. Intermaxillary elastic bands of 6-9 oz. were used for 2 months. This treatment modality dropped AHI values from 25 to 2.1 per hour. The study concluded that this approach could be an alternative to treat edentulous patients with OSA. Another case report published in the same year in the Korean Journal of Orthodontics, in which a 66-year-old adult with severe OSA received 2 OMIs in the mandible that were connected to a titratable OAm, and a custom facemask, showed a reduction of AHI, snoring, and OSA symptoms. In a later prospective clinical study by the same authors, 10 adults (60 ± 9.25 years) in which their mandibles were advanced using OMIs connected to a reverse facemask by rubber bands, it was found that this approach was efficient in reduction of AHI, and snoring, among other values. The force was applied 2 weeks after OMIs placement, but its magnitude was not specified. The OMI success rate was 80%, mainly due to mobility (Grade 1 or 2). OMIs used in this study were supplied by Dentos (Korea) and had a diameter of 1.6mm, and length of 10mm.
1.3.4 **OMIs Under Heavy Forces**

There are presently no in-vivo studies about heavy forces applied to OMIs when the mandible is advanced. Nevertheless, there are a few articles that have studied OMIs to indirectly anchor canines while combined with Herbst appliance (Table 2).

A recent prospective clinical study of 12 treated cases matched by age and gender in which OMIs are anchored to the Herbst appliance by an elastic chain exerting 4N of force for 4.6 months with the purpose of preventing incisor proclination. The OMI failure was 30% and they concluded that OMIs cannot prevent anchorage loss during treatment with a Herbst appliance\(^9\).

A later prospective clinical study of 60 patients (11.6 years/ SD 1.9) using an acrylic splint Herbst appliance and canines anchored to an OMI with Class II Division 1 malocclusions, also aimed to prevent incisor proclination. The sample was divided in 3 groups: without anchorage control; canines anchored to OMIs by elastic chains to canines; and by steel ties. The force applied to the OMIs was equivalent to 100g. After 7.4 months of treatment, all groups showed mandibular incisor flaring. All groups also resulted in mesial movement of the lower molars and overjet reduction. The OMIs failure rate in this study was 17.5\%\(^9\).

A recent randomized clinical trial using a conventional Herbst appliance combined with OMIs. The OMIs were used to anchor the lower canines by a metal ligature in a sample of 40 young patients (10-14 year of age) with Class II division 1 malocclusion. This RCT aims to evaluate lower incisor proclination with CBCT and has not yet reported results including OMI failure rate\(^9\).
A recent study measured the forces required for positioning the mandible forwards at 11.4 ± 2.4mm with the custom OAm, the overall force to reach the mandibular advancement was 13.6N (1387.4 gF) in magnitude after correction for friction\(^2\). On the other hand, retrusive force of the mandible after being advanced has been measured by a prospective clinical study of 18 adults that wore an occlusal splint with a hook attached to a tension/compression load cell and a transducer. The study found a maximum retrusion *effort* force of 198.2N at 7mm of mandibular advancement. The retrusive force progressively increases as the mandibular advancement increases from 0mm to 7mm with a 1mm increment. According to the authors, a single implant might not withstand the forces found\(^2\).

<table>
<thead>
<tr>
<th>Study</th>
<th>Description</th>
<th>Type of Force</th>
<th>Type of Appliance</th>
<th>Force Magnitude</th>
<th>OMI Failure Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bremen 2015</td>
<td>Prospective 12 cases Indirect anchorage to OMI</td>
<td>Shear</td>
<td>Herbst 4.6months</td>
<td>4 Newtons</td>
<td>30%</td>
</tr>
<tr>
<td>Manni 2016</td>
<td>Prospective 68 children Canines anchored to OMI</td>
<td>Shear</td>
<td>Acrylic Split Herbst 7.4months</td>
<td>100grs 1 Newton</td>
<td>17.5%</td>
</tr>
<tr>
<td>Batista 2017</td>
<td>RCT 40 cases Canines anchored to OMI</td>
<td>Shear</td>
<td>Herbst</td>
<td>Not Reported</td>
<td>Not Reported</td>
</tr>
</tbody>
</table>
Chapter 2: Clinical Trial

The present thesis is based on a previous pilot in-vitro study performed at University of British Columbia, Faculty of Dentistry by Dr. Benjamin Pliska and biomechanics engineering students that consisted of designing a novel oral appliance for the treatment of OSA anchored on OMIs with the goal of avoiding long-term side effects such as tooth movement. This new treatment could lead to better health outcomes for OSA patients by reducing the common side effect of tooth movement typically observed with long-term OAm use.

The novel appliance was fabricated with a CAD/CAM process - designed using SolidWorks™ software and then printed by using 3D printing technology. The prototype was tested in models that were mounted in an articulator, achieving good stability (Figure 2). OMIs were chosen as an anchorage mechanism since they are widely used in Orthodontics for anchorage purposes, relatively easy placement technique, high success rate, minimal side effects and lack of scar tissue after removal (Figure 3).

Figure 2 Prototype of novel oral appliance.  
Figure 3 Prototype of optimal OMI location.

Pictures provided by Dr. Benjamin Pliska, UBC Faculty of Dentistry, Vancouver, BC.
This pilot clinical trial represents the next step in better understanding the appliance design and evaluating the patient experience. This study complied with the Heath Information Protection Act (HIPA), and was approved by the Research Ethics Board at the University of British Columbia (UBC) H17-03108.

2.1 Objective

The objective of this study is to test a novel oral mandibular advancement appliance in patients with OSA and to better understand the appliance design and patient experience with the novel OAm.

2.2 Methodology

2.2.1 Sample

We aimed for a sample of 10 adult OSA patients that were successfully treated with OAm, from the UBC Sleep Apnea Clinic and from the private practice of Dr. Fernanda Almeida, both in Vancouver, BC.

2.2.2 Inclusion and Exclusion Criteria

The goal for the inclusion and exclusion criteria for patient selection was to remove as many confounding factors as possible to better understand the treatment effect. This was accomplished by recruiting only healthy, non-obese individuals. Table 3 and Table 4 contain the inclusion and exclusion criteria respectively.
### Table 3 Inclusion criteria.

<table>
<thead>
<tr>
<th>Inclusion Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Currently received or have previously received successful OSA treatment with an OAm;</td>
</tr>
<tr>
<td>Age 25 - 65 years old, who are able to freely provide informed consent;</td>
</tr>
<tr>
<td>Body Mass Index (BMI) ≤ 35;</td>
</tr>
<tr>
<td>AHI within the range 5≤AHI≤50 documented with PSG in the last 2 years, or</td>
</tr>
<tr>
<td>RDI within the range 20 ≤ RDI ≤ 50 documented with level III portable sleep test, or</td>
</tr>
<tr>
<td>Oxygen Desaturation Index (ODI) ≥ 10</td>
</tr>
</tbody>
</table>

### Table 4 Exclusion criteria.

<table>
<thead>
<tr>
<th>Exclusion Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extensive periodontal disease</td>
</tr>
<tr>
<td>Uncontrolled bleeding disorder</td>
</tr>
<tr>
<td>Uncontrolled bone metabolic disorder</td>
</tr>
<tr>
<td>Uncontrolled Immunocompromised</td>
</tr>
<tr>
<td>Uncontrolled Diabetes mellitus</td>
</tr>
<tr>
<td>Severe Xerostomia</td>
</tr>
<tr>
<td>Titanium allergy</td>
</tr>
<tr>
<td>Insufficient vertical opening to accommodate treatment with OAm;</td>
</tr>
<tr>
<td>Pregnancy (if a participant becomes pregnant during the trial, the participant will be withdrawn from the study).</td>
</tr>
<tr>
<td>Uncontrolled congestive heart failure (defined as a prior clinical diagnosis, an ejection cut-off of 40% or clinical sign in the opinion of a primary care physician or cardiologist) that makes it unsafe in the opinion of the investigators for the subject to participate in the trial;</td>
</tr>
<tr>
<td>Coronary artery disease unless stable for at least 6 months and considered by the investigators to have a stable disease;</td>
</tr>
<tr>
<td>Any history of angina, myocardial infarction or stroke;</td>
</tr>
<tr>
<td>Any history of major depressive disorder along with current moderate-severe disease;</td>
</tr>
<tr>
<td>Active cancer management (unless in remission for more than 1 year);</td>
</tr>
<tr>
<td>Known renal failure (with need for dialysis)</td>
</tr>
</tbody>
</table>
2.2.3 Clinical Protocol

A protocol for each clinical visit was developed, including baseline and final records, OMI insertion/re-insertion, and a clinical workflow. The novel appliance was planned to be inserted 4 weeks after OMIs placement and discontinued 4 weeks after delivery, with the patient having the choice to continue wearing the appliance if effective. Sleep data was planned to be collected before and after the intervention aiming to establish equivalent effectiveness between traditional OAm and the novel OMI supported oral appliance. Total trial time, for each subject, was planned to be 3 months.

2.2.3.1 Trial Visits

After initial recruitment, candidates were given at least a week to read through the informed consent document and ask questions before the trial began. A total of 6 visits per patient over a 3-month period were planned. A protocol was developed for each visit (see Visit Protocol). The visits included baseline records, OMIs placement, appliance insertion, 1-week follow-up, and final records at 4-weeks follow-up. An additional re-insertion visit was accounted for any OMI that fell off or became mobile. Baseline and final records were planned to be taken at visit 1 and 5 respectively and include 5 intraoral photos and 3 extraoral photo, an intraoral scan (TRIOS™-3Shape), panoramic and cephalogram radiographs (Planmeca™ ProMax), and a single overnight in-home sleep study with a Level III PMD (Alice NightOne™). Sides effects such as gingival irritation, soreness as well as patient perception were recorded after OMIs placement and appliance insertion. If the novel appliance was successful, the participants would have the option to continue wearing the new OAm device or remove the OMIs and return to
using the conventional appliance. Below is a summary of patient flow and visits for the study (Table 5).

**Table 5 Visit workflow.**

<table>
<thead>
<tr>
<th>Visit</th>
<th>Week</th>
<th>Time</th>
<th>Procedure</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visit 0</td>
<td>Week 0</td>
<td>N/A</td>
<td>Eligibility and Consent</td>
<td>Introductory phone interview for eligibility. Review study and answer questions. If eligible mail a copy of the informed consent.</td>
</tr>
<tr>
<td>Visit 1</td>
<td>Week 1</td>
<td>120 min</td>
<td>Baseline Records</td>
<td>Medical history; Dental and oral exam; Standard ortho records; Sleep monitor delivery; ESS; Sleep diary. Answer questions.</td>
</tr>
<tr>
<td>Visit 2</td>
<td>Week 2</td>
<td>90 min</td>
<td>OMI Insertion</td>
<td>OMI Insertion; Titration; Intraoral scan and STL file.</td>
</tr>
<tr>
<td>Visit 2.1</td>
<td></td>
<td>90min</td>
<td>OMI re-insertion/removal</td>
<td>As needed Record side effects</td>
</tr>
<tr>
<td>Visit 3</td>
<td>Week 4 to 8</td>
<td>60min</td>
<td>Appliance insertion</td>
<td>Instructions, adjustments, side effects</td>
</tr>
<tr>
<td>Visit 4</td>
<td>Week 5 to 9</td>
<td>45 min</td>
<td>Appliance 1-week follow-up</td>
<td>Side effects, adjustments</td>
</tr>
<tr>
<td>Visit 5</td>
<td>Week 9 to 13</td>
<td>120 min</td>
<td>Final records</td>
<td>Standard ortho records; Sleep monitor delivery; ESS; Questionnaires; Sleep diary; Arrange possible OMI removal</td>
</tr>
<tr>
<td>Visit 6</td>
<td>Week 11</td>
<td>30 min</td>
<td>OMI removal</td>
<td>End of trial</td>
</tr>
</tbody>
</table>
2.2.3.2 OMIs Insertion

A total of 6 OMIs for each subject were inserted: 4 in the maxilla, and 2 in the mandible. Panoramic radiographs and photos were evaluated by two investigators (BP, MNG) to determine the optimal location of the OMIs according to bone quality, cortical thickness, root proximity, and height of keratinized tissues. The preferred location in the maxilla was in the buccal alveolar process, distal to the canine and mesial of the first molar. The preferred location in the mandible was in the buccal alveolar process distal to the first molar. However, OMI location could vary depending on the specific patient anatomy. The OMIs (Dentos™ Model SH 1615-06) used in the study were 6mm length by 1.6mm diameter at the collar and 1.5mm at the tip. A 1mm collar was incorporated to allow enough soft tissue clearance from the appliance. The OMIs were inserted under topical anesthetic (Lidocaine 12.5%; Prilocaine 3%; Tetracaine 12.5%; Phenylephrine 3%) using a self-tapping method with a customized driver (Dentos™) by investigator MNG under BP supervision. If an OMI presented with Grade 2 mobility (>1mm) or if fallen off, was considered failure and another OMI was inserted after about 2 weeks. The new location varied according to the mucogingival junction (MGJ) height and interradicular distance. The OMIs were loaded 4 to 8 weeks after insertion allowing time for the device to be sized and manufactured, and for the OMIs to anchor into the bone. During this time, patients continued using their existing traditional OAm appliance. The conventional appliance was adjusted to relieve any contact to the inserted OMIs to reduce OMI failure. Regular communication via phone calls, emails, or text messages were planned. Any extra visit related to patient care or emergency was available to the participants.
2.2.3.3 Prototype OAm Design

The novel appliance was a computer-aided designed and manufactured (CAD-CAM) device fabricated with a biocompatible polyvinyl material (Oceanz BV, The Netherlands). The appliance consisted of an upper horseshoe shape crossing the midline and extending 2-3mm distal to the most distal OMI (Figure 4); and 2 individual sidebars attached to a Post in the appliance located 4mm anterior to the most anterior OMI (Figure 5). The sidebars attached to the Post and to the mandibular OMIs at an ideal inclination of 45° or less to obtain required mandibular advancement (Figure 6). The new device was customized for each subject by Vivian Chung, a Professional Engineer at Robert H.N. Ho Research Centre in Vancouver, BC, from a full mouth digital scan in a form of a STL file. Rendering and sizing were performed with SolidWorks™ software. The appliance was fabricated, and 3D printed by Oceanz™ lab in The Netherlands, which complies with ISO 9001 and 13485 standards. The side bars were sized to provide the same amount of mandibular protrusion as each patient’s original titration with their existing OAm. Appliance care and management instructions were planned to be discussed at the insertion visit.
The red arrow (1) indicates the Post, which is the anterior point of attachment; The right green (2) arrow indicates the socket for the OMI head; The left green arrow (3) indicates the area where the posterior OMI rests. Provided by Dr. Benjamin Pliska, UBC Faculty of Dentistry, Vancouver, BC.

Figure 5 Sidebar and socket design drawing

Provided by Dr. Benjamin Pliska, UBC Faculty of Dentistry, Vancouver, BC.
2.3 Data Collection

Patient information was kept in a master list that was stored on an UBC secured server. Each patient was assigned to an ID number in order to protect personal information. A summary of data collection at different stages of the trial is shown in Table 6.

Standard orthodontic records and respiratory sleep parameters were planned to be collected at baseline and 4-weeks after the appliance delivery. Sleep study data was scored blindly by an independent sleep technician. The sleep data included AHI, oxygen saturation, and ESS that measure daytime sleepiness (see Sleep Related Forms). Comparison of AHI between baseline with the traditional OAm and the follow up with the novel device was planned to be the primary outcome to determine equivalent effectiveness. Night-to-night variability of AHI was arbitrarily set at 5 episodes per hour. In addition, side effects such as implant mobility, gingival
irritation, and soreness, were collected by tactile and/or visual assessment. Additional information collected included years in treatment, existing titration, amount of crowding, and OMIs insertion location.

Compliance was obtained by using a self-reported sleep dairy (see Sleep Related Forms) to record number of hours per day of appliance wear, and number of days per week of use for each appliance. Reason(s) for switching from the new device to the conventional one was also to be self-recorded. Optimal compliance was defined as >4hrs of wearing time per night on at least 70% of the nights in a week. Compliance failure was defined as the inability or unwillingness of the patient to wear the appliance.

Patient experience was evaluated at the insertion visit by asking the patient about his/her perception in terms of bulkiness and protrusion of the appliance. Pain and discomfort when attaching the side bars were also recorded. Pain and soft tissue soreness were recorded by phone follow-up at 1, 3, 7 days post-insertion.

Table 6 Summary of data collection.

<table>
<thead>
<tr>
<th>T0 Baseline Records</th>
<th>T1 Appliance Insertion</th>
<th>T2 Final Records</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orthodontic Records</td>
<td>OMI mobility</td>
<td>Orthodontic Records</td>
</tr>
<tr>
<td>In-home sleep study</td>
<td>Patient Experience</td>
<td>In-home sleep study</td>
</tr>
<tr>
<td>Epworth Sleepiness Scale</td>
<td>Pain and Soreness</td>
<td>Epworth Sleepiness Scale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Patient Compliance - Sleep Diary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Patient Experience</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pain and Soreness</td>
</tr>
</tbody>
</table>
2.4  Results

2.4.1  Demographics

A total of 6 patients were recruited for the trial, but only 3 patients (2 Males and 1 Female) agreed to participate in the study. Sample mean age was 52.7 years with a range of 25 years. Mean years in treatment with oral appliances was 4.2 years. AHI was mild in 2 cases, and moderate in 1 case. Incisors were proclined in all participants (Table 7).

Table 7 Sample demographics.

<table>
<thead>
<tr>
<th>Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>53 years</td>
<td>65 years</td>
<td>40 years</td>
</tr>
<tr>
<td>Sex</td>
<td>M</td>
<td>M</td>
<td>F</td>
</tr>
<tr>
<td>Years in treatment</td>
<td>6 years</td>
<td>1 ½ years</td>
<td>5 years</td>
</tr>
<tr>
<td>BMI</td>
<td>25.30 Kg/m²</td>
<td>22.87 Kg/m²</td>
<td>26.60 Kg/m²</td>
</tr>
<tr>
<td>Neck Circumference</td>
<td>37cm</td>
<td>38.5cm</td>
<td>32.5cm</td>
</tr>
<tr>
<td>AHI</td>
<td>5.7</td>
<td>27</td>
<td>6.9</td>
</tr>
<tr>
<td>Mean Oxygen Saturation</td>
<td>98%</td>
<td>95%</td>
<td>96%</td>
</tr>
<tr>
<td>ESS</td>
<td>5</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Skeletal Class</td>
<td>II</td>
<td>I</td>
<td>II</td>
</tr>
<tr>
<td>Dental Class</td>
<td>II Div 2</td>
<td>II right, I left</td>
<td>I</td>
</tr>
<tr>
<td>OB</td>
<td>40%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>OJ</td>
<td>2mm</td>
<td>2mm</td>
<td>0mm</td>
</tr>
<tr>
<td>L1 to MP</td>
<td>100°</td>
<td>101.7°</td>
<td>102.9°</td>
</tr>
</tbody>
</table>
Patient #1 was a 53-year-old male with mild OSA (AHI 5.7), with a BMI of 25.3Kg/m² and 37cm neck circumference who was being treated with an OAm for 6 years. The first 4 years with Klearway™, and the next 2 years with a SomnoDent™ appliance. Patient reported bite changes as early as 2 years into the treatment and at recruitment he was afraid of more dental changes. The subject was healthy with good oral hygiene. He was skeletal Class II with an ANB of 7.3° and a normal mandibular plane angle with dental CII div 2 malocclusion, retroclined upper incisors to Sella-Nasion at 87.3°, and proclined lower incisors at 100° to Mandibular Plane without crowding. He had 2mm overjet and 40% overbite. He presented with reduced attached gingiva and recession on tooth #41 and #31 of 2mm and 1mm respectively (Figure 7, Figure 8, Figure 9). Baseline sleep data was obtained by a portable monitor device level III. AHI was 5.7, Mean oxygen saturation was 98%. ESS value of 5 was obtained from the questionnaire.

Figure 7 Initial photos patient #1.

53 years old male with a dental Class I division 2 with increased overbite. Gingival recession on lower right central incisor.
Figure 8 Initial panoramic radiograph patient #1.

Full dentition with exception of third molars. Mild restored dentition. Minimal alveolar bone loss.

Figure 9 Initial cephalometric radiograph patient#1

Skeletal Class II with and ANB of 7°, normal mandibular plane angle with retroclined and retruded upper incisors and proclined and protrusive lower incisors.
Patient #2 was a 65-year-old male with moderate OSA (AHI 27) who presented at initially with a BMI of 22.87 Kg/m$^2$ and 38.5cm neck circumference. The subject was being treated for the last 1.5 years with an OAm (SomnoDent™Flex). The patient had good health overall, with controlled high blood pressure and with good oral hygiene. He was skeletal Class I with an ANB of 2.2°, low mandibular plane angle, and dental CII on the right and Class I on the left side. He presented with 0mm overbite and 2mm overjet, with normal upper incisor inclination respect to Sella-Nasion at 102°, and proclined lower incisors at 101.7° to Mandibular Plane with mild lower crowding. He also presented with gingival recession in multiple posterior teeth, highly restored dentition and an implant on tooth #11 (Figure 10, Figure 11, Figure 12). Baseline sleep data was obtained by a portable monitor device level III. AHI was 27, Mean oxygen saturation was 95%. ESS value of 5 was obtained from the questionnaire.

**Figure 10 Initial photos patient #2.**

65 years old male with dental class II subdivision right with edge to edge anterior occlusion. Generalized gingival recession with thin phenotype.
Figure 11 Initial panoramic radiograph patient #2.

Highly restored dentition with moderate bone loss. Implant crown replacing right central incisors.

Figure 12 Cephalogram radiograph patient #2.

Skeletal Class I with flat mandibular plane angle. Lower incisor is proclined.
Patient #3 was a 42-year-old female with mild OSA, with a BMI of 26.6 Kg/m\(^2\) and 32.5cm neck circumference. The subject had been treated for the last 5 years with an OAm (SomnoDent™Flex). Subject was healthy, smoked occasionally, and her oral hygiene was good although she presented with stains at lingual aspect of upper and lower incisors. She was skeletal Class II with an ANB of 9.4\(^\circ\), normal mandibular plane angle, and dental Class I. She presented with no overbite and overjet, with retroclined upper incisors inclination respect to Sella-Nasion at 93\(^\circ\), and proclined lower incisors at 102.9\(^\circ\) to the mandibular plane, with uncrowded upper arch and mild lower crowding. She also presented with full dentition with exception of all third molars. Her dentition was highly restored with porcelain fused to metal crowns and endodontic treatment on tooth #25 and 46, as well as multiple composite restorations. Mild gingival recession on tooth #34, 41 and 42 was noted (Figure 13, Figure 14, Figure 15). Baseline sleep data was obtained by a portable monitor device level III. AHI was 6.9, mean oxygen saturation was 95\%. ESS value of 6 was obtained from the questionnaire.

**Figure 13 Initial photos patient #3.**

- 42 years old female with dental class I with minimal overjet and overbite. Mild lower crowding.
Figure 14 Initial panoramic radiograph patient #3.

Full permanent dentition with generalized alveolar bone loss and moderate restored dentition.

Figure 15 Cephalometric radiograph patient #3

Severe skeletal class II with and ANB of 9°, normal mandibular plane angle, retroclined upper incisors and proclined and protrusive lower incisor.
2.4.2 OMI Location

Optimal OMI location on the upper arch was between canine and first premolar anteriorly and first molar and second premolar posteriorly. On the lower arch the optimal location was between first and second molars. Due to anatomical factors such as root proximity, the optimal OMI location was only achieved in patient #3 (Table 8).

<table>
<thead>
<tr>
<th>Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper anterior OMIs</td>
<td>4 and 5</td>
<td>4 and 5</td>
<td>3 and 4</td>
</tr>
<tr>
<td>Upper posterior OMIs</td>
<td>5 and 6</td>
<td>5 and 6</td>
<td>5 and 6</td>
</tr>
<tr>
<td>Lower OMIs</td>
<td>6 and 5</td>
<td>6 and 5</td>
<td>7 and 6</td>
</tr>
</tbody>
</table>

*tooth numbers between which the OMI was located

In patient #1, OMIs were placed under topical anesthetic and inserted by self-drilling method. Location was not optimal, in the upper arch OMIs were between first molar and second premolar posteriorly, and between second premolar and first premolar anteriorly. In the lower arch OMIs were located between first molar and second premolar, all OMIs were directed apically (Figure 16).

Figure 16 OMIs locations patient #1.

Upper OMIs were placed between first and second premolar anteriorly, and between second premolar and first molar posteriorly. On the lower arch the OMIs were placed between first and second molar.
In patient #2, OMIs were placed under topical anesthetic and all of them were inserted by self-tapping method. Optimal OMI location was achieved in the upper arch while in the lower arch OMIs were not optimal, between first molar and second premolar. All OMIs were directed apically (Figure 17). Ibuprofen Tabs 400mg OTC, three times a day was prescribed for pain as needed for 3 days.

**Figure 17 OMIs locations patient #2.**

![OMIs locations patient #2](image1)

Upper OMIs were placed between canine and first premolar anteriorly, and between second premolar and first molar posteriorly. On the lower arch the OMOs were placed between second premolar and first molar.

In patient #3 OMIs were placed under topical anesthetic. Lower OMIs were inserted using the pilot hole method. Location for the upper arch was between first molar and second premolar posteriorly, and between canine and first premolar anteriorly. The left anterior OMI had to be inserted more apically respect to left posterior OMI due to root proximity. In the lower arch OMIs were located between first molar and second molar, all OMIs were directed apically (Figure 18). Ibuprofen Tabs 400mg OTC, three times a day was prescribed for pain as needed for 3 days.

**Figure 18 OMIs locations patient #3.**

![OMIs locations patient #3](image2)

Upper OMIs were placed between canine and first premolar anteriorly, and between second premolar and first molar posteriorly. On the lower arch the OMOs were placed between first and second molar.
2.4.3 OMI Failure

OMI failure was defined as an OMI that presented with mobility grade 2 or was lost. The overall failure rate for the study was 50.0%. Lower left OMIs failed as early as 3 days post-insertion. Failure rate for the upper arch was 38.46%, with most failures reported by patient #1. 29.16% of the OMIs presented with mobility grade 1 as early as 3 weeks post-insertion, most of which were located in the upper arch of patient #1. 33.3% of the OMIs presented with mobility grade 2 as early as 2 weeks post-insertion.

The lower left OMI on Patient #1 was lost 2 weeks post-insertion, with no pain reported. The OMI was re-inserted a week later to allow healing, at about 1mm coronal to the initial location. At the re-insertion visit, all upper OMIs presented with mobility grade 1 and were gently tightened until stability was obtained. This resulted in the collar of the OMI being partially buried, which required a new scan of the upper arch to be taken. Existing OAm was re-adjusted to avoid contact with the OMIs. The patient reported no mobility for all OMIs and no soreness or gingival irritation at 2 weeks after re-insertion. Approximately 16 weeks post-insertion, the right OMI was lost, with no pain reported. Due to upper and lower OMI failures, and lack of appliance retention, a decision was made to remove all OMIs and terminate the trial. At the removal visit, all upper anterior OMIs presented with mobility grade 2 (Table 9).

Patient #2 reported the lower left OMI fell off 3 days post-insertion, with no pain reported. The OMI was re-inserted 2 weeks later to allow healing, at 1mm apical to the initial location. No mobility of the remaining OMIs was observed at that time. 6 weeks later at the appliance insertion, lower left OMI presented with gingival inflammation and patient decided to terminate the trial. All OMIs were removed.
Patient #3 reported mobility on the lower left OMI with no pain at 2 weeks post-insertion. At the follow-up visit, the lower left, and the upper left anterior OMIs presented with mobility grade 2 and 1 respectively. The lower left OMI was removed, and the upper left anterior OMI was tightened until achieving stability. Existing OAm was re-adjusted to avoid contact with the OMIs and patient was booked 2 weeks later for re-insertion. 2 days prior to the re-insertion visit the patient reported the upper left anterior OMI was lost. During the re-insertion visit the lower right OMI presented with mobility grade 2 and it was removed; the lost upper left anterior was replaced; and two attempts were made to re-insert the lower right OMI without success. During a visit 3 weeks later both lower OMIs were re-inserted; the upper left anterior OMI presented with mobility grade 1 and it was decided to re-insert it about 3mm gingivally. 5 weeks after that, patient reported mobility of the lower right OMI, and was later lost. At the appliance insertion visit a new OMI was inserted in the lower right about 1mm apically from the previous one, and therefore the appliance was not inserted to allow time for the OMI to settle. The appliance was finally inserted 3 weeks later. At that visit, the upper left anterior and lower left OMIs presented mobility grade 1 and were tighten prior to appliance insertion. The lower left OMI was then lost 2 days after that. A summary of the failure by patient and location is presented in Table 9.

<table>
<thead>
<tr>
<th>OMI LOCATION</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Anterior</td>
<td>3 weeks – Mob 1 – Tightened 16 weeks – Mob 2 – Removed 1 OMI</td>
<td>No mobility 12 weeks – Removed 1 OMI</td>
<td>No mobility 19 weeks – Removed 1 OMI</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>3 weeks – Mob 1 – Tightened 16 weeks – Mob 2 – Removed 1 OMI</td>
<td>No mobility 12 weeks – Removed 1 OMI</td>
<td>2 weeks – Mob 1 – Tightened 4 weeks – Fell off – Replaced 10 weeks – Mob 1 – Tightened 19 weeks – Removed 2 OMI</td>
</tr>
<tr>
<td>Upper Posterior</td>
<td>3 weeks – Mob 1 – Tightened 16 weeks – Mob 2 – Removed 1 OMI</td>
<td>No mobility 12 weeks – Removed 1 OMI</td>
<td>No mobility 19 weeks – Removed 1 OMI</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>3 weeks – Mob 1 – Tightened 16 weeks – Mob 2 – Removed 1 OMI</td>
<td>No mobility 12 weeks – Removed 1 OMI</td>
<td>No mobility 19 weeks – Removed 1 OMI</td>
</tr>
</tbody>
</table>

Table 9 Summary of OMI failures.
<table>
<thead>
<tr>
<th>Lower Posterior</th>
<th>R</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 weeks – Fell off – Removed 1 OMI</td>
<td>No mobility 12 weeks – Removed 1 OMI</td>
<td>4 weeks – Mob 2 – Replaced 7 weeks – Mob 2 – Replaced 4 weeks – Mob 1 – Tightened 19 weeks – Removed 3 OMI</td>
</tr>
</tbody>
</table>

2.4.4 Appliance Retention and Design

Overall, the novel OAm appliance did not achieve adequate retention and stability with exception of patient #3. The lack of retention was attributed to the failure of the ball socket mechanism to properly hold the appliance. Contrarily, the sidebars did achieve adequate retention to the Post and lower OMIs.

For Patient #1, the appliance was inserted 9 weeks after the lower left OMI insertion due to design and fabrication process. The appliance did not achieve retention whatsoever. The sidebars engaged adequately to the OMIs (Figure 20), but when manipulated, generated mild to moderate pain as they impinged on the gingiva. The anterior section of the appliance and the Post were protrusive. Disocclusion of 2-3mm was present which represented the thickness of the bite registration material (Figure 19).

Figure 19 Appliance insertion patient #1.

Insertion of the novel appliance 8 weeks after OMI placement. Lack of contact of the upper posterior OMIs to the appliance, protrusion at the anterior vestibule, 3mm disocclusion.
For patient #2, the appliance was inserted 6 weeks after lower left OMI insertion. Upon appliance insertion, disocclusion of 2-3mm was observed, which represented the thickness of the bite registration material (Figure 21). The subject also reported that the appliance was bulky and uncomfortable on the upper lip (Figure 24). The sidebars engaged adequately to the lower OMIs, but their movement generated moderate pain as they impinged on the swollen gingiva (Figure 22, Figure 23). The appliance appeared to achieve retention, but it was immediately lost as soon as the subject moved the mandible. The patient reported pain as the appliance impinged on the gingival tissues. The patient decided then to terminate the trial and all OMIs were removed under local anesthetics.

Figure 21 Appliance insertion patient #2.

Insertion of the novel appliance 6 weeks after OMI placement. Protrusion at the anterior vestibule and disocclusion.
Figure 22 Frontal and lateral views of lower left OMI gingival irritation in patient #2.

Figure 23 Sidebar impingement on gingival tissue in patient #2.

Figure 24 Appliance protrusion at the upper lip in patient #2.
For patient #3, the appliance was inserted 6 weeks after the lower right OMI re-insertion. The retention was adequate when tested by finger pressure. However, the appliance was seated too high in the vestibule and the protrusion was considerable, generating discomfort, especially at the Posts area, which precluded us from attaching the sidebars, and for taking intraoral photographs (Figure 25).

Since the OMIs on Patient #3 were in an optimal position to achieve 45 degree of sidebar inclination, it was determined that the sidebar could be attached directly into the OMI without the need of the upper arch of the appliance. To evaluate this idea, thinner sidebars were designed and fabricated, and were inserted in both arches in combination with 2mm thick clear trays (Essix™) during the insertion visit (Figure 26). The sidebars were also beveled at the lower end which avoided tissue impingement (Figure 27). The trays were used to achieve tooth contact to limit mandibular movement improving retention and stability (see chapter 3.2.4 Force Analysis). The thinner sidebars, in conjunction with the trays, resulted in reduced appliance complexity and force distribution, as well as a reported increased comfort by the patient compared to the appliance.
Figure 25 Appliance protrusion at the upper lip in patient #3.

Figure 26 Modified sidebars combined with EssixTM trays.
Since the lower right OMI had to be tightened during that visit, the decision was made to send the patient without the appliance and with instructions to sleep with the Essix™ trays and wear ¼” 6oz intermaxillary elastics from the upper anterior OMIs to lower OMIs (Figure 28), for 2 consecutive nights while using a portable monitor device (Alice NightOne™). The patient reported not being able to insert elastics in the right side during the first night, sleeping with a single elastic on the left side. Nevertheless, the patient was able to record a full night of sleep. The second night the patient was able to insert the elastics on both sides after receiving instructions via phone. The lower right OMI fell off after approximately 4 hours of sleep, and thereafter the patient removed the elastics and ended the sleep study. The results from the sleep study reported an AHI the first night of 6.3, and the second night of 2.7.
2.4.5 **Patient Perception of the Novel OAm**

Patient perception was evaluated during appliance insertion only, since no appliance was handed over to the patients due to poor retention and stability. The main complaint was the bulkiness of the appliance at the anterior vestibule and the Post length which subjects reportedly impinged on the upper lip.

Sidebars caused pain of the soft tissues at the lower posterior OMI region in two subjects when the sidebars were being inserted and removed. No pain or discomfort reported during appliance and sidebar insertion in patient #3 (Table 10).

Traumatic ulcers were reported as early as 3 days post-insertion of OMIs in patient #2, while patient #1 reported no irritation whatsoever. In patient #3, irritation on the area of upper anterior OMIs was reported 7 days after OMI insertion. In patient #2 soft tissue irritation at the left cheek persisted for 4 weeks post OMI insertion, and in patient #3 irritation persisted for 1 week. All patients felt that OMIs in the upper arch were protrusive.

<table>
<thead>
<tr>
<th>Table 10 Patient perception to novel OAm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient</td>
</tr>
<tr>
<td>Bulky/Protrusive</td>
</tr>
<tr>
<td>Post length</td>
</tr>
<tr>
<td>Sidebars/Pain</td>
</tr>
</tbody>
</table>

In all cases, pain post OMI insertion was managed with Ibuprofen 400mg every 8 hours for a period of 3 days. Mild pain was reported at 1-week post-insertion by patient #1, and 3 days post-insertion by patient #2 and #3.
2.4.6 Termination of Clinical Trial

After the experiences of the first three patients in the trial, it was decided to terminate the study prematurely out of respect for patient safety and comfort. The clinical procedures of the study exposed significant design limitations with the current iteration of the prototype appliance. These include a greater dependence on OMI location than was originally anticipated, tissue impingement at the head of the OMI due to inadequate clearance for the appliance, and the high failure rate of the OMIs themselves.

In light of the clinical results, further analysis on plaster models was performed to better understand anatomical factors and their impact on OMI location, appliance design and retention, and the forces applied, leading to the next chapter of this thesis.
Chapter 3: Plaster Model Analysis

In the clinical section of this study, the OMIs were placed and limited in location based on the patient’s specific oral anatomy. OMI location was determined balancing a number of physiologic parameters, including number of teeth in the arch, height of the mucogingival junction, and root position. As was previously noted, this often resulted in inadequate appliance clearance or ability to provide sufficient mandibular protrusion clinically. The following chapter aims to better understand different anatomical characteristics involved in the optimal OMIs position, and their impact on the novel OAm design such that the resulting sidebar inclination produces the desired mandibular advancement. A set of measurements were proposed to analyze the resulting sidebar inclination for various possible OMI locations in the plaster models of 5 OSA patients with different malocclusions.

3.1 Objectives:

1. To establish optimal OMI location that results in a sidebar inclination of 45° or less by determining the angle at various possible locations in the plaster models of 5 OSA patients with different malocclusions.

2. Secondarily, to establish the feasibility of using OMIs as anchors for the OAm by obtaining the theoretical resultant forces applied to the OMIs in each of the configurations.

3.2 Methodology

3.2.1 Sample

The sample consisted of 5 sets of plaster models from patients previously recruited for treatment of OSA with oral appliances (SomnoMed™) obtained from the UBC sleep clinic
archives. This was a random, convenient sample of patients, selected to allow for a diverse set of malocclusions to be assessed. Each assigned with a number from 1 to 5, and the main occlusal characteristics and initial of titration amount were recorded.

3.2.2 **OMI Location**

The location for the various simulated OMI insertion points to be measured were set as: interradicular spaces in the anterior posterior plane ranging from distal of the right canine to the mesial of the right second molar in both upper and lower arches; 4mm from the free gingival margin in the vertical plane to provide safe interradicular space. According to Lee (Lee2009), a safe interradicular space of at least 3mm is present at this height (Figure 29).

**Figure 29 OMI marked locations for measurements.**

*Interradicular space 4mm above gingival margin, mesial to the root of the second and first molar, second and first premolars.*

3.2.3 **Plaster Model Measurements**

The angle formed by each pair of points between upper and lower arches was determined by measuring the anterior-posterior distance in millimeters of the each point relative to the vertical projection of the distal surface of the second molar in each arch (Figure 30), and the distance between each pair of points between lower and upper arches. Importantly, these measurements were performed with the models articulated in the patient’s actual clinically
determined 2/3rds maximum protrusive position. As each of these patients had previously been provided with an OAm, the required bite registrations were available in their clinical records (Figure 31).

The anterior-posterior distances measured in the lower arch are further offset by the amount of titration in millimeters.

**Figure 30 Upper and lower anterior-posterior measurements.**

**Figure 31 Measurement diagram.**
Using an approximation where the anterior-posterior planes on both arches are parallel, the distance described by each pair of points can be assumed to be the diagonal of a right triangle (Figure 32). Thus, the angle described by each pair of points in the upper and lower arches is represented by the trigonometric formula:

$$\theta = \tan^{-1} \frac{\text{Height}}{X_{\text{upper}} - (X_{\text{lower}} + X_{\text{titrated}})}$$

A set of further measurements were made to account for a Post (anterior point of attachment for the protrusion mechanism of the novel appliance design) offset that added 5mm anterior to the most anterior OMI point at the same anterior-posterior plane, and then offset by 4mm and 8mm inferiorly (Figure 33).
3.2.4 **Force Analysis**

In order to better understand the forces exerted on the OMIs, a mathematical model was proposed by using a free-body diagram shown in Figure 34 and its notations defined in Table 11.

**Table 11 Notations for the free-body diagram.**

<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>Mandible’s centre of gravity</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Sidebar angulation</td>
</tr>
<tr>
<td>B</td>
<td>Force exerted by the appliance sidebar on the mandible, oriented in the direction $\theta$. For simplicity, the model assumes this force acts at the point of the mandible’s center of gravity, O.</td>
</tr>
<tr>
<td>$R_{ANT}$</td>
<td>Reaction force on the mandible from the maxilla on tooth contact when the patient is resting in supine position.</td>
</tr>
<tr>
<td>$R_{POS}$</td>
<td>Reaction force on the mandible at the TMJ simplified as a frictionless roller joint, which only provides a reaction force perpendicular to the transverse plane.</td>
</tr>
<tr>
<td>W</td>
<td>Force due to mass of the mandible and soft tissue, including residual muscular and ligamentous resistance when patient is asleep.</td>
</tr>
</tbody>
</table>
Figure 34 Free-body diagram of the mandible in supine position.

*Free-body diagram of the mandible in supine position, with the sidebar force $B$ acting on the mandible at its center of gravity $O$. Provided by Vivian Chung, Research Engineer at the Centre for Hip Health and Mobility, Vancouver, BC*

In order to satisfy the moment equilibrium equation, $R_{ANT}$ must be greater than zero to prevent $R_{POS}$ from rotating the mandible. This can be shown by taking a moment summation about point $O$:

$$\sum \text{Moment}_O : R_{ANT} (d_{ant}) = R_{POS} (d_{ant})$$

If there was a gap left between the upper and lower teeth, there would be no reaction force $R_{ANT}$ resulting in no static equilibrium, and rotation of the mandible until the gap is closed.

The reaction force $R_{POS}$ cannot be zero, since it needs to counteract the horizontal component of $B$. Meanwhile force $B$ itself cannot be zero since in order to maintain mandibular protrusion, its vertical component needs to counteract the force $W$. This can be expressed as:

$$\sum \text{Force}_x : B \cdot \sin \theta = R_{ANT} + R_{POS} \quad (1)$$
\[ \sum_{\text{Force}_Y} : B \cdot \cos \theta = W \quad (2) \]

The sum of the forces on the vertical axis (2) describe a relationship where the force \(B\) exerted on the sidebar can be directly calculated if the angle and the force \(W\) are known.

Equation (2) can be re-arranged as:

\[ B = \frac{W}{\cos \theta} \quad (3) \]

The force \(W\) represents the intrusion force that would be applied to the OAm and has been estimated to be up to 22N and with an average of 13.6N per side\(^6\).

### 3.3 Results

#### 3.3.1 Sample

The sample consisted of the plaster models of 5 OSA patients treated with OAm, unrelated to the clinical aspects of this study. The sample was classified as: 2 patients with dental Class II division 2, one of which had extractions of two upper premolars; 2 patients with dental Class II division 1, one of which had extractions of three premolars and a canine; 1 patient with Class I without extractions. The mean titration was 5mm with a range of 2mm. Amount of crowding was mostly mild in the upper arch and moderate in the lower arch (Table 12).

<table>
<thead>
<tr>
<th>Set</th>
<th>Dental Class</th>
<th>Missing Teeth</th>
<th>Overjet</th>
<th>Overbite</th>
<th>Crowding Upper</th>
<th>Crowding Lower</th>
<th>Titration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>II Div 2</td>
<td>17, 24, 44</td>
<td>4mm</td>
<td>100%</td>
<td>Mild</td>
<td>Moderate</td>
<td>4mm</td>
</tr>
<tr>
<td>2</td>
<td>II Div 1</td>
<td>None</td>
<td>4mm</td>
<td>20%</td>
<td>Uncrowded</td>
<td>Mild</td>
<td>5mm</td>
</tr>
<tr>
<td>3</td>
<td>II Div 1</td>
<td>17, 13, 34, 45</td>
<td>6mm</td>
<td>30%</td>
<td>Uncrowded</td>
<td>Moderate</td>
<td>5mm</td>
</tr>
<tr>
<td>4</td>
<td>I</td>
<td>None</td>
<td>3mm</td>
<td>20%</td>
<td>Mild</td>
<td>Moderate</td>
<td>5mm</td>
</tr>
<tr>
<td>5</td>
<td>II Div 2</td>
<td>None</td>
<td>2mm</td>
<td>50%</td>
<td>Mid</td>
<td>Moderate</td>
<td>6mm</td>
</tr>
</tbody>
</table>
3.3.2 **Plaster Model Measurements**

Optimal locations for OMIs were established and measured. To determine the angle produced for each combination of OMIs locations, measurements of the diagonal distance were taken between: the lower OMI to the upper anterior Post position in the anterior-posterior plane; the lower OMI to the Post position offset inferiorly by 4mm, and then 8mm. Posteriorly, measurements were taken at initial titration and with steps of 1mm of advancement (in a direction along the occlusal plane) until double the initial titration (the defined maximum amount of titration that would be desired clinically).

When the diagonal distance was measured taking into account the Post offset, only the Class II division 2 non-extraction case obtained the desired 45 degrees of bar inclination at initial titration; none of the them resulted in less than 45 degrees at maximum titration. When measured 4mm inferiorly, the same case was the only one achieving the desired inclination up to the 10mm titration, but not at maximum titration. When measured 8mm inferiorly, the same case was the only one to present the desired angle at maximum titration, while the Class I non-extraction and Class II division 1 non-extraction presented desired lower angle at initial titration position only (Figure 35).
Figure 35 Sidebar angle vs titration for different malocclusion.

The Y axis shows the side bar inclination. The red line shows the threshold of 45 degree of bar inclination. The X axis is the amount of titration in each case. Each case is shown as a separate line connected by dots at 1mm increases in titration. Right graph shows measurements taken at the post, middle graph measurements taken when post was lowered 4mm and left when post was lowered 8mm. Only case of dental Class II div 2 was able to achieve ideal bar angulation at maximum titration.
3.3.3 **Force Analysis**

The results from the angle measurements were then used to calculate the force exerted on the OMI using Equation 3: $\mathcal{F} = \frac{W}{\cos \theta}$, assuming a force $W = 13.6\text{N}$. The forces obtained are shown in Figure 36. All of the cases resulted in forces on the OMI of above 15.0N at initial titration, and above 17.5N at maximum titration. The lowest forces were registered in the Class 2 division 2 non-extraction patient, which was the case that achieved optimal sidebar angulation at maximum titration. The highest force obtained was above 32.5N for the Class II division 1 extraction case at maximum titration with the Post at the original height.
Figure 36 OMI force vs titration for different malocclusion.

The Y axis shows Force in Newtons (N) exerted at lower OMI. The X axis is the amount of titration in each case. Each case is shown as a separate line connected by dots with 1mm increments of increased titration. Right graph shows measurements taken at the post, middle graph measurements taken when post was lowered 4mm and left when post was lowered 8mm. Only case of dental Class II div 2 was able to presents with the lower force at initial and maximum titration.
Chapter 4: Discussion

Treatment of OSA with OAm is an effective method to reduce upper airway collapse by positioning the mandible forward, thus opening the airway. Sleep parameters such as AHI, RDI, and symptoms such as snoring, and daytime sleepiness, are effectively reduced by this treatment approach.

Since OAm is held in place by the patient’s teeth, long-term effects on the dentition such as proclination of the lower incisor, reduction in overjet and overbite, posterior open bite, as well as Class III molar have been documented in the literature. Consequently, a novel OAm appliance held in place by OMIs, instead of the dentition, was developed as an alternative to conventional appliances.

This clinical study aimed to test the novel appliance combined with OMIs for the treatment of OSA and to better understand the appliance design and patient experience. Following early termination of the clinical trial, an in-vitro study to establish optimal OMI location in the dental models of 5 OAm patients, and to obtain the resultant forces applied to the OMI in each of the configurations was conducted.

4.1 Clinical Trial

This clinical study had a sample of 3 healthy non-obese subjects currently undergoing treatment for OSA with oral appliances (SomnoDent™). Initial recruitment was challenging due to the specific population available for recruitment, and the inclusion and exclusion criteria which further limited the sample size, since OSA subjects are usually obese and present with associated systemic diseases. No randomization was performed and blinding for case selection...
and intervention was not possible, introducing potential bias that limit may the conclusions of the study.

The OMIs locations was considered optimal only in patient #3. While on the other 2 patients, optimal location was not achieved due to anatomical limitations, particularly due to root proximity. Changes from optimal OMI location impacted the appliance design and force distribution, since the Post had to be relocated up to 14mm anteriorly, increasing the moment arm of the protrusion mechanism and changing the force distribution for which the appliance was designed.

During the study, a total of 24 OMIs were inserted. There was an overall OMI failure rate of 50.0%. Most of the upper OMIs failed at 16 weeks post-insertion, while the lower OMIs failed between 3 days to 16 weeks post-insertion, most of them failed at between 2 to 7 weeks post-insertion. Failure was particularly high in the mandible with 63.6% of the OMI being lost or becoming mobile, despite of efforts to diminish the risks of failure by using a pilot hole, avoiding excessive insertion torque and irrigating with saline to prevent bone overheating and necrosis.

Despite an atraumatic insertion protocol, our OMI failure rate was higher than the reported in the literature. A recent Systematic Review involving 52 studies totaling 4987 OMI in 2281 patients found a 13.5% overall failure rate. In the same study, failure rate in the mandible was higher than the overall at 19.3%, which correlates with our finding of 63.6% failure compared to the overall. A failure rate of 20% was reported in a novel clinical study of 10 adults treated with OMIs attached, with elastics to a facemask. The difference in failure rate with the literature could be attributed to the small sample size. Other factors that could have contributed to a high failure rate in the posterior mandible were bone mineral density, cortical bone thickness, attached gingiva, and a small vestibule limiting access space for insertion. Operator
experience could also have been a factor for high failure rate, but the literature does not support this claim.

All upper OMIs in patient #1 failed. This was unexpected since the literature showed low failure rate in the upper arch. This failure could be potentially attributed to cortical bone thickness compromising primary stability.

Most of the OMI failures in patient #3 were in the lower arch, which were replaced twice. This high failure rate was unexpected, and it can be potentially attributed to increased cortical bone thickness, excessive insertion torque, and bone overheating. Another possible factor could be light smoking habit of this patient, although the literature does not support high failure rate in smokers.

During the insertion visit the novel appliance presented with poor retention, tissue impingement, and failure of the OMIs. Overall retention was poor for the first 2 patients. The ball socket mechanism to attach the appliance failed due to OMI over-insertion in one patient, and excessive OMI angulation in the other. When the appliance was momentarily attached, a 2-3mm of disocclusion recorded by the titration registration material left the mandible free to move and caused the appliance to easily dislodge in a superior and anterior direction. The original appliance arch configuration was designed to be retentive mainly in an inferior and posterior direction, thus making any upward and forward movement of the mandible by the patient lead to dislodgement of the arch. In an effort to avoid free mandibular movements, 2mm Essix™ vacuum-formed retainers in both arches were inserted in patient #3 and when inserting the sidebars, mandible stability was achieved. This confirmed that occlusal contact between the arches must exist to achieve stability (See Force calculation).
Several modifications to the original appliance design were made throughout the study to overcome three main issues: appliance clearance; OMI angle of insertion; and sidebar angulation.

Appliance clearance depends on the distance between the OMI ball centroid to the attached gingiva. This distance was designed to be at least 2mm. When the upper OMIs were over-inserted, resulting in a partially buried collar, the appliance had to be modified to achieve clearance. The modified appliance prevented the socket from completely retaining the ball head of the OMI, and thus affecting retention. This happened in patient #1 in which upper OMIs had to be over-inserted due to grade 1 mobility (Figure 37).

Figure 37 Modified ball-socket mechanism in patient #1.

[Image of modified ball-socket mechanism]

OMI ball head partially filling the socket, no retention was obtained.

The angle of OMI insertion also played a role in the retention of the appliance. As shown in Figure 38, when the OMI was inserted angled downward, appliance fitting was difficult to achieved but still possible without modifying the appliance cross-sectional geometry (problem case #1). This was encountered in patient #2. When OMI was inserted angled downward and too deeply into the gingiva, the appliance cross-section had to be modified to achieve reasonable fitting and clearance to overcome anatomical landmarks (problem case #2). This was
encountered in patient #1. The modification would require reducing the cross-sectional area of the appliance and could thus lead to material failure.

**Figure 38 OMI angulation effects on appliance clearance.**

Sidebars ends also were modified to achieve clearance and avoid the tissue impingement observed in Patient #1 and #2. The lower end of the sidebar in patient #3 was beveled to allow free movement around the lower OMI to avoid soft tissue trauma. The patient did not report pain when sidebars were attached to the lower OMI and left free to move.

A maximum $45^\circ$ sidebar angulation was arbitrarily established in order to maintain the mandible in a forward position. A higher angle will tend to allow the mandible to move backwards by a “Pendulum Effect”. The angulation depended on the locations of the Post and the OMI in the mandible. By design, the Post was offset 4mm anteriorly from the most anterior maxillary OMI.
In Patient #1 and #2, the maxillary anterior OMI had to be inserted more posteriorly than what the appliance was designed to accommodate. This forced the sidebar inclination angle to be higher due to the fixed Post location (Figure 39). To overcome this, the Post was moved anteriorly 14mm and 10mm respectively for each patient. The alteration increased the moment arms, increasing mechanical stresses on the appliance which affected retention. Having the Post moved also increased the appliance dimensions anteriorly causing excessive protrusion.

Figure 39 Sidebar inclination at different OMIs and Posts location.

![Sidebar inclination at two different lower point of attachment. Post represent anterior point of attachment, moved anteriorly to compensate for OMI location. Provided by Vivian Chung, Research Engineer at the Centre for Hip Health and Mobility, Vancouver, BC.](image)

Traumatic ulcers of the adjacent mobile mucosa of cheeks by the OMI head were reported, similar to mucosa and soft tissue affected by mechanical trauma by recently bonded brackets, despite recommending the use of orthodontic wax.

In our study, traumatic ulcers were reported as early as 3 days post-insertion of OMIs in patient #2, while patient #1 reported no irritation whatsoever. Patient #3 reported irritation on the area of upper anterior OMIs 7 days post-insertion. Irritation persisted for 4 weeks post-replacement of the lower left OMI area for patient #2, while irritation persisted for 1 week for patient #3 post-insertion. Nevertheless, tissue reaction to OMI was temporary and individuals tolerated the implants well, has assumed from clinical experience with orthodontic patients.
where OMIs are often used. Mild pain was reported at 1-week follow-up by patient #1, and at 3 days post-insertion by patient #2 and #3. In both cases, pain was managed with Ibuprofen 400mg every 8 hours for 3 days.

Bulkiness of the appliance and the Post were reported by all patients. For patient #1 and 2, the anterior part of the appliance had to be modified more anteriorly to accommodate for the Post increasing appliance dimension anteriorly causing excessive protrusion. Patient #3 reported that the Posts were excessively high in the vestibule, this was because the appliance had to be modified to be aligned to the left OMI placed more apically due to anatomical factor such as root proximity and keratinized tissues.

Patient #3 was able to wear upper and lower 2 mm clear trays combined with ¼’ 6oz intermaxillary elastics on the left side only for a full night of sleep. Results of the sleep study showed a decrease in AHI from 6.9 at baseline to 6.3. The second night, the patient was able to wear the elastics in both sides but only for 4 hrs due to failure of the lower right OMI, recording a partial night of sleep. Nevertheless, the AHI decreased from 6.9 at baseline to 2.7. In light of this results, the use of intermaxillary elastics combined with orthodontic retainers could be another alternative to the novel appliance tried in this study. Future studies with larger sample size are needed to test this modality of treatment.

4.2 Plaster Model Analysis

The sample consisted of 5 sets of plaster models from patients previously recruited for treatment of OSA with oral appliances. A variety of malocclusions were chosen in an effort to diversify the sample. Even though the sample size was small and had a high risk of bias in case
selection, its analysis would still provide new knowledge and would contribute towards a better understanding the appliance design and anatomical limitations.

For the analysis, OMIs locations were marked in right side on both arches at the interradicular spaces from mesial of second molar to distal of the canine, 4mm apically from the gingival margin. It was assumed that adequate interradicular space was present, which is not always possible due to root proximity, introducing location bias.

The measurements and angle calculation showed that optimal angulation was achieved only in the Class II division 2 malocclusion non-extraction case at maximum titration and with the Post located 8mm inferiorly. In that case, a retrusive mandible allowed the OMIs to be more favorably located to achieve optimal sidebar angulation leading to mandibular advancement. This suggests that there are anatomical contributors that may limit the type of case for the novel appliance, or that the lower attachment point or OMI itself needs to be placed as posteriorly as possible. Nevertheless, the results may be influenced by case selection bias and due to the small sample size, they should be taken with caution. A larger sample, including different treated and untreated malocclusions is needed to arrive to a more definite conclusion.

4.3 Force Analysis

In an attempt to better understand the forces exerted on the OMIs, a free body diagram was used to arrive to a simplified mathematical model to determine the force acting in the OMIs. The results showed that, assuming a $W = 13.6\, \text{N}$, all of the cases resulted in forces above $15\, \text{N}$. This value was high compared to the reported by the literature in which a force of up to $4\, \text{N}$ was applied to the OMIs when combined with a Herbst appliance$^{89}$, suggesting that OMI may not be adequate to withstand the forces from the novel appliance. An alternative to OMIs would by
mini-plate, which is a subperiosteal plate held by 2-3 screws, with an attachment head that extends through the gingiva into the oral cavity, capable of withstanding higher loads. Moreover, the highest forces calculated had a minimum of 24N at initial titration and a maximum of 32.5N at maximum titration for the Class II division 1 extraction case. Since the sidebars were designed to release when the patient generates a jaw intrusion force greater than 20N per side, there is high risk of unintended sidebar release with use in this case.

The free-body diagram also showed that in order to maintain equilibrium while using the appliance, contact between the teeth is required. This was the case experienced during the attachment attempts on patients #1 and #2, where the appliance did not achieve retention, partially due to the lack of occlusal contact between the dental arches.

A limitation of this analysis is that the numerical value for the retrusive force (W) was taken from a single study\textsuperscript{62} which introduced confounding factors. Also, the simplifications required to arrive at a mathematical model such as the appliance force acting at the mandible center of resistance, and the TMJ acting as a frictionless roller joint, weaken the strength of the conclusions that the model can lead to. Therefore, the results from force analysis should be taken with caution due to small sample size and risk of bias, as well as limited data available related to mandibular force upon advancement.
Chapter 5: Conclusions

This thesis aimed to test a novel OAm, suggest design improvements, and further the understanding of how anatomical factors influence the appliance design by measuring dental casts. The novel appliance achieved poor retention when tried on patients. This was attributed to failure of the ball socket mechanism due to OMIs location and angulation, as well as lack of occlusal contact that allowed the mandible to rotate freely. The plaster model analysis provided a better understanding of the anatomical factors contributing to the OMI position and their impact in the design of the novel appliance. The analysis showed that OMI location is crucial to achieve adequate mandibular advancement. It also demonstrated that a case presenting dental Class II division 2 with a full complement of teeth was the only occlusal scheme able to achieve optimal sidebar inclination at maximum titration, and only when the Post was lowered by 8mm below the arch of the appliance. This finding could limit the novel appliance to certain malocclusions, although a bigger sample is needed to arrive to final conclusion. The mathematical model showed the highest force received for the lower OMI was 32.5N, which is well above the 13N reported in the literature as maximum force levels applied to OMIs. This leads to a conclusion that OMIs may not be the ideal anchorage system for the novel device.

The study and model analysis also drew the following conclusions:

1. To achieve optimal sidebar angulation for mandibular advancement: (a) the optimal location for OMIs is distal of the upper canine and mesial to the lower second molar or further posteriorly; and (b) the Post on the arch of the appliance, which serves as the forward attachment point for the advancement mechanism should be lowered as close as possible to the occlusal plane, or at least by 8mm.
2. A minimum 2mm distance from the ball centroid to the attached gingiva should be maintained to allow clearance from the soft tissues. However, this limits the ability to modify the appliance to accommodate for OMI location and angulation.

3. The upper OMIs should be placed angulated apically in order to avoid negative effect on the appliance clearance and retention mechanism.

4. Optimal Post location should be no more than 4mm forward from the most anterior OMI to avoid mechanical stress and tissue impingement.

5. It is crucial to have contact between the upper and lower teeth to maintain mandibular advancement. Tooth contact can be achieved either directly or through an intermediate spacer such as an Essix™ tray of 1mm or 2mm thickness depending on the amount of disocclusion given by the titration registration material.

6. Sidebars should be beveled at its lower end to prevent tissue impingement and pain, when being attached to the OMI, as well as when they are left free to move when attaching the upper end to the Post on the arch.

7. For patient comfort, the bulk of the appliance should be close to the occlusal plane so as to limit the pressure pushing up on the upper lip.

The study was limited by the small sample size and might not be representative of the OSA population as a whole. Also, it was not possible to use blinding for case selection and intervention, and subjects and plaster models were not randomly selected, introducing bias that may limit the conclusions of this study. However, the selection of only healthy and non-obese patients reduced confounding factors. Furthermore, the visit by visit protocol developed for this study can be used in future studies.
The novel oral appliance opens a new area of research in which OMIIs are combined with OAm. In light of the results, particularly high OMI failure rate, mini-plates might emerge as a viable alternative to anchor the oral appliance. Mini-plates combined with sidebars or heavy intermaxillary elastics might be, in certain cases, a viable treatment alternative to OSA patients with less discomfort, without side effects on the occlusion since no appliance is being held by the dentition.
Bibliography


Appendices

Appendix A  Visit Protocol

A.1  Eligibility and Consent

<table>
<thead>
<tr>
<th>SUBJECT ID:____________</th>
<th>VISIT DATE:________</th>
</tr>
</thead>
</table>

**Eligibility and Consent**

1. **Eligibility (Inclusion/Exclusion) Criteria:**
   - Were the eligibility criteria assessed with the inclusion/exclusion criteria form complete? □ Yes □ No
   - Note! Inclusion/exclusion criteria must be assessed prior to or at the beginning of Visit 2 and prior to beginning any study procedures.

2. **Consent Form:**
   - Was the consent form signed by patient? □ Yes □ No
   - Note! A consent form must be signed prior to Visit 2 and prior to beginning any study procedures. Also, please ensure the consent form is signed and dated by both the subject and a member of the investigative team. Please ensure the subject/study patient receives a copy of the consent form. The original signed consent should be kept by the investigative team.

3. **Patient’s Next Study Visit:**
   - The patient’s next visit, Visit 1, should be scheduled 1 week from the completion of this visit.
   - Date: __________ Time: __________

4. **Visit Notes:**

   Investigative Team Initials/Date: ____________________________
A.2 Visit 1: Baseline Records

### Visit 1 (Baseline Records)

#### 1. Standard Orthodontic Records:
- Was a cephalogram obtained? □ Yes □ No
- Was a panoramic x-ray obtained? □ Yes □ No
- Were intra-oral/extra-oral photographs taken? □ Yes □ No
- Were the patient’s digital impressions taken at this visit? □ Yes □ No
- If not, specify date at which they will be taken:

#### 2. Sleep Monitor Delivery:
- Was the patient given their sleep monitor? □ Yes □ No
- Was the patient trained on how to set up their sleep monitor at home? □ Yes □ No
- Was the patient instructed to return the sleep monitor within 1 week? □ Yes □ No
- Was the patient asked for any other questions? □ Yes □ No

#### 3. Sleep Monitor Return:
- How will the patient return their sleep monitor? □ Courier □ drop-off
- Courier: □ N/A
- Was the patient given a return shipping label and letter, and box □ Yes □ No
- Was the patient instructed on how return their sleep monitor? □ Yes □ No
- Drop-Off: □ N/A
- Date: □ Yes □ No
  - Time:

#### 4. Epworth Sleepiness Scale (ESS):
- Did the patient complete the ESS questionnaire? □ Yes □ No
- Was the score transferred to Redcap and the Excel study sheet? □ Yes □ No

#### 5. Diagnostic Sleep Investigations Report:
- Was the unscored report downloaded and sent for scoring? □ Yes □ No
- Was unscored sleep study saved in patient’s file? □ Yes □ No
- Was the scored sleep study saved in the patient’s file? □ Yes □ No

---

BIMA – V2 [H17-03108]  Page 1 of 2
THE UNIVERSITY OF BRITISH COLUMBIA
Faculty of Dentistry
Research and Graduate Studies

SUBJECT ID: ____________ VISIT DATE: ____________

6. Patient's Next Study Visit:
The patient's next visit, Visit 2, should be scheduled 1 week from the completion of this visit.
Date: ____________ Time: ____________

7. Visit Notes:

Investigative Team Initials/Date: ____________________________

BIMA –V2 [IH17-03108] Page 2 of 2
### A.3 Visit 2: Mini-Implant Placement

#### 1. Materials and Supplies:
- Local anesthetic kit (carpule – needle – syringe) □
- Composition and amount: □
- Mini-implant Kit □
- Exam Kit □
- Mini-implant specifications:

#### 2. Surgical Procedure:
- Assistant Name:
- Technique Used:
- Mini-Implant Locations:
- Complications:

#### 3. Digital Impressions:
- Were dental impressions taken during this visit? □ Yes □ No

#### 4. Lab Technician:
- Was the existing titration amount recorded? □ Yes □ No
- Were the STL files uploaded in workspace? □ Yes □ No
6. Patient’s Next Study Visit:
The patient’s next visit, Visit 3, should be scheduled 1 week from the completion of this visit.
Date:  
Time:  

7. Visit Notes:

Investigative Team Initials/Date: __________________________
A.4 Visit 2.1: Emergency/ Re-Insertion

Visit 2.1 (Mini-Implant re-insertion)

1. Materials and Supplies:
   - Local anesthetic kit (carpule – needle – syringe)
   - Composition and amount:
   - Mini-implant Kit
   - Exam Kit
   - Mini-implant specifications:

2. Surgical Procedure:
   - Assistant Name:
   - Technique Used:
   - Mini-Implant Locations:
   - Complications:

3. Digital Impressions:
   - Were dental impressions taken during this visit? □ Yes □ No

4. Lab Technician:
   - Was the existing titration amount recorded? □ Yes □ No
   - Were the STL files uploaded in workspace? □ Yes □ No
6. Patient’s Next Study Visit:
The patient’s next visit, Visit 3, should be scheduled 1 week from the completion of this visit.
Date: 
Time: 

7. Visit Notes:

Investigative Team Initials/Date: ___________________________
A.5 Visit 3: Appliance Insertion

Visit 3 (Appliance Insertion)

1. Side Effects:
   - Was implant mobility recorded? Grade _______  □ Yes □ No
   - Was gingival irritation and soreness present? □ Yes □ No
   
   Mini-implant mobility assessment (Ngiam et al 2012)
   
<table>
<thead>
<tr>
<th>Grade 0</th>
<th>Grade 1</th>
<th>Grade 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>No mobility</td>
<td>&lt;0.5mm mobility</td>
<td>&gt;1mm mobility</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Partial/total mobility or loss</td>
</tr>
</tbody>
</table>

2. Appliance Insertion:
   - Were the insertion and care instructions given? □ Yes □ No
   - Was the patient asked if he/she had any questions □ Yes □ No
   - Were any adjustments needed for the appliance? □ Yes □ No
   - If yes, please describe: ____________________________

3. Patient’s Next Study Visit:
   - The patient’s next visit, Visit 5, should be scheduled 1 week from the completion of this visit.
   - Date: ____________________
   - Time: ____________________

4. Visit Notes:

Investigative Team Initials/Date: ____________________________

BIMA [H17-03108]:V4
A.6 Visit 4: 1-week Follow-up

1. Side Effects:
   - Was implant mobility recorded? Grade ______
   - Was gingival irritation and soreness present? □ Yes □ No
   - Was jaw pain present? □ Yes □ No
   - Was excess of saliva present? □ Yes □ No
   - Other side effects:

<table>
<thead>
<tr>
<th>Mini-implant mobility assessment (Ngiam et al 2012)</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Mobility Assessment Table]</td>
</tr>
</tbody>
</table>

2. Sleep Diary:
   - Was the patient given their sleep diary? □ Yes □ No
   - Was the patient trained on how to record in their sleep diary? □ Yes □ No

3. Appliance check:
   - Was the appliance fit and stability checked? □ Yes □ No
   - Was the patient asked if he/she had any questions □ Yes □ No
   - Were any adjustments needed for the appliance? □ Yes □ No
   - If yes, please describe:
4. Patient's Next Study Visit:
The patient's next visit, Visit 6, should be scheduled 3 weeks from the completion of this visit.
Date:       Time:

5. Visit Notes:

Investigative Team Initials/Date: ____________________________
A.7  Visit 5: Final Records/ 1-month Follow-up

Visit 5 (1-Month Follow-Up/ Final Records)

1. Patient History Update:
   Were the patient’s medical history and medications updated? □ Yes □ No
   Record changes here:

2. Side Effects:
   Was implant mobility recorded? Grade □ □ □ Yes □ No
   Was gingival irritation and soreness present? □ Yes □ No
   Was jaw pain present? □ Yes □ No
   Was excess of salivation present? □ Yes □ No
   Other side effects:

   Mini-implant mobility assessment (Ngiam et al 2012)
   
<table>
<thead>
<tr>
<th>Grade</th>
<th>Grade 1</th>
<th>Grade 2</th>
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<tr>
<td>No mobility</td>
<td>&lt;0.5mm mobility</td>
<td>&gt;1mm mobility</td>
</tr>
<tr>
<td></td>
<td>Partial/total mobility or loss</td>
<td></td>
</tr>
</tbody>
</table>

3. Appliance check
   Was the appliance fit and stability checked? □ Yes □ No
   Was the patient asked if he/she had any questions □ Yes □ No
   Were any adjustments needed for the appliance? □ Yes □ No
   If yes, please describe:

4. Standard Orthodontic Records:
   Was a cephalogram obtained? □ Yes □ No
   Was a panoramic x-ray obtained? □ Yes □ No
   Were infra-oral/extra-oral photographs taken? □ Yes □ No
   Were the patient’s digital impressions taken at this visit? □ Yes □ No
   If not, specify date at which they will be taken:
### 5. Sleep Monitor Delivery:

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Was the patient given their sleep monitor?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was the patient trained on how to set up their sleep monitor at home?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was the patient instructed to return the sleep monitor within 1 week?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was the patient asked for any other questions?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 6. Sleep Monitor Return:

<table>
<thead>
<tr>
<th>Question</th>
<th>Courier</th>
<th>drop-off</th>
</tr>
</thead>
<tbody>
<tr>
<td>How will the patient return their sleep monitor?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Courier</td>
<td>□ N/A</td>
<td></td>
</tr>
<tr>
<td>Was the patient given a return shipping label and letter, and box</td>
<td>□ Yes</td>
<td>□ No</td>
</tr>
<tr>
<td>Was the patient instructed on how return their sleep monitor?</td>
<td>□ Yes</td>
<td>□ No</td>
</tr>
<tr>
<td>Drop-Off</td>
<td>□ N/A</td>
<td></td>
</tr>
<tr>
<td>Was the patient’s drop-off scheduled within 1 week from the completion of this visit?</td>
<td>□ Yes</td>
<td>□ No</td>
</tr>
<tr>
<td>Date</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 7. Diagnostic Sleep Investigations Report:

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Was the unscored report downloaded and sent for scoring?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was unscored sleep report saved in patient’s file?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was the scored sleep report saved in the patient’s file?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Were the scored data transferred to Redcap and the Excel study sheet?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 8. Sleep Diary

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did the patient keep adequate records in the sleep diary?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was the patient asked if he/she had any problems or concerns filling out the diary?</td>
<td>□ Yes</td>
<td>□ No</td>
</tr>
</tbody>
</table>

### 9. Epworth Sleepiness Scale (ESS):

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did the patient complete the ESS questionnaire?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was the score transferred to Redcap and the Excel study sheet?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 10. Focused Interview

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Was the interview audio recorded?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was the recorded interview transcribed?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was the interview coded?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
11. Voluntary Treatment Termination:
Was the patient asked to continue or not in the study?  □ Yes □ No
If patient continues in the study:
If yes, was the informed consent renewed?  □ Yes □ No
Was he patient file transfer to the treating dentist?  □ Yes □ No
Dentist Name:
If patient terminates the study:
Was the patient booked for mini-implant removal  □ Yes □ No

11. Patient's Next Study Visit:
The patient's next visit, Visit 7, should be scheduled 1 week mini-implant removal or 3 months from the completion of this visit.
Sleep device must be sent a within a week before the Visit 7 as indicated below:
Date:  Time:

12. Visit Notes:

Investigative Team Initials/Date: _____________________________
A.8 Visit 6: Mini-Implant Removal

Visit 6 (Mini-Implant Removal)

1. Materials and Supplies:
   - Local anesthetic kit (carpule – needle – syringe)
   - Composition and amount:
   - Mini-implant Kit
   - Exam Kit
   - Mini-implant specifications:

2. Surgical Procedure:
   - Assistant Name:
   - Technique Used:
   - Complications:

3. Visit Notes:

Investigative Team Initials/Date: ___________________________
Appendix B  Sleep Related Forms

B.1  Epworth Sleepiness Scale

Patient ID ___________  Visit ___________  Date___________

Epworth Sleepiness Scale (sleepapnea.com)

How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired?

This refers to your usual way of life in recent times.

Even if you haven’t done some of these things recently try to work out how they would have affected you.

Use the following scale to choose the most appropriate number for each situation:

0 = would never doze
1 = slight chance of dozing
2 = moderate chance of dozing
3 = high chance of dozing

It is important that you answer each question as best you can.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Chance of Dozing (0-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting and reading</td>
<td></td>
</tr>
<tr>
<td>Watching TV</td>
<td></td>
</tr>
<tr>
<td>Sitting, inactive in a public place (e.g. a theatre or a meeting)</td>
<td></td>
</tr>
<tr>
<td>As a passenger in a car for an hour without a break</td>
<td></td>
</tr>
<tr>
<td>Lying down to rest in the afternoon when circumstances permit</td>
<td></td>
</tr>
<tr>
<td>Sitting and talking to someone</td>
<td></td>
</tr>
<tr>
<td>Sitting quietly after a lunch without alcohol</td>
<td></td>
</tr>
<tr>
<td>In a car, while stopped for a few minutes in the traffic</td>
<td></td>
</tr>
</tbody>
</table>

THANK YOU FOR YOUR COOPERATION
### B.2 Sleep Diary

**Date** | **Traditional Appliance** | **New Appliance** | **Comments**
--- | --- | --- | ---
Apr 12, 2018 | 11:30pm 3:00am | 3:00am 6:00am | Due to discomfort
Apr 13, 2018 | 11:00pm 6:00am | - - | Forgot wearing new appliance
B.3 Medical Sleep Test

Level III Sleep Test

Date of Sleep Study: ____________________
Brand name: ____________________ Model Number: ____________________

Oxygen

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean O2 Saturation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min O2 Saturation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ODI 4%</td>
<td>per hour</td>
<td></td>
</tr>
<tr>
<td>ODI 3%</td>
<td>per hour</td>
<td></td>
</tr>
<tr>
<td>Total Recording Time</td>
<td>min</td>
<td></td>
</tr>
<tr>
<td>Total Time in Bed</td>
<td>min</td>
<td></td>
</tr>
<tr>
<td>Total Recording Time Saturation &lt;90%</td>
<td>%</td>
<td></td>
</tr>
</tbody>
</table>

Apnea/Hypopnea Indices

<table>
<thead>
<tr>
<th></th>
<th>per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHl/RDI</td>
<td></td>
</tr>
<tr>
<td>Obstructive Apnea Index</td>
<td></td>
</tr>
<tr>
<td>Central Apnea Index</td>
<td></td>
</tr>
<tr>
<td>Total Apnea Index</td>
<td>per hour</td>
</tr>
<tr>
<td>Total Hypopnea Index</td>
<td>per hour</td>
</tr>
<tr>
<td>Arousal Index</td>
<td>per hour</td>
</tr>
<tr>
<td>Snoring Duration</td>
<td>% TST</td>
</tr>
<tr>
<td>Snoring Index</td>
<td>per hour</td>
</tr>
</tbody>
</table>

Patient ID________ Visit # ________ Date ______________

BIMA  Level III Sleep Study
V1.0 13DEC2017  Page 1 of 1
B.4 Interview

Patient ID ___________ Visit ___________ Date___________

Treatment Interview

Interviewer name: ___________________________
Start time: ___________________________
End time: ___________________________

Intro: We want to better understand the new experience in relation with the old appliance and to get recommendation for improvements with a few questions,

Compared with old appliance:

Overall experience/Satisfaction

1. Tell me about your overall experience wearing the new appliance.

Appliance experience:

2. How do you like your new appliance?

3. How do you like the insertion of the new appliance?

Recommendation for improvements (design).

4. Tell me how it might be different from the old appliance.

5. What would you recommend as changes for the new appliance?

Other:

6. Is there anything else you like to add?