2019

Measurement of maximum vertical space between teeth as a factor in digital guide design for dental implant placement in angle class I and class II population

BOSTON UNIVERSITY

HENRY M. GOLDMAN SCHOOL OF DENTAL MEDICINE

THESIS

MEASUREMENT OF MAXIMUM VERTICAL SPACE BETWEEN TEETH AS A FACTOR IN DIGITAL GUIDE DESIGN FOR DENTAL IMPLANT PLACEMENT IN ANGLE CLASS I AND CLASS II POPULATION

by

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Submitted in partial fulfillment of the requirements for the degree of

Master of Science in Dentistry
In the Department of Periodontology

2019

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DEDICATION

I would like to dedicate this work to my always biggest support, Yu family and Liao family. I want to thank people who made this project possible through endless patience to teach me Albert Price, Wayne Gonnerman, and Yihong Zhao.

MEASUREMENT OF MAXIMUM VERTICAL SPACE BETWEEN TEETH AS A FACTOR IN DIGITAL GUIDE DESIGN FOR DENTAL IMPLANT PLACEMENT IN ANGLE CLASS I AND CLASS II POPULATION

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Boston University, Henry M. Goldman School of Dental Medicine, 2019

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ABSTRACT

Purpose: The objective of this research was to measure MVS between the central incisors and the posterior areas to evaluate whether computer designed guides can be used.

Materials and Methods: A total of 150 adult subjects (aged 22−78) were included. The population was further stratified by race, sex and Angle Classification. The examiner measured the maximum vertical space (MVS) at six specific sites. Measurements were repeated twice at each site. In addition overbite and ovejet were measured at the central incisor position. The pilot drill/guide appliance combination space requirement was tested with each category of MVS measurement.

Results: (i) there was a race effect, with African American having a greater maximum vertical space measurement than Caucasian and Asian respectively ($P < 0.0001$); (ii) there was a also gender effect, with males having a greater maximum vertical space measurement than females($P < 0.0001$); (iii) there was an inverse association with overjet on central incisors and first premolars, with less overjet subjects having a greater maximum vertical space measurement ($P < 0.05$). We found that overall only 76% of the female

cohort in our sample satisfied this space requirement of Nobel Guide (45mm) at the central incisor position.

Summary: Using the Nobel computer guided surgery minimum dimension requirement of 45mm, our findings suggest that first premolar or second molar implants could not be placed in our sample of dentulous patients, while a central incisor implant could be placed in 76%-100% of subjects depending on gender and race factors.

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LIST OF ABBREVIATIONS

BU ..... Boston University

DICOM .....Digital Imaging and Communications in Medicine

MIP .....Maximum Intercuspation

MMO..... Maximum Mouth Opening

MVS..... Maximum Vertical Space

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Chapter 1. Introduction

The problems associated with limited mouth opening could be represented by two patients recently seen in our clinic. One patient in good health and with excellent oral hygiene wanted to have two implants to replace the previously extracted first and second molars in the lower right quadrant. Her anterior mouth opening was limited to 33 mm and she had been referred by a private practitioner whose implant tools would not allow placement. In another referral, a perfectly fabricated, computer generated, surgical guide could not be used in the patient's mouth due to his limited mouth opening.

In general, dental treatments can be uncomfortable for the patient with limited mouth opening, and difficult or impossible for the dentist. The access for instrumentation required for various procedures should be evaluated at the initial exam. To treat patients with limited mouth opening, the dentist needs to adapt with small rotary instruments such as dental burs with small heads and a short axis.[16]

It is important to ascertain the patient's maximum mouth opening prior to establishing a treatment protocol. If the mouth opening is limiting, the patient and the dentist need to recognize this as a complicating factor.[17] Procedures such as endodontic treatment in molars can be quite complicated and, in some cases, treatment will be limited to anterior teeth. Extraction may then be the treatment of choice for posterior teeth.[17] In standard prosthodontic treatment, in patients with reduced mouth opening, rotational paths of insertion and reduction in occlusal vertical dimension may complicate taking conventional impressions. In some cases it is necessary to obtain preliminary impressions, followed by the use of modified individualized trays to obtain definitive impressions.[16] In

our new era of digital planning and construction of surgical guides, limited mouth opening may prevent accurate direct digital impressions and force the practitioner to resort to scanning a model. This affects the quality of the digital information which in turn affects the fabrication of the surgical guide.

In the process of guided implant surgery, an acrylic appliance is fabricated and then must be inserted between the dental arches and over the teeth prior to drilling (see Figure 8.). Various drill diameters are then inserted into a very restrictive guide sleeve in the appliance to create the osteotomy or hole in the bone which then receives the dental implant. Guidance by this drill sleeve requires the drill/handpiece combination to be perpendicular to the surface of the appliance which determines the necessary trajectory dictated by the bone site evaluation. This demand for adequate vertical access in the patients mouth is central to the need for pre-treatment evaluation of maximum vertical opening. For example, the NobelGuide manual for guided dental implant surgery requires the guide to have a minimum thickness of 2.5-3 mm of acrylic material in all areas and 1mm must be added for application of the guide sleeve. The twist drill for a guided pilot drilling is 40.9mm. In this case, the total access space of 45 mm would be necessary to utilize the guided implant surgery appliance. As directed in the Nobel Concept Manual pp52-53: First the appliance is positioned, then the guide sleeve is placed and finally the drill is inserted.

Measurement techniques of linear mouth opening may be designed to determine either the vertical distance traveled by the mandible[1] or the functional access to the mouth.[5,8,11,12,14] The former is best assessed by a measurement that includes the overbite

while the latter is the best measured by inter-incisal distance.[6] It is necessary to use a method of measurement that is easy, quick, and precise.[15] One study concluded that intraoral measurements using a ruler were precise and accurate.[2] We devised a measurement protocol that could easily be reproduced and be useful in an implant placement guide design.

Our research was designed to determine whether a representative sample of patients from the BU dental clinic have sufficient opening to allow use of a standard Nobel Guide Implant template, guide sleeve, handpiece and drill combination.(See Figure 4-8.) In addition, we hypothesized that there could be a relationship between a patient's anterior mouth opening and their posterior opening which would provide a simple clinical planning measurement. If a positive relationship between anterior maximum vertical space, (also called Maximal Mouth Opening or MMO) and posterior MVS exists then, the minimal anterior MVS measured could be an efficient planning measurement in choosing a guided implant appliance/system. To the best of the author's knowledge, there have been no other studies evaluating the association between computer guided implant placement and limited mouth opening.

Chapter 2. Review of the Literature

The range of mouth opening is a significant factor in the diagnosis of many clinical conditions and can have implications for the management and treatment of patients. Limited mouth opening can be associated with temporomandibular joint (TMJ) dysfunction syndrome, trauma, neuromuscular disorders, odontogenic infection, congenital and developmental anomalies and advanced oral malignancy. A reduction in mouth opening may cause masticatory and social difficulties for the patient, and poses problems for the dentist and the anesthetist. Measurement of mouth opening has been used to assess two clinical problems – functional mouth opening (the maximum anterior vertical measurement for access to the oral cavity) and TMJ movement. The methods of measuring mouth opening described in the literature are numerous.[6]

Assessment of mouth opening is an important part of the basic examination of patients for clinicians involved in treatment of head and neck disorders. In order to diagnose an abnormality, knowledge of the normal condition is essential. A review of the literature highlights a need for standardization both of the dimension measured and of the instrument used for measuring mouth opening in order to facilitate comparison between studies.[6] When designing a study which measures linear mouth opening, it is first necessary to determine the information sought; the vertical distance traveled by the mandible[1] or the functional access to the mouth.[5,8,11,12,14] The former is best assessed by a technique which includes the overbite while inter-incisal edge distance is the best reflection of the latter, and the most applicable to our study.[6]

Maximum mouth opening (MMO) measures the maximum distance from the incisal edge of the maxillary central incisors to the opposing teeth. In our review of existing literature we found that these measurements have not been related to digital guide design for dental implant placement. MMO has been determined either by using a ruler/caliper[8-11] or even by using the width of three/four fingers.[5] Some studies[3,8] performed MMO measurement more than once and recorded the highest value while other studies[10,12,14] performed it only once. Hesse et al. found it necessary to open the mouth maximally more than four times in adult females and three times in adult males to record a maximum value of MMO.[3] In contrast, Yao et al. stated that the first measurement of MMO was generally the greatest among the three measurements taken for each subject due to decreasing muscle power with succeeding measurements.[8] A measurement point such as the incisor edge is relatively more permanent and more easily determined in inter-incisal distance measurement compared to the sum of inter-incisal distance and overbite.[8] In addition, Wood and Branco concluded that intraoral measurements using a ruler were precise and accurate.[2] It is of great value to use a method of measurement that is easy, quick, and precise.[15]

Several studies[1,4-10,12-14] investigated MMO among different populations. In a study by Müller et al. on a sample of 20719 Swiss population aged 4–17, the average MMO was found to be 45 mm.[14] Agerberg in a study of 200 Swedish adults, aged 18–25 reported a mean MMO value of 54.55mm.[1] El-Abdin et al. studied 1158 Saudi Arabian subjects, aged 5–70 and reported a mean MMO value of 46.12mm.[4] Zawawi et al. studied 140 USA subjects, aged 21–42, and reported a mean MMO value of 48.8mm.[5] Gallagher et al.

studied 1513 Irish subjects, aged 16–99, and reported a mean MMO value of 42.2mm.[6] Sousa et al. studied 303 Brazil subjects, aged 6–14, and reported a mean MMO value of 43.70mm.[7] Yao et al. studied 1442 Taiwan subjects, aged 20–80, and reported a mean MMO value of 49.10mm.[8] Sawair et al. studied 496 Jordan subjects, aged 15–80, and reported a mean MMO value of 42.90mm.[9] Sohail and Amjad studied 450 UAE, Indian, Pakistan subjects, aged 19–24, and reported a mean MMO value of 53.24mm, 52.6mm, 53.6mm respectively.[10] Casanova-Rosado et al. studied 254 Mexican subjects, aged 14–24, and reported a mean value MMO of 46.61mm.[12] Khare et al. studied 894 Indian subjects, aged 21–70, and reported a mean MMO value of 47.8mm.[13] As noted above, a wide variation in the range of MMO from 42.2mm to 54.5mm has been reported. Most of these studies revealed that the mouth opening increases with age until adulthood and that females have a smaller mouth opening compared to males. Therefore, it is important to establish the normal MMO for each specific population in order to be able to make a diagnosis of reduced mouth opening.[15]

MMO variations could be due to differences in sample size, measurement methodology, age, or differences in anatomic characteristics of these populations.[15] This statement is supported by several studies which reported that the MMO was correlated with craniofacial morphology, mandibular length, body height and weight.[11,14] Casanova-Rosado et al.[12] suggested that the difference between males and females in MMO is likely due to the physical size; males are generally larger than females and hence the head and face bone structures are accordingly bigger. Similar findings were observed by Gallagher et al.,[6] Yao et al.,[8] Sawair et al.,[9] Sohail and Amjad,[10] who assessed MMO in adult subjects.

In contrast, no significant differences in MMO were found between male and female children.[7,11] Thus variations may be masked by differences in skeletal age and growth stage. Müller et al.[14] mentioned that growth results in increasing mandibular length which geometrically influences the linear inter-incisal measurements. Further, Sousa et al.[7] reported that the gender difference in MMO in adults is not observed in children because they do not have the sexual maturity of adults.

Virtual implant-prosthetic planning provides a variety of interesting perspectives in terms of diagnostics, individual treatment planning and exact surgical and prosthetic implementation.[19,20] There are many types of surgical guidance techniques available to transfer the virtual planning data to the operative site, including the traditional surgical guide and the computer designed guide.[21] The traditional guide can be fabricated from a replica of a partial or full arch denture, or a wax-up dental model.

Computer guided surgery uses a static tooth, bone, or soft tissue borne template, fabricated in plastic materials, that defines the position and trajectory of implant placement through incorporation of a guide sleeve. This guide sleeve is set relative to the adjacent anatomic structures by incorporating 3D data from a bone CT or CBCT (using a DICOM format) merged with an 3D formatted data set from a surface scan of the teeth (using an STL format) and then blending virtual tooth form and implant shape/size from an associated software library. This workflow then provides a virtual model of the planned replacement parts within the individual patients existing bone and soft tissue anatomy with the objective of avoiding infringement upon adjacent vital structures.

The potential advantage of guided surgery is the ability to plan and optimize the implant position in a restoration-driven placement. Moreover, computer-guided techniques can help to decrease postoperative discomfort and allows immediate implant function, as they enable implant placement with minimal surgical trauma.[24] It can also reduce the possibility of damage to the adjacent critical structures such as bones, nerves, adjacent tooth roots, and sinus cavities.[23]

Chapter 3. Materials and Methods

Overview/ Inclusion and Exclusion Criteria

Recruitment:

Patients who had been assigned to Boston University Dental Medicine Department of Periodontology were screened for eligibility for the study at the time of their procedure appointment. For those who were potential participants, the research coordinator explained the research purpose and procedure in detail. If a subject agreed to participate, informed consent was obtained and questions by participants were answered fully before signing the consent. After obtaining the consent, the participant was given a study number.

Procedure:

The patient history was taken and a questionnaire provided to each patient at the time of clinical oral examination. The information collected included the age, race gender, past history of any trauma, pain, or clicking sound at rest or during jaw movements, and history of head and neck disorders. The clinical examination consisted of a general dental examination inspecting the pre-auricular area for any swelling, erythema, or tenderness. The area directly over the temporomandibular joint was palpated when the patient opened and closed the mandible. The extent of the mandibular condylar movement was noted. The masticatory and cervical muscles were also palpated. In order to measure anterior maximum vertical space (MVS) and posterior MVS, each subject was asked to open his/her mouth as wide as possible.

1. An ink mark (Double head writer marker, Lion Pencil Co., LTD, Taiwan) was placed on the center of the maxillary central incisors edge, first premolars' buccal cusp tip, and second molars' mesiobuccal cusp tip.
2. The patient was instructed to close to determine maximum intercupspation (MIP), which refers to the occlusal position of the mandible in which the cusps of the teeth of both arches fully interpose themselves with the cusps of the teeth of the opposing arch. The Angle Class* was determined in this position.
3. A mark was placed below the maxillary mark on the buccal face of the opposing mandibular tooth.
4. The patient was instructed to open in order to measure the distance from the lower tooth buccal face mark to that tooth's edge this was designated as overbite. We then measured the distance from that lower tooth edge to the maxillary incisor edge this was labeled as incisor MVS.
5. Overjet was measured horizontally from the labial surface of the mandibular central incisors to the lingual surface of the maxillary central incisor in the MIP position using a standard periodontal probe. (CCS SE UNC PROBE, 1-15, Stainless Steel, Hu-Friedy, USA)

*Edward H. Angle published the first classification of malocclusion in 1899. The Angle Classification was based on the relationship of the mesiobuccal cusp of the maxillary first molar and the buccal groove the mandibular first molar.

The vertical distance between the opposing teeth was measured with a Boley gauge**. The examination and measurements were performed while the subject was seated

comfortably in the dental chair in an upright position. The examiner measured six tooth positions, the maximum distance from the incisal edge of the maxillary central incisors to the opposing teeth, the maximum distance from the maxillary first premolars' buccal cusp tip to the opposing teeth, and the maximum distance from the maxillary second molars' mesiobuccal cusp tip to the opposing teeth. Overjet and overbite measurements using UNC probe were performed on upper right central incisor and its opposing tooth. Maximum opening measurements were repeated twice at each site and then measurement moved to next site.

Anterior MVS was defined as the distance between central incisors while the posterior MVS was measured at two locations - first premolars and then at the mesiobuccal cusp of second molars which framed the posterior access space.

Study duration: 5 minutes

Subject participation duration: 20 minutes

Withdrawal from the study reasons:

1) Failure to comply with the study
2) Any illness that might affect the outcomes

**Boley gauge (Pearson Dental Suppliers Co., Sylmar, Calif.) was used to maximum mouth opening at each patients visit. Each measurement was rounded to the nearest mm.

Inclusion:

In order to be eligible for this study, individuals had to meet the following inclusion and exclusion criteria:

- Presence of teeth at necessary measurement sites (upper and lower central incisors, upper and lower first premolars, and upper and lower second molars)

Exclusion:

An individual with any of the following criteria was excluded from participation in this study:

- History of jaw, head or face trauma.
- History of signs or symptoms of jaw or face pain (either at rest or during function)
- History of bruxism
- History of temporomandibular joint sounds
- Facial or dental developmental abnormalities
- Dental prosthesis on the anterior teeth, first premolars, and second molars
- Class III malocclusion (anterior crossbite)

The mixed linear regression model with unstructured residual covariance matrix was used in our analysis. Age and Angle classification were controlled in all analyses as potential confounding variables. The mixed linear regression models were used to test the effects of gender, race, side (left/right), overjet, and overbite on Maximum Mouth Opening (MMO) by tooth types (i.e., incisor, molar and premolar). All statistical analyses were carried out using SAS 9.4. All hypothesis tests are two-sided at a significance level of 0.05.

Chapter 4. Results

This study was composed of 150 subjects with 69 males and 81 females. Among the 150, 50 (33.33%) were Asian, 31 (20.67%) were African American and 69 (46.0%) were Caucasian. Among the 150 subjects, 117 (78.0%) were Angle Class I on both sides, 31(20.67%) were Angle Class II on both sides, 1 subject(0.67%) was Angle Class I on right side and Angle Class II on left side and 1 subject(0.67%) was Angle Class II on right side and Angle Class I on left side. The race of the subject was self identified. Overbite medically refers to the extent of vertical (superior-inferior) overlap of the maxillary central incisors over the mandibular central incisors, measured relative to the incisal edges. Overjet is the extent of horizontal (anterior-posterior) overlap of the maxillary central incisors over the mandibular central incisors. In class II (division I) malocclusion the overjet is increased since the maxillary central incisors are protruded. (see Table 1. for age, overbite, and overjet distribution both overall and broken down by gender)

	Age	Overbite(mm)	Overjet(mm)
Overall Mean ± SD Overall Range	41.23 ± 13.82 (22 to 78)	3.06 ± 2.09 (-2 to 12)	2.88 ± 1.65 (0 to 8)
Male Mean ± SD	42.16 ± 14.51	2.86 ± 2.02	2.81 ± 1.83
Female Mean ± SD	40.43 ± 13.24	3.22 ± 2.14	2.94 ± 1.49
*negative overbite means open bite.			

Table 1. Overall age, overbite, and overjet distribution broken down by gender

	Mean ± SD (mm)	Confidence interval (mm)
Central Incisor	47.51 ± 0.51	46.50-48.52
First Premolar	37.78 ± 0.43	36.93-38.63
Second Molar	21.70 ± 0.51	21.12-22.27

Table 2. Overall MVS at each location

	Mean ± SD (mm)	Confidence interval (mm)
Central Incisor	50.2 ± 0.53	49.2-51.3
First Premolar	39.6 ± 0.44	38.8-40.5
Second Molar	23.1 ± 0.30	22.5-23.7

Table 3. Male MVS at each location

	Mean ± SD (mm)	Confidence interval (mm)
Central Incisor	45.3 ± 0.49	44.3-46.2
First Premolar	36.3 ± 0.41	35.5-37.1
Second Molar	20.8 ± 0.28	20.2-21.3

Table 4. Female MVS at each location

	Mean ± SD (mm)	Confidence interval (mm)
Central Incisor	52.1 ± 0.80	50.5-53.6
First Premolar	41.2 ± 0.67	39.9-42.5
Second Molar	23.2 ± 0.46	22.3-24.1

Table 5. African American MVS at each location

	Mean ± SD (mm)	Confidence interval (mm)
Central Incisor	47.9 ± 0.53	46.8-48.9
First Premolar	37.9 ± 0.45	37.1-38.8
Second Molar	22.1 ± 0.31	21.5-22.7

Table 6. Caucasian MVS at each location

	Mean ± SD (mm)	Confidence interval (mm)
Central Incisor	44.3 ± 0.67	43.0-45.6
First Premolar	35.7± 0.57	34.6-36.8
Second Molar	20.6 ± 0.39	19.8-21.4

Table 7. Asian MVS at each location

	Mean ± SD (mm)	Confidence interval (mm)
Central Incisor	47.5 ± 0.35	46.8-48.2
First Premolar	38.0 ± 0.31	37.4-38.6
Second Molar	21.7 ± 0.21	21.3-22.1

Table 8. Right side MVS at each location

	Mean ± SD (mm)	Confidence interval (mm)
Central Incisor	47.6 ± 0.36	46.9-48.3
First Premolar	37.7 ± 0.30	37.1-38.3
Second Molar	21.9 ± 0.20	21.5-22.3

Table 9. Left side MVS at each location

	African American	Caucasian	Asian
Central Incisor	100%	90.3%	83.8%
First Premolar	0%	0%	0%
Second Molar	0%	0%	0%

Table 10. Application of Nobel Guide criteria (45mm) to access average MVS measurements in different race

	Male	Female
Central Incisor	91.3%	76.3%
First Premolar	0%	0%
Second Molar	0%	0%

Table 11. Application of Nobel Guide criteria (45mm) to access average MVS measurements in different gender

The mixed regression analysis showed that (i) there was a race effect, with African American having a greater maximum vertical space measurement than Caucasian and Asian respectively ($P < 0.0001$); (ii) there was also a gender effect, with males having a greater maximum vertical space measurement than females($P < 0.0001$); (iii) there was a negative association with overjet on central incisors and first premolars, with less overjet subjects having a greater maximum vertical space measurement ($P < 0.05$) and (iv) there was no difference between the sides ‘left’ and ‘right’ side groups ($P > 0.05$).

Variables	Overall	Female	Male
Sample size	150	81(54)	69(46)
Age	41.23±13.82	40.43±13.24	42.16±14.51
Overbite	3.06±2.09	3.22±2.14	2.86±2.02
Overjet	2.88±1.65	2.94±1.49	2.81±1.83
Race			
Asian	50(33.33)	21(14)	29(19.33)
African American	31(20.67)	17(11.33)	14(9.33)
Caucasian	69(46)	43(28.67)	26(17.33)
Angle Classification			
R:I L:I	117(78)	58(38.67)	59(39.33)
R:I L:II	1(0.67)	1(0.67)	0(0)
R:II L:I	1(0.67)	0(0)	1(0.67)
R:II L:II	31(20.67)	22(14.67)	9(6)

Table 12. Demographic Data in Study Subjects

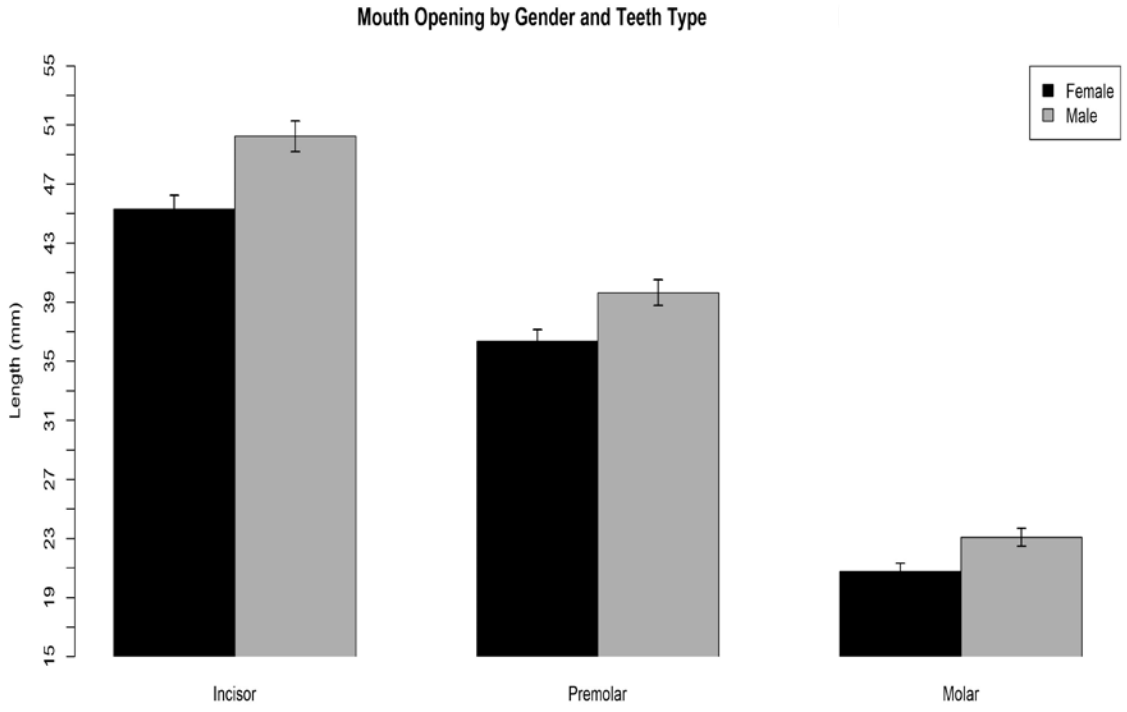

Figure 1. Mouth Opening by Gender and Teeth Type

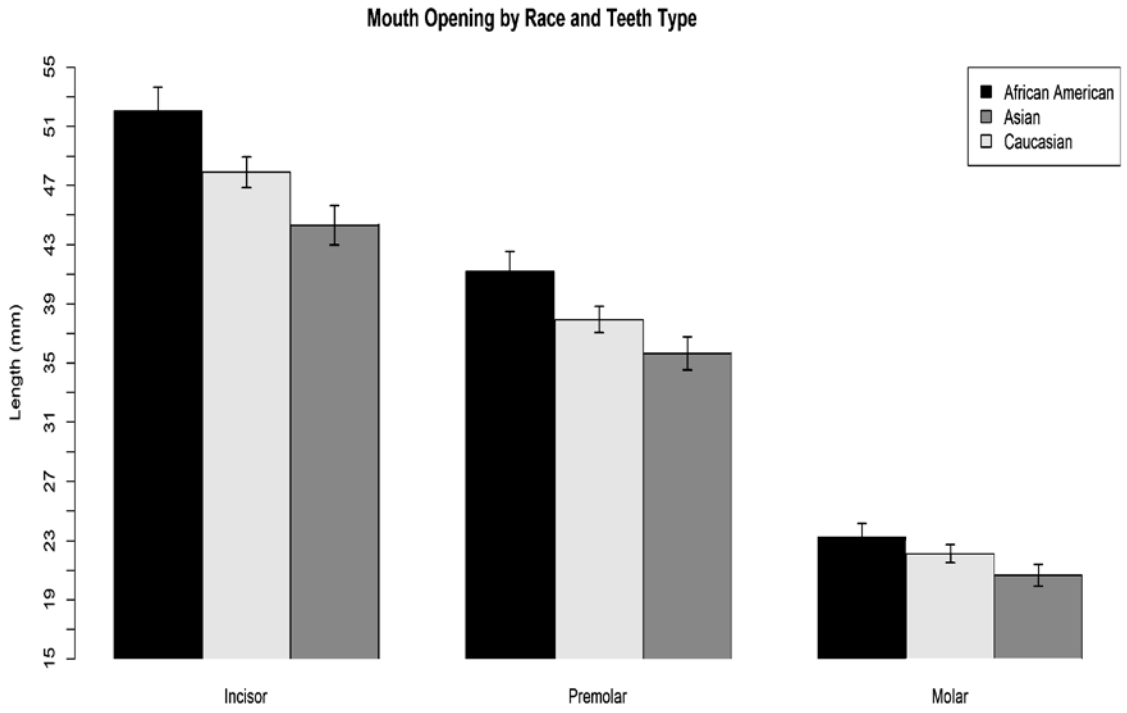

Figure 2. Mouth Opening by Race and Teeth Type

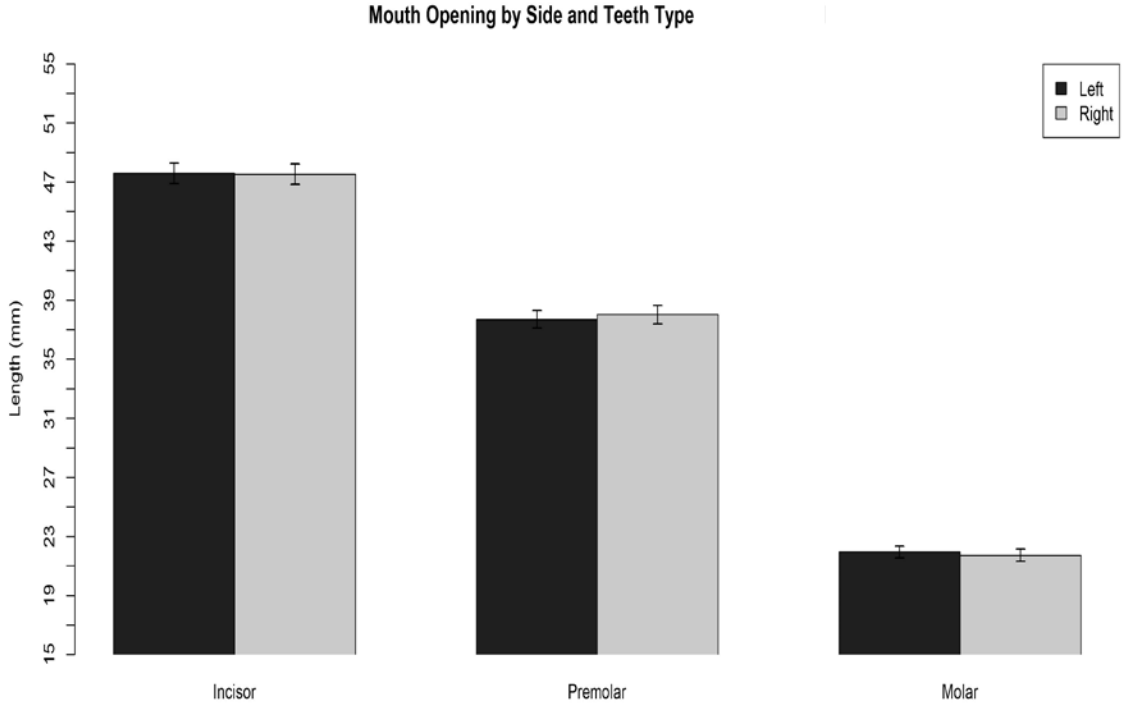

Figure 3. Mouth Opening by Side and Teeth Type

Figure 4. Components used in Nobel Guide procedure: Nobel 2.0mm pilot drill, Nobel Surgical Guide, and Nobel guide reduction sleeve RP 2.0mm, and Handpiece - W&H (WS-75) (clockwise from upper left)

Figure 5. The length of the Nobel 2.0mm pilot drill used in BU clinic measured 40.9mm with the Boley Gauge

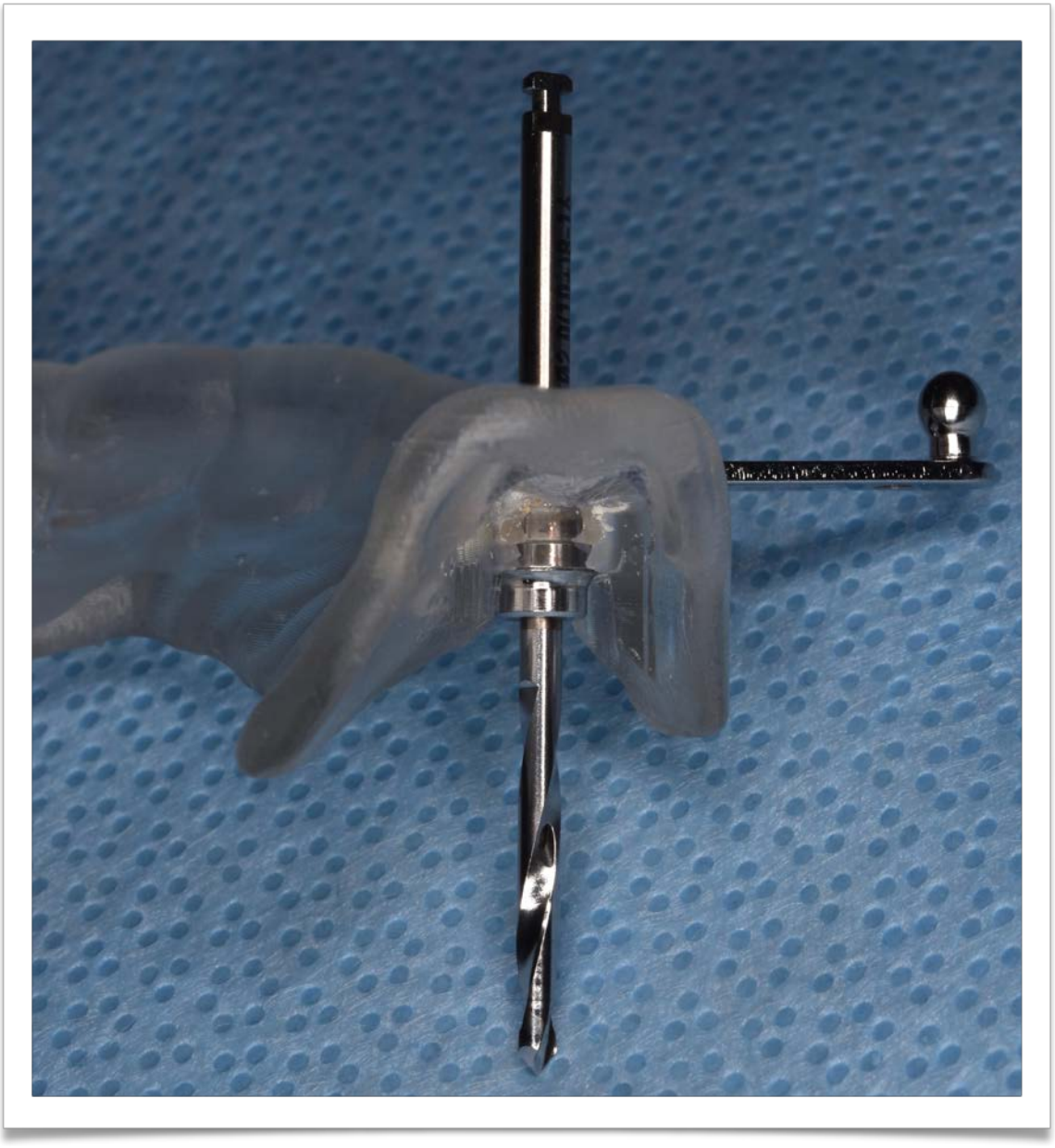

Figure 6. Nobel 2.0mm pilot drill, Nobel Surgical Guide, and Nobel guide reduction sleeve RP 2.0mm top to bottom (from distal)

Figure 7. Nobel 2.0mm pilot drill, Nobel Surgical Guide, and Nobel guide reduction sleeve RP 2.0mm top to bottom (from lingual)

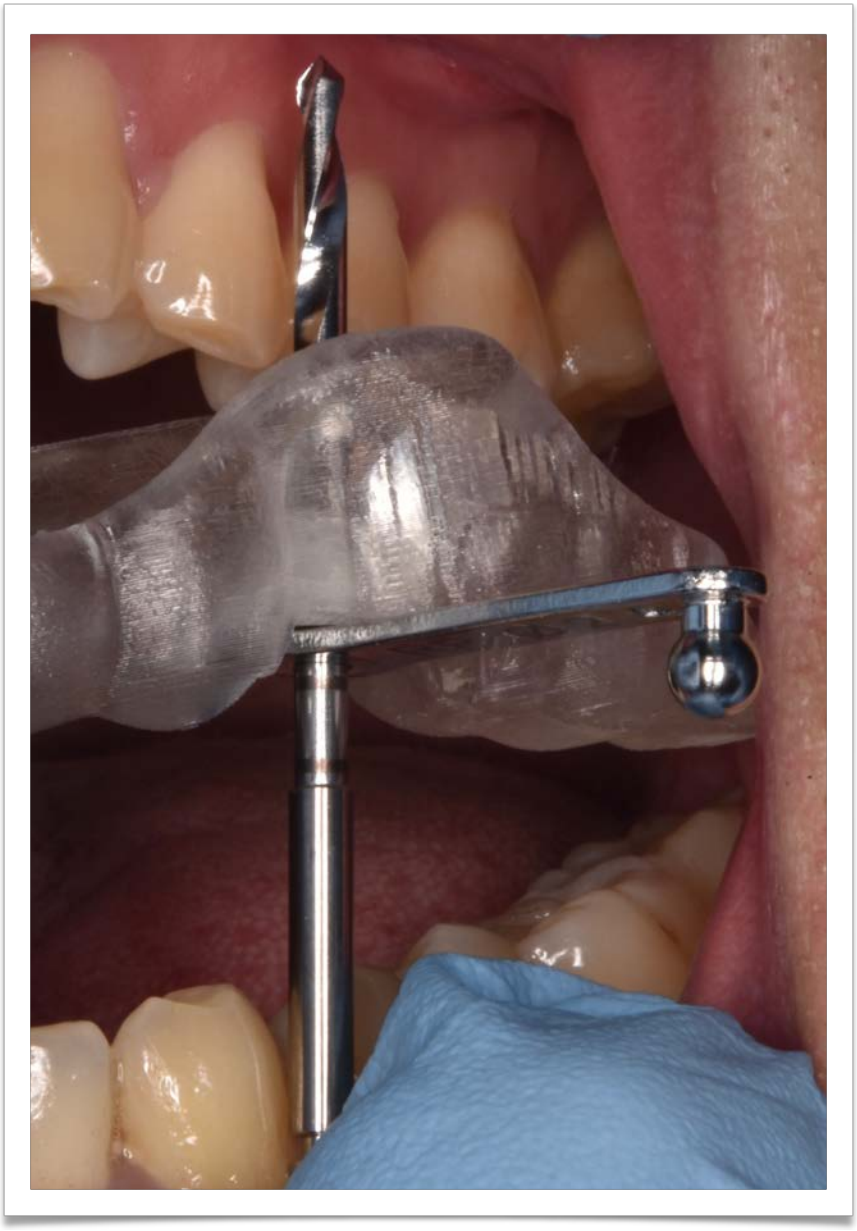

Figure 8. Nobel 2.0mm pilot drill, Nobel Surgical Guide, and Nobel guide reduction sleeve RP 2.0mm top to bottom (intraoral view) This entire assembly with addition of the handpieace attached at bottom of the drill must be placed between the two arches of teeth.

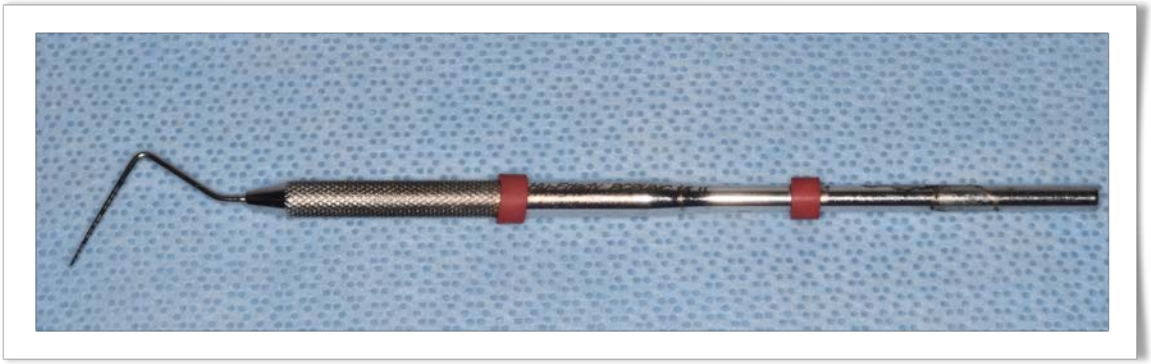

Figure 9. UNC Probe, 1-15, Stainless Steel, Hu-Friedy, USA

Chapter 5. Discussion

Maximum mouth opening is a common concern for dentists in daily practice. In this study, we define maximum mouth opening as the anterior maximum vertical space (MVS) between the incisal edges of the maxillary and mandibular central incisors in an open position. The posterior MVS was measured at two locations, defined as maximum distance from the maxillary first premolars' buccal cusp tip to the opposing tooth and the maximum distance from the maxillary second molar' mesiobuccal cusp tip to the opposing tooth. These two sites include or frame the most frequently implanted areas.

Previous studies have found that maximum mouth opening was influenced by both gender and age. In adult studies (See Table 13.), Agerberg[1] on a sample of 200 Sweden aged 18-25, the average MMO was found to be 54.55mm, the similar age range group by Sohail and Amjad[10] on a mixed sample of 450 UAE, Indian, Pakistan aged 19-24, the average MMO was found to be 53.24mm, 52.6mm, 53.6mm. Geographically these groups in Sohail and Amjad[10] study were more closely related in ethnic/racial similarity. Our three groups were quite different in racial profile which probably accounts for increased variability in outcome.(See Table 14.) One of the largest studies was carried out by Yao et al.[8] on a sample of 1442 Taiwansese adults aged 20–80, the average MMO was found to be 49.10mm. In the similar age range study Khare et al.[13] studied 894 Indian adults, aged 21–70. They reported a mean value for a MMO of 47.8mm. Zawawi et al.[5] on a sample of 140 USA subjects aged 21-42, the average MMO was found to be 48.8mm. In our more racially varied population we found an overall average mean of 47.51mm for central incisor

MVS (See Table 2.). While the range varied from 44.3mm for Asians to 52.1mm for African Americans with Caucasian subjects at 47.9mm. (See Table 14.)

When these other adult studies looked at the change in mouth opening with age and found that the mean MMO in adults decreased with age it matched our findings. Overjet had an inverse association with the anterior MVS and first premolar MVS but had no effect on second molar MVS. This relationship may suggest an underlying anatomic variance and should be explored further.

To the best of the author's knowledge, there have been no studies relating guided implant surgery appliance utilization and limited mouth opening. The focus in the literature has been on anterior incisor MMO measures but not on other teeth like premolars or molars which affect access space for implant placement.

Studies	Age group	Country	Sample size	MMO (mm)
Agerberg[1]	18-25	Sweden	200	54.55
Zawawi et al.[5]	21-42	USA	140	48.8
Yao et al.[8]	20-80	Taiwan	1442	49.10
Sohail and Amjad[10]	19-24	UAE, India, Pakistan	450	53.24 52.6 53.6
Khare et al.[13]	21-70	India	894	47.8
Yu et al. (this study)	22-78	USA	150	47.51

Table 13. Comparison of maximum mouth opening (MMO) - this study to similar age group found in different studies

Studies	Age group	Population	Sample size	MMO (mm)
Sohail and Amjad10	19-24	UAE, India, Pakistan	450	53.24 52.6 53.6
Yu et al. (this study)	22-78	African American, Caucasian, Asian	150	52.1 47.9 44.3

Table 14. Comparison of maximum mouth opening (MMO) - this study to Sohail and Amjad[10] study

Guided implant surgery in dentulous patients includes the planning of implant placement based on a combination of DICOM and stereolithographic data. This information is translated into construction of an appliance which can be inserted over the adjacent teeth to guide the implant drill sequence. The drills are inserted into a very restrictive guide sleeve to control the osteotomy at each site. Limited MVS creates limitations on usage of this appliance in many patients.

As an example, in the NobelGuide concept manual of 2012 the following instruction are found:

1) On page 8 it states: A minimum mouth opening of 40 mm at implant sites is required to accommodate guided surgery tooling.
2) On page 30 under guide template production: ensure that the mechanical strength of the surgical template conforms to the recommended thickness of 2.5-3 mm.
3) On page 46/47 illustrations depict the drill guide stop thickness to be 1mm.
4) The length of the clinic handpiece combined with Nobel 2mm pilot drill used in BU clinic measured 40.9mm (use 41mm for estimate)
5) This actually results in a total vertical access required of: 3 + 1+ 41 = 45mm.
6) The 2012 Nobel Concept Manual visually depicts the following sequence on pp52-53: Position the guide, place the reduction sleeve, and insert the drill.

In the present study, the MVS between the central incisors edge, first premolars' cusp tip, and second molars' mesiobuccal cusp tip were measured. When the population was identified according to gender, the average MVS measurements equals or exceeds the 45mm requirement in female subjects at central incisors, first premolars, and second molars

in 76.3%, 0%, and 0% respectively. The average MVS measurement equals or exceeds the 45mm required space in male subjects at central incisors, first premolars, and second molars in 91.3%, 0%, and 0% respectively.

When our study population was categorized according to race, the average MVS measurements exceeds the 45mm space requirement in Asian subjects at the central incisors, first premolars, second molars in 83.8%, 0%, and 0% respectively. The average MVS measurements exceeds 45mm in Caucasian subjects at central incisors, first premolars, second molars in 90.3%, 0%, and 0% respectively. The average MVS measurements exceeds 45mm in African American subjects at central incisors, first premolars, second molars in 100.0%, 0%, and 0% respectively.

When our study population was identified according to overjet, there was a negative association with overjet at the central incisor and first premolar positions, with less overjet subjects having a greater maximum vertical space measurement. This effect did not apply at the second molar position. The vertical movement of the molars area is less than incisor or premolar locations when opening the mouth due to rotation centered at the temporomandibular joint.

With regard to our quest for a single measurement to identify limitations of access, we found that there is a relationship between anterior MVS and posterior MVS. However, the model's ability to use anterior MVS to predict accurately posterior MVS is not strong. In addition, it only takes the clinician minutes to measure posterior MVS. Consequently, there would be limited use of the model based of the relationship between anterior MVS and posterior MVS for precision dentistry.

In review of our study design we found one possible bias in approach, our measurement always started from upper right second molar, right first premolar, right central incisor, then left central incisor, left first premolar, and finished on left second molar. If we plan the next study design, we might use random assignment to measure MVS in random order to increase the predictability. With regard to this, however, we found no significant difference between right and left sides.

To the best of author's knowledge, this is the first study to measure MVS in the first premolar and second molar areas. Based on our literature reviews, the previous studies measured only maximum mouth opening (MMO) in the incisor area which equals anterior MVS in this study. Limited vertical space is one of the main reasons why the computer guided surgery cannot be universally applied. If we can predict this problem before we start to mill the guide, it would save excessive expense for the patient but also the clinician's time.

This study outcome suggests very limited use for a guided implant surgery appliance in posterior areas, since only the incisor space met the minimum vertical space requirement of 45mm. All African American subjects meet criteria to do computer guided surgery at central incisors. However, nearly 1 out of 4 female subjects have limited anterior MVS which would not allowed computer guided surgery. (See Table 11.)

The unexpected result in this study was the finding that neither the first premolar MVS nor the second molar MVS allows a 45mm appliance to be used in a completely dentulous population. In reality, some of these patients could be treated with computer guided surgery in these areas. For example by inserting the drill into the assembled

guide/sleeve before inserting the appliance into the mouth. But this approach does not follow the Nobel Concept Protocol.

It should be noted that this study was on a sample population of dentulous subjects. A variety of full or partially edentulous subjects may not be affected with the same limitations. As an alternate approach, the dental implant planning angulation could be modified by using a custom abutment to correct the angulation of the implant body. Further research is needed to provide evidence in this field. For example, comparison of different implant company products or clinical data to show which guided implant appliance worked well, or by using shorter drills, or the use of thinner material for the appliance. In addition the inverse association of overjet and Angle class III subjects should be explored. To that end, the present study contributes preliminary data.

Chapter 6. Conclusion

The maximum vertical space measurement (anterior and posterior) is an important factor which limits the use of a guided implant surgery appliance. Using the Nobel computer guided surgery minimum dimension requirement of 45mm, our findings suggest that first premolar or second molar implants could not be placed in our sample of dentulous patients, while a central incisor implant could be placed in 76%-100% of these subjects depending on gender and race factors. Compared to the more homogeneous groups in study by Sohail and Amjad[10], our study population was more heterogenous and we noted a marked difference in the means and range between racial groups.

Guided surgery is challenging when the patient has limited mouth opening. The previous studies measured only maximum mouth opening (MMO) in the incisor area which we labeled anterior maximum vertical space (MVS) in this study. This is the first study to measure MVS in the first premolar and second molar areas, which is critical information if these guides are to be recommended for universal application. We suggest that "the workflow" for designing these appliances be modified to include preliminary measurements of MVS at all three sites (incisal, first premolar, and mesio-buccal cups of second molar).

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