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The Immediate Effect of Changing Mandibular Position on Cross-Sectional Airway and Head Position

Thesis submitted in partial fulfillment of the requirement for the degree of Master of Science

Thesis submitted by
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Abstract

Background: In prosthodontics, controversy exists about maxillo-mandibular (mx/md) relationship changes that may be needed to improve esthetics and function. Alterations in mandibular position may have an impact on airway size and head position. The primary aim was to compare the immediate effect of three different methods of altering the mx/md relationship in an adult population; on pharyngeal measurements of mean and minimum cross-sectional area (CSA) in the upright position, at functional residual capacity (FRC) using acoustic reflectometry (AR). The secondary aim was to assess head position changes for these three mx/md relationship positions using a cervical range of motion (CROM) device.

Methods: Fifty adult subjects range 18-84 years (average 46 years) using a crossover double-blind trial had three mx/md relationship positions recorded; centric relation (CR), phonetic bite (PB) and maximum intercuspal position (MIP).

The subjects were assessed for pharyngeal CSA, at FRC and head position after a 15-minute habituation period. The outcomes were measured using repeated-measures ANOVA for airway and Friedman's non-parametric test for head position.

Results: The average mean (SD) cross-sectional areas were CR 2.62 (0.48) cm^2; MIP 2.62 (0.56) cm^2 and PB 2.68 (0.53) cm^2 (p value=0.663). The average minimum cross-sectional areas were CR 1.60 (0.52) cm^2; MIP 1.70 (0.49) cm^2 and PB 1.62 (0.53) cm^2 (p.

=0.271). There was no statistically significant difference for the mean and minimum cross-sectional area between the three-mx/md relationships. The median head position were CR 0° horizontal, 4° sagittal and 0° coronal; MIP 0° horizontal, 4° sagittal and 0° coronal; PB 0° horizontal, 2° sagittal and 0° lateral. There was no statistically significant difference for the change in head position (horizontal p.=0.956, sagittal p.=0.155 and coronal p.=0.451) between the three mx/md relationships.

Conclusion: The findings suggest that the mx/md relationship change from MIP to CR and PB did not affect pharyngeal CSA at FRC or head position in the awake subject. These findings provide clinicians with the ability to feel relatively confident to restore prosthodontic reconstructions, to any of these positions without concern for airway or head position changes in the awake patient.

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Introduction

Background

The dentist's role is to maintain the health of the masticatory system. In order to provide optimum care various dental disciplines change the maxillo-mandibular (mx/md) relationship by altering either the size or shape of the maxilla, mandible, and teeth, or by positional changes of the mandible. As alterations to the mx/md position also affect the head position and airway size, these two characteristics need to be considered when treatment planning.

In prosthodontics, Niswonger was first to describe the need to change the mx/md relationship by altering the anterior-posterior (A-P) and vertical dimensions.[1] The mandible is often repositioned to improve esthetics and function, as in the case of the worn dentition when there is insufficient room to restore the anterior and posterior teeth. Although the situations when changes need to be made to the mx/md relationships have often been agreed on, the way in which these changes should be made has been more controversial.[2]

With the recent interest in the dental impact on the fields of sleep and craniofacial pain, research has highlighted the dentist's role in the treatment of obstructive sleep apnea (OSA),[3, 4] headaches and neck pain,[5-7] which are often related to these same mx/md relationships and the impact they have on airway and head position.

Acoustic Reflection

Jackson *et al.* first reported on acoustic reflection (AR) in the literature in 1997.[8] AR quantifies the cross-sectional area of the oral cavity to the hypopharynx, and was first proposed by Fredberg *et al.* to measure the area of the pharynx.[9] An audible sound signal is sent down through a wave tube sealed at the subject's mouth and into the respiratory system. The acoustic impulses are transmitted into the oral cavity and are partially reflected when there is a change in cross-sectional area. A microphone records the changes in the reflected pulse wave in comparison to the audible sound signal. The analysis of these sound waves by a computer using a mathematical algorithm provides a two-dimensional graph measuring cross-sectional area as a function of distance to the mouth. The x-axis measures distance and the y-axis the cross-sectional area. Using this graph it is then possible to measure the cross-sectional area (y) at any point along the x-axis, and by using two distance points one can measure area and/or volume. The development of a commercial instrument by Benson Hood Laboratories, Pembroke, MA, USA distributed by Sleep Group Solutions, North Miami Beach, FL 33162, USA, named the Eccovision Pharyngometer™ (Appendix C) provided a simple way for clinicians to assess pharyngeal airway. [10]

Protocols for the use of AR (Appendix I) and normative values for adult and child populations have been produced using comparative studies. [10-16] Kamal in his landmark study of 350 subjects provided normative values for adults. Males had a mean CSA of the pharynx of 3.194cm^2 and females 2.814cm^2.[11] In a further study on 50 asymptomatic subjects he confirmed that the results for CSA were repeatable 7-10 days after the initial recordings for mean pharyngeal area. [13]

Marshall *et al*. proved AR accuracy against MRI with10 subjects using air rather than helium to send acoustic signals. The mean oro-pharynx CSA were AR 1.0±SD 0.3 cm^2 and MRI 0.9±SD 0.5cm^2 (p value=0.77). [17] D'Urzo *et al.* confirmed its accuracy against CT scans with 11 subjects. [18] Their mean glottis CSA was 1.8 ± 0.8 cm^2 using AR and 1.7 ± 0.9 cm^2 using CT (r=0.95%, p-value < 0.0001).[27] Further studies have been performed using AR to assess its value for accuracy and reliability. [11, 18-22] Vivano has the most recent comprehensive review of acoustic reflexion. [23]

AR has many advantages over other methods of airway assessment. It is cost effective, quick and simple to use, providing a dynamic two-dimensional picture in time, and is non-invasive compared to other imaging techniques.[17]. Its disadvantages are that it requires a degree of co-operation, and can only be used while the patient is awake. As pharyngeal dimensions are subject to posture changes, following a set protocol is vital (Appendix I). [11, 22, 24, 25]

The size of the airway is an important factor in both health and pathology. [3, 4, 26-34] The narrowing of the pharyngeal airway is a common cause of OSA and permanent or transient positional changes to the mx/md relationship can impact the airway size favourably or unfavourably. [28, 35-38] Airway size has been measured in many different ways. MRI and CT techniques have been used to investigate, in three-dimensions, the changes in airway size before and after OSA therapy with mandibular advancement devices (MAD). [36, 39] AR has also been used in the assessment and understanding of OSA to assess both the position of the obstruction, and whether the narrowing is due to the caliber or collapsibility of the pharynx in adults and children. [15, 40-44] The therapeutic benefit occurs by altering the mx/md relationship. [27] Our study will investigate the immediate effects on cross-sectional airway (CSA) of maxillo-mandibular (mx/md) relationship changes in prosthodontics using AR where previously airway has not been assessed.

Lung volumes are traditionally used to describe the dimensions of the airway components.[45] Lung volumes refer to the volume of gas in the lung, and are broken up into several components. Total lung capacity (TLC) is the volume of gas in the lung on maximum voluntary inspiration. The residual volume (RV) is defined as the lowest lung volume at maximum expiration and the functional residual capacity (FRC) is the volume of gas in the lungs at end expiration, implicitly during tidal breathing, and normally at rest (Appendix V).[45] Both RV and FRC are static lung volumes, and can be measured by acoustic reflection(AR). The Eccovison Pharyngometer[TM] Benson Hood Laboratories, Pembroke, MA, USA distributed by Sleep Group Solutions, North Miami Beach, FL 33162, USA (Appendix C), an acoustic reflection device, records the cross sectional airway (CSA) at RV and FRC.[10, 21-28] Our study will use FRC during tidal breathing at rest to determine the smallest CSA of the airway between the levels of the oro-pharyngeal junction and the glottis at different mx/md positions.

Obstructive Sleep Apnea

Obstructive sleep apnea (OSA) is a multifactorial condition, and its etiology involves many factors, including changes in the size of the airway (caliber), airway collapsibility, dilator muscle mechanics, lung volume physics, and craniofacial growth and development.[45-47]

Studies have shown that patients with OSA have a smaller pharyngeal minimum and mean cross sectional airway (CSA) than control subjects, and that these CSAs decrease from the seated to the supine position.[20, 42, 48-50] Further studies have shown that the upright-seated position provides information predictive of OSA.[51, 52] Martin *et al.* showed that there was a decrease in CSA size at the oro-pharyngeal junction (OPJ) in the seated position in controls with no sleep disordered breathing (SDB) ($p<0.02$), to snorers ($p< 0.01$) to subjects with sleep apnea/hypopnea syndrome with matched body weight index using AR at FRC.[51] However when AR was performed in the supine position on these same subjects there was no statistical difference in airway between the groups, suggesting that OSA patients defend their airway from collapse more than snorers or control patients. Similarly Bradley *et al.* showed that apneic non- obese subjects have more compliant airways than controls using AR at residual volume (RV) in the seated position and also have a smaller airway assessed in the seated position compared to controls using AR at FRC.[48] Brown *et al.* similarly observed apneic subjects had a reduced collapsibility compared to controls, and suggested that there may be a critical narrowing that causes critical pressure problems and collapse.[53] Thus OSA patients differentiate themselves more than normal subjects in the seated position whilst awake at FRC for caliber and at RV for compliance.

There are other considerations when dealing with subjects with OSA. In a study of 568 subjects Patel *et al.* concluded that minimum CSA is a highly heritable trait,[54] but that environmental factors such as weight, fluid retention, age and gender all play a part in the caliber of the airway.[43, 55-60] Often the airway is narrowest at the OPJ, but structural narrowing can occur from the velopharynx all the way to the hypopharynx.[51, 61] It is critical to maintain a 4cm water pressure differential between atmospheric and critical pressure for airway patency otherwise collapse of the airway will occur.[62] Changing this differential can occur by either increasing the airway caliber or decreasing the airway wall compliance. Continuous positive airway pressure machines (CPAP) and sleep apnea mandibular advancement devices (MAD) affect both of these mechanisms.[27, 28] Although it is not possible to determine whether any increase in airway caliber will be protective against OSA for a particular patient it is reasonable to assume that a larger caliber would be more advantageous than a smaller one. This study will use AR to investigate whether a particular method of recording the mx/md position routinely provides a larger CSA of the airway.

Head Position and Airway

Head position and cervical mechanics are affected by airway adequacy and breathing mechanics. Many studies have confirmed that both children and adults with airway problems, abnormal craniofacial growth and development, or OSA have counter-clockwise rotations of the head with increased extension of the head in relation to the cervical vertebral column defined as an increase in cranio-cervical angle.[4, 33, 63-68] Suggestions proposed for the mechanisms involved in this change include alterations to the mode of breathing, physiological adaptation aimed at maintaining airway adequacy, and impingement on the oro-pharyngeal airway by the mandible and tongu**e.**

Mode of Breathing

Vig *et al.* demonstrated that changing the mx/md relationship by occluding the noses of 30 dental students and forced obligatory oral breathing resulted in in an increase in cranio-cervical angles.[69] The mean difference in cranio-cervical angle from baseline after 15-minutes of induced oral respiration was statistically significant at 2.5 degrees ($p \leq 0.001$) in extension. This increased to 4.3 degrees at the end of the first hour, and 4.8 degrees at 2 hours was statistically significant ($p \leq 0.001$). After removal of the nose clip and the re-establishment of nasal breathing, head posture returned to baseline. As our study is concerned with the immediate effect of changing mx/md relationship position, at a 15-minutes delay before assessing head position, a statistically significant change from the above study is long enough to see potential changes.

Physiological Adaption

Behlfelt showed that children with enlarged tonsillar tissue had greater cranio-cervical angles by 4-8 degrees when compared with children with normal tonsillar tissue.[64] Both Linder-Aronson and Zettergren-Welk *et al*. confirmed that children with large adenoids had faces that were developing vertically with a short posterior face height and a larger anterior face height and with increased cranio-cervical angles in comparison to a control group. After adenoidectomy craniofacial growth of the subjects approached the morphology of the control group.[70, 71] Harvold produced malocclusions and changes in craniofacial morphology with longer lower face heights by sealing the nasal passages of monkeys.[72] This lead to theories about how airway function affects craniofacial development. Solow and Kreiberg proposed that changes in cranio-cervical angles could lead to changes in cranio-facial development which they termed the "soft tissue stretch" hypothesis.[73] Previously Moss proposed the "functional matrix hypothesis" where functional complexes mutually interact with each other under genetic and environmental influences. The narrowing of either the nasal or oral functional matrix, would affect other functional matrices and the surrounding tissues.[74, 75]

Impingement on Oro-pharyngeal Airway

Solow *et al.* in their study of 50 participants found that OSA subjects had cranio-cervical angles 10 degrees greater than those without OSA.[4] Although head position varies for each individual subject, counter-clockwise rotations are adaptions connected to increasing the airway size.[76] In our study we aim to observe change in head posture after a 15-minute interval to assess different mx/md positions common in prosthodontics.

Head, Body and Mandibular Position

The literature on the effect of altering mandibular position on head posture is conflicting. Some studies have found insignificant changes in head posture after alteration of the mandibular position,[77-79] while others have found significant changes after altering mandibular position.[6, 80, 81] An increase in either the height dimension of the mandibular teeth occluding with the mandibular teeth described as the occlusal vertical dimension (OVD) or an anterior-posterior (A-P) change in the mx/md relationship of occlusion has been shown to change head posture.[12, 78] Moya *et al.* found that a significant counter-clockwise rotation (4 to 5.5mm) in head position occurred after one hour in 15 subjects with painful neck supporting muscles after increasing the OVD by placing full-arch maxillary occlusal splints.[80] Miralles *et al.*[81] used cephalometric radiographs to study changes in head position caused by placing an orthodontic appliance to correct posterior cross bite and increase the OVD and found forward head posture in fifteen patients.[71] Sakaguchi *et al.* used an orthotic to increase and stabilize a new OVD in also in a small sample of 15 TMD subjects and noted no change in head posture immediately in contrast to the above studies, but did find a downward clockwise rotation of the head and an improved cervical range of motion after two weeks wear.[82] There are limited head posture studies on changes to the mx/md relationship, most on small sample sizes that have used different research populations and designs and therefore could result in conflicting results. It is possible that early head posture changes could be due to excessive changes in OVD or head posture changes are needed to maintain a viable airway.[11]

Different mx/md relationship positions have different effects on posture. Some mandibular positions may have more beneficial effects than others in improving gait stability, increasing deltoid strength, improving range of cervical motion and reducing facial muscle EMG activity.[7, 83-88] Alterations in mandibular position have been shown to alter body posture in both humans and rat studies.[5, 89, 90] Abduljabbar *et al*. showed that increasing the OVD using orthotics in 20 female subjects with temporo-mandibular disorders and loss of OVD statistically significantly increased deltoid strength in an isometric test from the original OVD mx/md relationship position. These same subjects also had placebo orthotics made that did not increase the OVD and these had no deltoid strength improvement.[87] Chakfa *et al.* showed that by increasing the OVD in increments of 2mm in subjects with an initially reduced OVD at some increased OVD they reached an OVD of maximum deltoid strength, and that further increases in OVD reduced strength.[88] Thus there may be a small range of mx/md relationship positions that provide the ideal head and body position that could be used in prosthodontics.

Browne *et al.* reviewed the literature on craniofacial and cranio-cervical pain, and concluded that the published data clearly demonstrates both neurophysiologic and neuroanatomic connections between the neck and head due to the strong connectivity between the trigeminal and cervical motor systems and sensory responses.[91] It is clear from research that the mx/md relationship has a relationship to head position.[33, 66, 80, 81, 92] It is not known how the alterations in mx/md relationship interact with changes in head position to alter the airway size and shape.

From research it is clear that it will be important to allow subjects to adapt to a changed mx/md relationship before assessing their airway.[4, 33, 63-67] As there have been no studies assessing the relationship of airway size to the mx/md relationships used in prosthodontics, our study needs to define an exact time to re-establish a new head position after changing the mx/md relationship. Vig *et al.* found the greatest change in head posture occurred at 15-minutes after altering the mx/md position and due to limited research about time for head position to stabilize, our study will use this time frame to allow interaction between head position and the mx/md relationship. [69]

Cervical Range of Motion

The cervical range of motion is used as an indication of cervical function. The cervical range of motion (CROM) goniometer is a device that was developed by Performance Attainment Associates 12805 Lake Blvd Lindstrom, MN 55045 CA., USA as a tool to measure cervical range of motion (Appendix D). [93] It was developed for use in cervical mobility clinical and scientific studies to provide a measurable way of confirming head movement changes. Health professionals use this device to produce baseline information and also assess treatment outcomes especially measuring cervical rotation and forward head posture. [94, 95] The CROM (Performance Attainment Associates 12805 Lake Blvd Lindstrom, MN 55045 CA., USA) measures range of motion (ROM) in the sagittal, coronal and horizontal planes by the use of inclinometers. As it is able to measure all three planes at the same time, it is ideal for measuring postural changes, and has been used in head posture research. [79] Many studies to date have confirmed that the CROM (Performance Attainment Associates 12805 Lake Blvd Lindstrom, MN 55045 CA., USA) is accurate and reliable. [96-103] Tousignant *et al.* validated cervical range of motion using this device against radiographs as a gold standard in a population of 31 healthy subjects without neck pain and found a strong correlation in both extension ($p<0.001$) and flexion ($p<.001$) .[105] Two recent systematic reviews have compared the CROM (Performance Attainment Associates 12805 Lake Blvd Lindstrom, MN 55045 CA., USA) to other methods such as visual assessment, tape measurements, and single inclinometers. The reviews confirmed accuracy and reliability. [104, 105] It has advantages over other methods, as it is accurate, light\weight and easy to use and we will use it to determine changes from one mx/md relationship to another and to assess if there is a particular method for establishing the mx/md relationship that confers an advantage in head position.

Maxillo-Mandibular Relationships

In all dental disciplines there are specific procedural techniques used to change the maxillo/mandibular (mx/md) relationships. [106, 107] Various reasons for both increasing and holding the status quo of occlusal vertical dimension (OVD) have been proposed including lack of tooth structure, space to develop a stable occlusion and aesthetics. [106, 108] Techniques designed to alter the mx/md relationship in prosthodontics have continued to evolve from concepts laid down by earlier researchers such as Posselt, who proposed an envelope of function for border mandibular movements and thus developed repeatable posterior border positions for reconstruction on articulators.[111] Controversy exists about the ideal condylar relationship to rehabilitate to and in turn the ideal mx/md relationship.

[2, 109-113] In more recent times engineering models based on the use of articulators have competed with biological models of occlusion based on the body's ability to adapt under the control of many feedback mechanisms.[114, 115] This has altered our understanding of concepts of mx/md positioning, suggesting occlusion needs to be assessed both statically and dynamically, providing and a range of possibilities for a successful mx/md relationships.[112, 113, 116, 117] It will thus be important in our study to compare the common posterior and anterior condylar positions, as this will include the spectrum of possible mx/md relationships. CR is the most common posterior position defined as the mx/md relationship in which the condyles articulate with the thinnest avascular portion of their respective disks with the condyle/disc complex in an antero-superior position against the slopes of the articular eminence.[105] Phonetic bite position (PB) the most anterior position is the mx/md position found using the smallest speaking space defined as the space that occurs between the incisal or/and occlusal surfaces of the maxillary and mandibular teeth during speech.[118] They will be used in this research project to further our understanding of the effect even minor changes have on airway and head position.

Occlusal Vertical Dimension and Postural Vertical Dimension

The occlusal vertical dimension (OVD) is defined in the Glossary of Prosthodontic terms as "the distance measured between two points when the occluding members are in contact".[118] Postural vertical dimension (PVD) is any mandibular relationship occurring during minimal muscle contraction.[118] This position varies depending on influencing factors, mainly the muscles' visco-elasticity and postural muscle tone.[119] The difference between PVD and OVD is the inter-occlusal distance (IOD) or freeway space. Controversy has existed about whether one could change the OVD as the IOD was once thought to be immutable and any changes to OVD would invade this space. Today this has been discredited and a range of possibilities for the OVD exist.[120-122] Dawson maintains that as eruption keeps pace with wear, no loss of vertical dimension occurs, and there is constancy of the mx/md dimension due to elevator muscle contraction against the loaded temporo-mandibular joints (tmjs).[123, 124] He argued that although Atwood showed variations in PVD there is a constancy of OVD, and that only in exceptional circumstances of severe wear should the OVD be increased.[124, 125] Recent studies have shown that IOD is not immutable, and many have confirmed OVD can be changed and a new IOD created.[126-131] Bloom shows a case using a changed mx/md relationship using centric relation to create a new occlusal scheme and explains that it is rarely necessary to increase vertical dimension more than 2mm when following Dawson's technique.[126] Abduo in his recent review of OVD literature concluded that the smallest increase in OVD is best with up to a 5mm increase justified.[108] An increase in the OVD may be linked to the success of removable orthoses in the treatment of patients with temporomandibular disorders (tmd).[79, 132] Fu demonstrated that opening the vertical on TMD patients with a flat plane splint balanced the mandible, removed the obstruction to closure, reduced TMD signs and symptoms, and centered the mandible.[133] It would appear therefore that there still exists controversy as to the best method of taking mx/md relationships and as yet there is no consensus on OVD in mx/md relationship recording, nor any studies comparing cross-sectional airway with changes in restorative OVD.

Maximal Intercuspal Position

MIP is defined as the complete intercuspation of the opposing teeth independent of condylar position, sometimes referred to as the best fit of the teeth.[118] It is easily reproduced, is accurate and is the position chosen in fixed prosthodontics due to the simplicity of reproduction. Changing this position in a restorative case can mean the need to provide many more crowns at a significant cost to the patient. The bite registration technique involves simple closure of the patient into a wax or silicon bite in their most comfortable closed position with maximum intercuspation of teeth. Unless there is a significant esthetic or functional reason to alter the mx/md position, MIP is chosen as the relationship of choice in prosthodontic reconstruction.[108]

The most common reason to change the mx/md relationship from MIP is excessive wear or loss of teeth.[108] Two of the common methods used to alter the mx/md relationship are centric relation (CR) and phonetic bite (PB). MIP and CR are both accurate and reproducible, even in patients suffering from temporo-mandibular disorders (TMD)[134, 135] CR and MIP are not normally coincident in the human dentition, and coincidence may occur in as few as 26% of cases when a mx/ md registration is taken at CR the occlusal vertical dimension (OVD) will be changed in the 74% of subjects.[139] Unlike CR and MIP, PB is not reproducible accurately but is an anterior position that was first used in removable prosthodontics.

Centric Relation

Centric relation (CR) most recent Glossary of Prosthodontic terms definition is the mx/md relationship in which the condyles articulate with the thinnest avascular portion of their respective disks with the condyle/disc complex in an antero-superior position against the slopes of the articular eminence. This position is independent of tooth contact. The position is clinically discernible when the mandible is directed superiorly and anteriorly. It describes purely rotary movement about the transverse horizontal axis.[118] Over time the CR mandibular position definition has shifted the mandible forward and now more closely approaches the postural vertical dimension (PVD).[119] Okeson said it is no longer important that all discs must be properly positioned to maintain a healthy joint. [136] Dawson has called this an adapted centric position, [137] and in the absence of pain on bi-manual manipulation, the adapted centric, although not CR by the definition above, is an accepted bite registration of CR. This will be the definition we will use as it is impossible to be sure the discs are in place as we will not be using imaging techniques. [126, 135, 138] McKee showed using the bi-manipulation method a .11mm inter-reliability between bite registrations using Denar Centric-check.[135]

Dawson describes his technique that will be adapted for use in this study. (Appendix H) [123] He writes that CR requires both condyles to be moved to their antero-superior positions after deprogramming the subject's muscles then load testing with the bi-manual manipulation technique to confirm seating of the condyles in the fossa with no pain. [139] A change in mx/ md relationship from MIP to CR generally causes the mandible to distalise, the overjet to increase and the overbite to decrease. [140] Deprogramming can be accomplished with anterior deprogrammers and to provide anterior support to control the overjet and overbite in recording the CR registration. [141] Many techniques require the use of anterior deprogrammers such as a Lucia jig (made from various materials), tongue blade, leaf gauge or OSU Woelfel gauge. [141, 142] Dawson has recommended the use of an anterior jig such as a Lucia jig for simplicity along with the bi-manual technique. [123] Others have changed the anterior jig to a different material for ease of use. [143-147]

Phonetic Bite

The phonetic bite (PB) technique is the mx/md position found using the smallest speaking space produced by the sibilant phoneme. It is usually a more vertical and forward position from MIP as the mandible shifts forward to pronounce the "s" sound. The PB was first described as a technique used in complete reconstruction for full removable dentures, a situation in which MIP cannot be used, and there are few landmarks available to the clinician to judge the correct mx/md relationship. [148, 149] There has been a large amount of debate in the literature over whether the PB is a reproducible mx/md position. [134, 135, 149-151] Miralles *et al.* found that the use of the PB increased the inter-occlusal distance (IOD), an average of 3.39±1.13mm, and that this was a statistically significant change produced in the IOD by either the swallow bite 1.53± .52mm or relaxed position 1.82±.73mm bite technique. [150] Studies have shown that IOD is not a static vertical measurement, but is found within a range of 0-5.8mm. [148, 149, 152] This is within the range found for the PB by Silverman. [148, 153]

Conclusion

There is little research comparing the effect on airway of the different ways of establishing mx/md relationships. This study will measure the effect of altering mandibular position on the mean and minimum CSA and head position. We will investigate three mandibular positions, MIP, CR and PB. AR will be used to investigate the alterations in CSA associated with each mandibular position, and the CROM device will be used to determine changes in head position. It is hoped that the information gathered will help to increase our knowledge on the interactions between changes in mandibular position, head position and airway size. This may lead to a better understanding of the effects that altering mandibular position has on the cervical structures and airway, and provide information that dental clinicians can use to determine the best method for choosing a mx/md relationship and for increasing the OVD when it is indicated for comprehensive restorative cases.

Specific Aims and Hypothesis

Aim

The primary aim was to compare the immediate effect of altering the maxillo-mandibular (mx/md) relationship in an adult population on pharyngeal measurements of mean and minimal cross-sectional area in the upright position, at functional residual capacity (FRC) using acoustic reflection (AR). The mx/md positions to be evaluated were the maximum intercuspal position (MIP), the phonetic bite (PB) and centric relation (CR). The secondary aim was to compare the immediate effect of altering the mx/md relationship on head position assessed using a cervical range of motion (CROM) goniometer, Performance Attainment Associates 12805 Lake Blvd Lindstrom, MN 55045 CA., USA. (Appendix D)

Hypothesis

The hypothesis was that the immediate effect of altering the mandibular position from MIP to CR and PB would increase the size of both mean and minimum cross-sectional area and would affect head position.

Research Design and Methods

Participants

This study was a double blinded crossover clinical trial on 50 adult subjects. All subjects were chosen from patients attending “Advanced Dental” dental practice in Nelson, New Zealand. The Exclusion Criteria were age under 18 years; adults who could not have a bite registration taken, (including those who had less than one molar per quadrant and one opposing upper and lower incisor and those who were unable to open their mouth wide enough without pain for bite registration). Those who could have a bite registration but failed load testing in CR were excluded, as were adults with more than 1.93 mm inter-occlusal space between the posterior teeth in the CR bite position. Adults who were unable to perform the acoustic reflection (AR) test due to either a history of pulmonary disease, intellectual incapacity or motor control diseases were excluded along with those who were unable to understand the meaning of the consent form.

Recruitment Plan

Patients 18+ years of age, who were registered at "Advanced Dental" dental practice and either, arrived at reception or had an appointment were asked whether they wished to participate in the research project. The patients who agreed to participate in the study were told that the study procedures would require one hour and fifteen minutes of their time and were given information about the study and a consent form to take home to read. A Research Assistant (RA) booked a screening appointment and concurrent appointment with the investigating dentist. The RA explained the study procedures and reviewed the consent form with participants on the day of their participation.

Appointment

Participants signed a consent form when they presented for the study appointment (Appendix F). A $30 voucher was given to all participants as remuneration for their time and travel expenses.

Ethical Considerations

The coordinating researcher and RAs completed international on-line CITI research exams (Appendix M). Ethics approval "Health and Disability Ethics Committees" 12/STH/52 received 21 December 2012.

Confidentiality

Individual study results were confidential but all participants who indicated on the consent form that they wished to be notified of the study results received a summary of the study conclusions.

Blinding and Randomization Procedures

The coordinating researcher/ investigating dentist performed the CR and PB mx/md registrations on all participants. One of two research assistants (RA1, RA2) collected the registrations and allocated the order for the participant, having previously randomized them by picking at random from a box one of three colors to indicate the trial order (Appendix Q). The investigating dentist confirmed the oro-pharyngeal junction and the glottis and set these parameters on the "x" axis at MIP, CR and PB using the Ecovision™ acoustic reflection machine Benson Hood Laboratories, Pembroke, MA, USA distributed by Sleep Group Solutions, North Miami Beach, FL 33162, USA (AR). The two trained research assistants (RA) performed all AR and head position measurements. The RA who performed all the AR had over ten years experience and recorded over one thousand AR recordings with the machine. Each subject was allocated a study identification number using a random number generator (Microsoft Excel 2007). A record of the subjects' names, identification numbers, and bite registration identifications are kept in a book in a locked draw/cabinet that one RA had access to.

One RA entered the study identification number into the AR machine followed by the letters MIP, CR or PB to indicate three separate trials. RA1 stored the photograph of the de-identified AR data and the CROM (Performance Attainment Associates 12805 Lake Blvd Lindstrom, MN 55045 CA., USA) inclinometer readings using a Sony Cybershot Camera. The photographic data was downloaded on to a USB drive for the co-coordinating investigator to use. The digital photos on the camera were deleted.

The numerical data were manually recorded for each subject from the CROM and AR screen by the research assistant onto the Excel **s**preadsheet.

The Excel spreadsheet was protected by password. Although the co-coordinating investigator interpreted the results he was previously blinded from recordings and still had de-identified participant names.

Maxillo/ Mandibular Registration

The coordinating investigator performed all bite registrations. The anterior stop for CR using a jig (Appendix G) was made from Triad™ Trubyte™ VLC material, DENTSPLY International Inc., York, PA, USA (Appendix R) and PB using micro brushes (Appendix O). The posterior registration was recorded using vinyl polysiloxane (VPS) material (3420 Fostoria Way STE. A-200. San Ramon, California 94583 USA.) (Appendix N).

Centric Relation

CR bite registration was taken in the supine position following the Dawson protocol (Appendix H). This modification was made for ease of use and biocompatibility.

The posterior minimal clearance between the closest upper and lower posterior teeth was checked using a leaf gauge (Appendix S) to verify that the posterior freeway space was within 1.93mm. The triad jig was adjusted until this criterion was met. The patient was supported but not guided into a mandibular closing arc with the thumb of the right hand on the chin in the hollow above the mandibular symphysis and the rest of the fingers supporting the mandible as the patient closed their mouth. The mandible was manipulated into an anterior-superior position and absence of pain on loading was confirmed (Appendix H). The CR bite registration posterior section was recorded with Star™VPS "Heavy Stiff Bite" Danville Engineering, San Ramon Ca. (Appendix N) by a RA while the co-coordinating investigator supported the chin.

Phonetic Bite

The technique was adapted from Singh *et al.* (Appendix L). [154] Subjects were asked to count from 60-70 as per the Singh protocol. The PB mx/md registration was taken on the last sibilant phenome as the subjects said "Mississippi Miss" to increase repeatability.

Maximum Intercuspal Position

A bite registration was not necessary. Subjects were asked to lightly hold their teeth together when the MIP registration was needed.

Trimming of Bite Registrations

The coordinating investigator inspected all VPS bite registrations extra-orally to confirm accuracy. The mx/md bite registration was trimmed with a number 11 scalpel blade, one quarter of the occlusal width from the palatal aspect.

Measurement of Head Position and Airway Volume

RA1 and RA2 performed head position measurements with a cervical range of motion device (CROM) Performance Attainment Associates 12805 Lake Blvd Lindstrom, MN 55045 CA., USA (Appendix D) and airway volume with an "Eccovision" pharyngometer (AR) Benson Hood Laboratories, Pembroke, MA, USA distributed by Sleep Group Solutions of North Miami Beach, FL 33162, USA (Appendix C). Both the coordinating researcher and the experienced research assistant having assessed over two hundred AR recordings on patients, practiced to confirm consistency and to identify the oro-pharyngeal and glottis using Kamal's protocol. [155] Once convinced they had consistency and reproducibility, a three participant pilot study was then performed using the study protocols to confirm inter-operator reliability. Participants sat in the same chair for both CROM and AR. The CROM was fitted (Appendix D), and 15-minutes of habituation with each mx/md position was allowed before each measurement of head position. This same head position was used when measuring airway volume. The subjects were asked to look straight ahead for one minute prior to recording the inclinometer measurements and the FRC volume. Measurements were taken in coronal, horizontal and sagittal positions and recorded in degrees.

Measurement of Airway Volume

Participants were seated in same chair for all measurements of AR. This was performed directly after the head posture measurements. Two RAs performed the AR procedure on the participants. AR was performed following Kamal's protocol for each of the three-mx/md relationships MIP, CR and PB (Appendix I). This protocol was adapted having three graphs for each mx/md bite registration. An RA confirmed head posture had not changed by monitoring the inclinometers. A spirit level was fitted to the AR tube to confirm horizontal alignment of the tube prior to measuring the functional residual capacity (FRC) recording (Appendix V). The FRC was recorded for 3 positions MIP, PB and CR following the protocol by Kamal [156].

Outcomes

The primary outcome was the size of the cross-sectional area of the airway.

The secondary outcome was head position.

Variables

The independent variable was change in mx/md relationship.

The dependent variables were cross-sectional airway area measured in millimeters and head position measured in degrees.

Statistical Analysis

A power calculation was conducted using nQuery Advisor (Version 7.0). Assuming the effect size of Δ^2=1.12 a sample size of n=50 is adequate to obtain a Type 1 error rate of 5% and a power over 99%.

Demographic information was collected including age, sex and molar and incisal relationships.(Table 1) Means and standard deviations (SD) were reported for continuous airway variables. The primary outcome was cross-sectional area and was analyzed using repeated-measures analysis of variance. The secondary outcome was head position and was analyzed using Friedman's test for non-parametric variables.(Table 2) Statistical analysis was conducted using SAS (Version 9.2).

After each set of 3 AR tests not observed by the researcher the graphs were assessed and the coefficient of variation was calculated on IBM®SSPS® 2010 Statistics Premium Gradpack Shrinkwrap version 19 ©1989 (Appendix E). If it was greater than 10% the trial was repeated.

Results

In this study there were 50 subjects (28 male and 22 female) subjects of Caucasian race with a mean age 46(SD=14.67) years. There were 25 Class I, 18 Class II and 7 Class III subjects. There were changes in all three mx/md relationship positions. (Table 1)

Looking at anterior-posterior (A-P) positioning based on the incisal relationship of the 50 subjects as a comparison, CR was the most posterior position by 0.71mm (mean 3.51mm, SD=2.30) followed by MIP (mean 2.80mm, SD±2.07). The most anterior position was PB by 0.78mm (mean 2.02mm, SD±2.25). The total overall A-P difference was 1.49mm. (Table 1, Graph 1)

Occlusal vertical dimension (OVD) was greatest for the PB mx/md relationship. It was 1.33mm (mean -.32mm, SD=1.30) more vertical than CR (mean 1.01mm, SD 1.70) and 2.58mm more vertical than MIP (mean 2.26mm, SD=1.79). (Graph 1)

The average mean and minimal cross-sectional area of the pharynx as seen in Table 2, Graph 2 show that the average mean CSAs were CR 2.62 (SD= 0.48) cm^2; MIP 2.62 (SD= 0.56)cm^2 and PB 2.68 (SD= 0.53)cm^2 (p value= 0.663). The average minimum CSAs were CR 1.60(SD = 0.52)cm^2; MIP 1.70(SD= 0.49)cm^2 and PB 1.62(SD= 0.53)cm^2 (p value= 0.271). There was no statistically significant difference using repeated-measures ANOVA for the mean and minimum cross-sectional area between the three-mx/md relationships.

The average minimum oro-pharyngeal junction and glottis of the pharynx also seen in Table 1 show that the average minimum oro-pharyngeal junction CSAs were CR 1.70 (SD= 0.56) cm^2; MIP 1.87(SD= 0.68) cm^2 and PB 1.80(SD= 0.57) cm^2 (p value= 0.075). The average minimum glottises CSAs were CR 2.63(SD=0.61) cm^2; MIP 2.65(SD= 0.79) cm^2 and PB 2.65(SD=0.64) cm^2 (p value= 0.978). There was no statistically significant difference for the minimum oro-pharyngeal and glottis CSA between the three mx/md relationships.

The median head positions were as follows: CR (0° horizontal, 4° sagittal and 0° coronal) planes; MIP (0° horizontal, 4° sagittal and 0° coronal) planes; PB (0° horizontal, 2° sagittal and 0° lateral) planes. There was no statistically significant difference for the change in head position (horizontal p .956, sagittal p .155 and coronal) planes (p=0.451) between the three mx/md relationships.

Discussion

For all average subjects' cross sectional areas in Table 2, both minimal and mean measurements were not statistically significant.

Various reasons could be suggested as possible causes for this result. As the mx/md relationship change was only 1.49mm from the most posterior to anterior position and the change was only 2.58mm in vertical from the least OVD to the greatest OVD, this change may have had limited effect on the pharyngeal space. Mean CR was 0.71mm posterior to and 1.25mm more vertical than MIP whereas PB was 0.54mm anterior and 1.7mm more vertical than MIP.

Another reason could be that the A-P and vertical changes were not large enough differences to pick up changes using acoustic reflection as the measuring tool. There are possible errors in using AR with CSA through partial reflection of sound waves being less accurate at predicting CSA than CT or MRI. [18, 157] AR has technique sensitivity issues so in our study we controlled by repeating the tests for consistency, by education and recording accuracy following Kamal's protocol. [156]. It is possible that the 15-minute time frame for head postural habituation may not have been long enough to achieve head posture changes, as previous research has shown that changes in head posture do affect pharyngeal airway space. [158]

In our study the average mean pharyngeal CSA was 2.62(SD =0.56) cm^2, the mean age was 46 years(SD=14.68) with 28 male and 22 female subjects. The average minimum pharyngeal CSA was 1.7(SD=0.49) cm^2 and minimum oro-pharyngeal junction (OPJ) of 1.87 (SD=0.49) cm^2. In Kamal's normative study of 350 subjects he suggested both the mean and minimum cross-sectional are important measurements for OSA and it is noted that his study values are larger than our values. [156] He observed an average of mean pharyngeal CSA of 3.194(SD=0.31) cm^2 in males and 2.814(SD= 0.331) cm^2 in females. He also observed the minimum pharyngeal CSA for males 2.7cm^2 and for females 2.1cm^2. Their study had 271 males and 79 females. Their ages varied from 21 years to 39 years (average, 27.6 years). Combining these measurements provides an average of 3.004cm^2. His study had different exclusion criteria with a different population as our sample were all of Caucasian origin, were on average older, were not screened for disorders such as OSA and had 36% class 2 subjects. Singh *et al.* in their research on a population of TMD patients explained that using PB at functional residual capacity (FRC) was 12% greater than the FRC at baseline although there were no statistical data on the cross sectional area(CSA). This is a larger increase than our study sample of only 2.16%. Although the subjects' ages were similar at average age 42.7 years(SD±15) with 17 male and 29 female subjects, their exclusion criteria were different being all TMD patients. TMD patients often have a reduced OVD or a larger overjet, and as they were being fitted with orthotics the OVD would have been increased more than our study. Although there was a 12% increase from baseline it was statistically insignificant. [154]

Our subjects compared very closely to both the Cleveland cohort of white subjects studied by Patel and colleagues where the mean pharyngeal CSA was 2.65(SD±0.67) cm^2 and minimum pharyngeal CSA being 1.9(SD=0.57) cm^2 with an average age 42.1 years(SD=19.2), [54] and Jung and colleagues where their subjects average age was 47(SD=21) without OSA and 54 years of age(SD=13) with OSA. Their study had an average pharyngeal mean CSA of 2.52 (SD=0.42) cm^2 and minimum pharyngeal oro-pharyngeal OPJ of 1.61(SD=0.27) cm^2 without OSA and 2.36(SD=0.42) cm^2 and minimum pharyngeal OPJ CSA of 1.44(SD=0.35) cm^2 with OSA. [159]

In our study as the subjects were their own controls we are not concerned about the size of the respective mean and minimum cross-sectional areas but the relative CSA difference between the mx/md relationship sizes.

Studies using mandibular advancement appliances (MAD) on OSA subjects show the main affect on the pharyngeal airway is through the protrusive effect of the appliance. [27, 160] In fact using placebo appliances with just vertical and no protrusion did not improve and in some had a detrimental effect on AHI in OSA subjects. [161, 162] The oro-pharyngeal junction and the velopharynx have been shown to predict treatment response with MAD devices. [3, 27, 163, 164] The most effective change in opening the pharyngeal airway is 50%-75% protrusion, and since maximum protrusion is in the range of 8-11mm then significant airway changes are more likely to be seen at greater A-P of 5-8mm than our study result that was closer to 1.5mm. [3] Thus this amount of change in protrusion would not be in the therapeutic range required for successful OSA improvement. However Zhao *et al.* using MRI to study changes at 2mm protrusive increments using MAD appliances on 11 subjects found the mean and minimum increase in CSA at the velopharynx significantly increased from 3.27(SD=9.36) mm to 8.45(SD=7.59) mm and 4.00 (SD=7.25mm) to 6.64(SD=6.87) mm at 2mm protrusion from MIP. [35] This change disagrees with our study and may be due to better accuracy with MRI or the population being OSA subjects. This also could be due to a larger OVD increase and protrusion combination similar to Singh et al due to the MAD appliance needing plastic on the occlusal surfaces. [165]

Minimum mean and OPJ CSA are important measurements in OSA, as discussed above. In our study both mx/md relationships changed positions, CR and PB, had increased OVD from MIP, with CR being more posterior and PB being more anterior position from MIP. This resulted in MIP having the largest minimal mean and OPJ CSA. This may be due to the clockwise rotation of the mandible by more vertical change than protrusion that is known to reduce the airway as seen in Class II vertical growing subjects but the result was not statistically significant. [64]

Ferreira *et al.* using CT on ten asymptomatic subjects could not identify condylar changes from MIP to CR and our change was also insignificant from a linear perspective. [166] However the closest p-value=0.075 to be significant from an airway perspective in our study was minimal OPJ CSA at 1.87(SD=0.68) cm^2 at MIP, compared to 1.80(SD=0.57) cm^2at PB, and 1.70(SD=0.56) cm^2at CR. Although not significant statistically, CR is the most posterior position and is trending smaller than both MIP and PB. In our study there were 18 Class II subjects. Studies have shown that Class II subjects have smaller pharyngeal airways than Class I and III subjects with larger overjets or overbites and that protrusion improves the airway as seen in bi-maxillary surgical reconstruction, orthotropics and MAD therapies. [31, 38, 167-170] Further research could identify whether groups of subjects that had a larger change from MIP to PB had a greater change in pharyngeal CSA as well. It may also be relevant that as CR is trending to be smaller from a minimal CSA that these patients would be better served by using a mx/md relationship position placed further anteriorly.

In the literature review prior to the study design we discussed whether to use functional residual capacity (FRC) and/or residual volume (RV). To reiterate two factors common to OSA that MAD appliances and CPAP try to address are airway caliber and collapsibility. [27, 28] FRC identifies the caliber using acoustic reflection(AR) and RV aims to confirm the collapsibility of the airway using AR. It would be useful also to know the effect small changes make to the collapsibility of the airway using AR in prosthodontics, and further studies could also add to the studies that have shown that OSA patients have a smaller pharyngeal minimum and mean cross sectional area than control subjects and these reduce from seated to supine position. [42, 48, 49, 53, 61]

Our study was performed in the seated position and although a supine technique could have been used we felt this initial research was better in the seated position at FRC. It is known that in the awake subject that head position will change to provide an adequate airway. [164] Vos *et al.* showed in their research using CT, airflow resistance modelling and polysomnography that although there is a variation in pharyngeal size, it is the shape of the awake pharyngeal airway that is more important. They also showed there is a relationship between the awake pharyngeal minimal cross-sectional area and AHI on OSA subjects. Thus the geometry is more important than whether one is awake or asleep. [39]

In prosthodontics, controversy still exists about the ideal position to re-establish a mutilated dentition. Different groups of the dental community choose condylar positions such as CR, neuro-muscular or phonetic bite, to establish the mx/md relationship position. These positions are chosen for various reasons such as: reproducibility, lack of landmarks, incisal wear, too large an increase for posterior crowns, or concerns with immutability of the freeway space (postural vertical dimension-OVD). Most prosthodontic reconstructions are increased within a range of 2-5mm. [108] This research chose CR as the posterior border position and PB as the anterior border position, and thus all mx/md relationship positions within this range by inference would also be within this range for airway and head position. [109, 111, 171, 172] We chose to increase the OVD for both CR and PB by the smallest amount possible. Some prosthodontic rehabilitaion clinicians choose to restore back to the unworn height from incisal cemento-enamel junction to cemento-enamel junction (CEJ/CEJ) which ranges from 18-21mm. Both temporo-mandibular disorder and sleep dental medicine usually increase a larger amount than this range as they need to fit at least 2mm of plastic between the posterior teeth. Our study mean MIP CEJ/CEJ was 16.51(SD=2.42) mm and this increased to CR 17.88 (SD=2.12) mm and PB 19.15(SD=2.12) mm. Our OVD change therefore could possibly be increased further and this may have had an effect on airway and head position.

Head position change was also not statistically significant. The likely cause was due to the lack of change in pharyngeal space as the changes in incisal relationship were minimal. A second reason could be that 15 minutes was too short a timeframe to stabilize a long term head position. Studies on head position have been on specific populations such as orthodontic subjects or TMD subjects, so it is difficult to compare with our study. [69, 80, 81] There is an association between head position and mandibular position. Miyaoka and colleagues showed that opening the mouth wide causes head movement and these movements are functionally coupled. [173] Daly *et al.* showed that opening the mandible 8mm altered head posture. Head posture could be linked to gravity, functional activities such as breathing and swallowing. [173, 174] In our study head position only changed in the sagittal plane and although not statistically significant there was a 2° clockwise rotation of the head from MIP to the PB position.

The strength of our research was that the sample size does include a cross-section of age in a population that was their own controls with one researcher providing all the mx/md relationships blinded from the airway and head position recordings in a double blind study. As expected CR was a more retrusive position compared to MIP, and PB was anterior to MIP. Two limitations were that it was only Caucasian subjects and radiographs were not taken to confirm CR. It could be argued that it would have been more relevant to hold the head position constant for all three mx/md relationship positions. This would be relevant in the supine position but as head position can affect airway in the vertical position allowing the subject to accommodate the new mx/md relationship in the upright-seated position provided an accurate depiction of what occurs naturally providing a more realistic AR reading.

Further studies could provide information in the supine position, or RV in the seated position to identify the collapsed effect on the pharynx. As Class II subjects and subjects with larger overjets were expected to have the largest change in airway these sub-group subjects could be assessed separately.

Conclusion

This research has found that the immediate effect of changing the maxillo/mandibular (mx/md) relationship for prosthetics have minimal effect on the awake general population of subject's mean and minimal CSA of the pharyngeal airway or head position using acoustic reflection. The reason for this is unknown but likely due to the small A-P change and vertical change from MIP to CR and PB.

If further research identifies that the immediate effect and the long term effect of one position provides a larger pharyngeal airway then it would be appropriate to look at the benefit of that mx/md relationship position over other mx/md relationships.

These findings provide clinicians with the ability to feel relatively confident to restore dentitions whether with fixed or removable techniques, to any mx/md relationship positions between CR and PB without concern for airway or head position changes in the awake patient.

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