# DETERMINATION of OCCLUSAL PLANE USING BONY ANATOMICAL LANDMARKS THROUGH THE ANALYSIS of CONE BEAM COMPUTED TOMOGRAPHY

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# ABSTRACT

Karona Apsara Tum: Determination of Occlusal Plane Using Bony Anatomical Landmarks Through the Analysis of Cone Beam Computed Tomography
(Under the direction of Glenn E. Minsley)

Statement of problem: Establishing the occlusal plane of the edentulous mouth is challenging but with the accuracy of 3D radiography, the orientation of the occlusal plane can be determined using stable anatomical landmarks.

Purpose: The purpose of this study was to determine the location of the occlusal plane in relation to stable, bony anatomical structures.

Material and Methods: Stable bony structures were identified and the orientation of the occlusal plane was determined in relation to these landmarks, using CBCT scans.

Results: The anterior determinant of occlusal plane is located 29mm (95% CI: 28.3mm to 30.0mm) inferior to the anterior nasal spine (ANS). In relation to the hamular notch-incisal edge (HNI) plane, the occlusal plane forms a $15.5^{o}$ angle (95% CI: $14.7^{o}$ to $16.2^{o}$).

Conclusions: Results from this study will enable dentists and technicians to accurately locate the occlusal plane in a virtual environment without the use of an analog face-bow.

To my family: I could not have accomplished all of this without you.
I am grateful for the sacrifices you have made in helping me realize my dream.

To my mentor:  Thank you for your guidance and support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

# INTRODUCTION

Smile is a universal welcoming sign and expression of happiness. Due to aging process and broken dentition, the smile may be severely compromised. In order to re-establish the proper location of teeth in edentulous mouth, the location of incisal edge and natural occlusal plane must be determined. The proper orientation of maxillary cast in an articulator facilitates the establishment of the occlusal plane. This step is traditionally accomplished by using a face-bow transfer. Since its introduction in 1899, the advantages and disadvantages of the face-bow in prosthodontic rehabilitation have been thoroughly discussed, however, the relationship between the face-bow hinge axis and the true hinge axis as well as the clinical value of hinge axis determination has been questioned and inconclusively discussed.

## 1.1. Invention of the face-bow

A face-bow transfer records and preserves the relationship of the maxillae to condylar hinge axis. Although, Bonwill, Hayes, Walker and Balkwill recognized the importance of maintaining the relationship of the maxillae to the condylar hinge axis, it was Gysi's and Snow's invention that were able to replicate this relationship. Gysi's face-bow was "capable of obtaining more than one position relation record" (1), making it a combination of tracing device and face-bow, however "it lacked the simplicity of Snow's unifunction face-bow". In view of this, Snow was given the credit for introducing the face-bow to the public.

All prototypes of face-bows in use today are based on Snow's face-bow design (2). There are two types of face-bows available, arbitrary face-bow and kinematic or hinge-bow. The use of kinematic face-bow "is capable of determining the rotational center of the hinge axis of the condyles" (1). "The area of the true hinge axis was located by palpating the subject's condyles during opening and closing of the mandible" (2). While it is important to accurately capture the relationship of the maxillae to the condylar hinge axis and transfer that relationship to a semi-adjustable articulator, the use of such face-bow is not of a practical one. Using a kinematic face-bow is a lengthy and difficult procedure and requires greater initial investment. Although the kinematic face-bow is used to actually locate the hinge axis, the arbitrary face-bow technique is considerably less time-consuming and sufficiently accurate for routine procedures (2).

### 1.2. Location of arbitrary vs. actual hinge axis

Beyron (3) in 1942 compared the relationship of arbitrary hinge axis to the true hinge axis and determined that only 10 out of 39 study subjects have normal occlusion. Schallhorn's study (1) selected 70 dental students with normal occlusion and full complement of at least 28 teeth to determine the location of true hinge axis in relation to the arbitrary hinge axis. All recordings were made to opening of 10mm, a pure hinge-axis. It was reported by McCullom (4) and confirmed by Eberle (5) that the mouth may be opened at least one-half inch on a purely hinge basis. According to Shallhorn 95% of the true hinge axis locations fall within 5mm radius of an arbitrary axis (1). The results from his study combined with other findings, Schallhorn concluded in his treatise:

“1. The arbitrary axis of rotation as set forth by Snow, Gilmer, Hanau, Gysi and others, of 13mm anterior to the tragus on the trageal-canthus line comes very close to an average determined axis on individuals with normal jaw relationships.”

“2. One can feel justified in using the arbitrary axis for face-bow mountings on a semi-adjustable articulator since, in over 95 percent of the subjects with normal jaw relationships, the kinematic center lies within a radius of 5 mm from the arbitrary center, which is considered by Arstad and others to be within the limits of negligible error.”

“3. I would agree with Schuyler, Arstad, and others that the determining of the kinematic center of rotation is not nearly as important as the obtaining of proper centric and vertical relationship records.”

Conversely, Walker declared that only 20% of the true axis locations are within 5mm radius of the arbitrary location while 60% are within 6mm or more (6). Joyce found “only 50% of the arbitrary hinge axes were within a 5 mm radius of the true hinge axis, while 89% were within a 6 mm radius” (7). Comparing all studies that investigated the difference in the arbitrary axis and the kinematic axis, the results are variable ranging from 20% to 95% of the arbitrary hinge axis points, falling within a 5 mm radius of the true hinge axis point. The consensus is that a kinematic face-bow provided the most accurate method of mounting (8). However according to Joyce “the arbitrary location is a common method of determining the axis for complete denture treatment” (7). Joyce added, although in a “two-way analysis of variance demonstrated that the ear-bow is not statistically reliable or repeatable, this does not suggest that it is unsuitable clinically”.

### 1.3. Effects of using arbitrary hinge axis on fixed dental restorations

According to Arstad's (9) investigation on mandibular movements, "… an error of 5mm from the hinge-axis, that exits in arbitrary face-bow, results in an error of only 0.2mm in the articulator. With "a hinge movement of 2 mm in the articulator, the molar of the lower jaw model will have contact with its antagonist 0.2 mm mesial or distal to the intraoral occlusal position of the molar after a corresponding mandibular movement of 2 mm." This conclusion is supported by Schuyler's (10) finding that such recordings take place in proper centric and vertical relationships. Arstad further said "to locate the patient's hinge-axis, however, is an exceedingly difficult and time wasting task"(9). According to Schlosser (11), although the arbitrary axis is not precise, it is close enough for all practical purposes, and he bases this contention upon years of clinical experience. With the difference of 5mm generating a negligible amount of error, many clinicians agreed that determining the accurate location of the true hinge axis does not outweigh the disadvantages of the kinematic face-bow.

In spite of its inherited error, Larry Weinberg (12) in 1961 published an article that approved the use of nonkinematic face-bow in construction of restorations. However, he expressed the importance of two essential steps in properly mounting a maxillary cast in an articulator: (1) the transverse hinge axis of the patient must be located and (2) an anterior point of orientation is selected. It has been shown experimentally and mathematically that an error of +/- 5mm in transverse hinge axis location produced an extremely small anteroposterior mandibular displacement. Furthermore, the same reasonable error in the transverse hinge axis location +/- 5mm "has practically no effect on eccentric interocclusal record reading on the articulator". Thus "transverse hinge axis can be located by anatomic average measurements on a line from the middle of the tragus of the ear to the corner of the eye. The pins of the face-bow are adjusted 11 to 13mm from the posterior border of the tragus on the tragus-eye line." Regarding the anterior point of orientation there are varying point of orientation that the transverse hinge axis form the horizontal plane of reference. Some methods use an orbital pointer on top of the articulator, other parallel the plane of occlusion with ala-tragus line, while some use a line drawn from the tragus of the ear to the anterior nasal spine. "These anterior point of reference points can raise or lower the face-bow mounting by +/- 16mm". When the face-bow is oriented 16mm too high or too low. If the maxillary cast is placed 16mm too high in the articulator, the condylar path is reduced from 40 degrees to 31 degrees, which translated to a decrease on cusp height of 0.2mm in the second molar region, if the total cuspal inclination is 3mm tall. "The magnitude of this error is so small that it justifies the use of the face-bow", according to Weinberg.

### 1.4. Advantages and disadvantages of the face-bow

For many years the usefulness of the face-bow has generated discussion and controversy in dentistry (1). Logan considered it indispensible in the fabrication of dentures (13) whereas Stansbery considered it to be useless (14). The advantages and disadvantages of the face-bow have been studies thoroughly. Lazzari (15) has determined and listed the advantages of the face-bow:

" (1) It permits a more accurate use of lateral rotation points for the arrangement of teeth."

"(2 ) It aids in securing the anteroposterior cast position with relation to the condyles of the mandible."

“ (3) It registers the horizontal relationship of the casts quite accurately, and thus assists in correctly locating the incisal plane.”

“(4) It is an aid in the vertical positioning of the casts on the articulator.”

This list of the face-bow’s advantages has solidified its usefulness in denture fabrication.

However, Stansbery (14) contested that the use of the face-bow is not necessary. Additionally, Stansbery offered an alternative technique in obtaining “positional relation records” without the use of the face-bow. This view is echoed by Craddock and Symmons (16) in their comprehensive evaluation of the face-bow and its lack of importance in denture construction. Despite these opinions and positional papers, prosthetic literatures acknowledge the advantages of the face-bow and its use in dentistry. Schallhorn referred to the face-bow as “neither useless nor indispensible, but it offers certain advantages when used properly, and therefor merits a place in prosthetic dentistry.” (1)

**1.5. Is it crucial to use a face-bow in denture fabrication?**

To accurately answer this question, Craddock (16) in 1952 published the results of his investigation that demonstrated “precisely what may happen when a face-bow is used and when it is not used and to assigning quantitative measures to the differences observed”. He investigated an error of 2cm in anteroposterior position of cast in relationship to intercondylar axis and determined that “the resulting errors in the occlusal relations of full dentures are so small as to be incapable of clinical detection”. “If, after more than fifty years of indecision, prosthetists decide to discard their face-bows they may do so with a clear conscience” (16).

### 1.6. Comparison of traditional (T) vs. simplified (S) denture fabrication technique

There are two methods of fabricating conventional dentures as illustrated by a cross-sectional study in the UK and the USA, a traditional (T) and a simplified (S) method (17). Hyde and Clark (18,19) stated that the T method uses more complex and time-consuming techniques. This method is favored by prosthodontists and is taught in most North American dental schools. On the contrary, most general dentists treat edentulous patients with S techniques, which reduce the number of visits and time required to fabricate the prostheses.

Previously Duncan and Taylor (20) compared the number of visits for fabrication and post-delivery adjustments between traditional and simplified impression techniques, and found a significant reduction in the number of visits required by the simplified method. A randomized controlled single blind clinical trial conducted by Kawai et al to "evaluate the effect of differences in traditional (T) and simplified (S) fabrication methods on patient satisfaction, as well as the quality of the dentures assessed by blinded prosthodontists" (17). The difference between (T) and (S) denture fabrication methods include final impression, use of face-bow transfer and clinical remount. The results provide evidence that a simplified (S) method of fabricating conventional dentures yields similar patient satisfaction and perceived denture quality as a traditional (T) approach. "This suggests that the time-consuming procedures of the traditional method, such as final impressions using border molding and secondary impression materials, face-bow transfer, semi- adjustable articulator and re-mount procedures, have little influence on outcome"(17). "Clark (21) noted that the amount of time devoted to the teaching of complete dentures in today's curriculum is much less than in past years, resulting in insufficient time for adequate instruction". The simplicity of simplified denture making technique combined with insufficient training in traditional denture fabrication protocols led many dentists to disregard several procedures including the use of face-bow transfer in denture fabrication.

## 1.7. Incorporation of technological advancement in denture fabrication

With the advancement and accuracy improvement in computer-aided design and computer-aided manufacturing (CAD/CAM) technologies, some concepts and techniques traditionally considered indisputable are now undergoing intensive revision. Prosthodontics laboratory procedures such as casting are being replaced by computerized milling and 3D printing. Laboratory procedures are not the only aspect of dentistry that is moving away from analogue and toward digital setting. Clinical procedure such as impression making in fixed restorations is being replaced by intra-oral scanner. With stones models being replaced by their scanned and digitized replica, many laboratory companies are in search of a proper method to orient these digitized casts to virtual articulator. Some laboratories rely on mounted records from dental offices that used mechanical articulator, analog face-bow transfer and traditional CR records (22,23). According to Bidra (24) the two commercial laboratories that offer fabrication of digital dentures using CAD/CAM technology, are still relying on traditional final impression technique and face-bow transfer. Currently digital dentures fabrication is relying on a combination of analog and digital procedures.

With much dental and laboratory procedures being accomplished in digital setting, the need for digital radiograph with high accuracy has increased. Cone-beam computed tomography (CBCT) has gained much popularity in the field of oral diagnosis and maxillofacial imaging, facilitating three-dimensional (3D) visualization, evaluation and analysis. For years CBCT has been utilized as a 3D visualization tool for anatomical structures of the head and neck area. Recently it was determined that CBCT's ability to identify the depth of dental caries and endodontic pathology exceeded 2D radiography (25). CBCT's superior diagnostic ability for numerous diagnostic tasks and usefulness in implant treatment planning has earned its place significant and useful imaging tool for dental practice (26). Dentists are utilizing CBCT scan as a diagnostic tool for dental pathologies, 3D visualization tool for implants placement and could be used for the analysis of anatomical structures to determine maxillary occlusal plane orientation.

Currently cone beam computer tomography is being used as a foundation for the creation of a virtual patient. Data other than radiographic can be integrated into the CBCT volume such as optical impressions, jaw tracking motion and 3D photographs of the patient's soft tissues thus enhancing digital dentistry capabilities. This leads to significant digital workflow advantages for diagnosis, treatment planning, fabrication and delivery of therapeutic devices such as surgical guides for implants, night guards and sleep apnea appliances. Because of these productivity advantages more and more CBCT units are being employed in generalist and specialty practices. As dose and pricing are lowered this trend will only increase. Therefore it is not unreasonable to assume that in the near future most dentists and dental specialists will utilize some form of CBCT imaging in their practice.

The aim of this study was to use stable anatomical landmarks visualized in CBCT scans to determine the location and angulation of the natural occlusal plane. Some of these biological structures include the anterior nasal spine (ANS) and hamular notches (HN). The accuracy of a CBCT scan as a 3D visualization tool of anatomical structures enables precise calculation of linear and angulation relationships between biological and dental structures to determine the proper location natural occlusal plane and its relations to reference planes such as Frankfort Horizontal and Camper's plane. With these anthropomorphic values, dental practitioners can be equipped with an alternative method to properly establish the location of incisal edge as well as the plane of occlusion without the use of analog face-bow.

# MATERIAL AND METHODS

Fifty cone beam computed tomography scans of patients who were seen in the Oral and Maxillofacial Radiology Clinic were selected for this study. All CBCTs used in this study were already taken previously and stored on the School of Dentistry DICOM server. Sample size was selected based on an initial statistical analysis of ten scans. The small standard deviation among available of interest afforded the sample size to be conservative and yet yielded statistically significant results.

The CBCTs that were analyzed in this research project were captured from 06/01/2013 to 12/1/2015 using the Galileos 15x15 and Care Stream 9300 17x13.5 systems. Scans from the Galileos and CS 9300 were selected due to their large volume size, thus ensuring all anatomical landmarks of interest would be available for analysis.

The radiographic analyses of anatomical landmarks were determined using SimPlant Orthodontics and Orthognatics(O&O) software. This software was used to identify anatomical and dental landmarks through sagittal, coronal and axial cross-sections of 3D structures, enabling precise location of anatomical landmarks. In addition to its capability of locating bony structures, it is also capable of drawing a line between two points, a plane between three points and calculating the distances and angulations between points, lines and planes.

Study inclusion and exclusion criteria are listed in Table 1. Scans that met the inclusion criteria were de-identified.

Statistical analysis: The alpha value was preset at 0.05.

Analysis of CBCT Scans:

Once CBCT scans were anonymized, SimPlant O&O software was used to determine angulation and linear relationships between anatomical landmarks of interest (Figure 1). Anatomical location of the hamular notch is defined by the notch or fissure formed at the junction of the maxilla and the hamular process of the sphenoid bone, just beyond the distal end of the alveolar process. Below are lists of definitions and mathematical relationships between anatomical structures. All anatomical structures and dental landmarks used in this study are listed in Table 2.

Definitions of planes:

1. Occlusal plane is defined by point mid incisal edge of maxillary central incisors and mesiolingual cusp of maxillary first molars.
2. HNI plane is defined by point left hamular notch, point right hamular notch and point mid incisal edge.
3. Frankfort Horizontal plane is defined by point left porion, point right porion and point mid orbitale.
4. Camper's plane is defined by left porion, right porion and point ANS

Measureable variables:

1. Distance (in mm) between point ANS to point mid incisal edge of maxillary central incisors

2. Distance (in mm) between point mid hamular notch to point mid incisal edge of maxillary central incisors
3. Angulation (in degrees) difference between HNI and natural occlusal planes
4. Angulation (in degrees) difference between Frankfort Horizontal and occlusal plane
5. Angulation (in degrees) difference between Camper's and occlusal plane

## RESULTS

The results are listed below.

The mean distance from ANS to mid Incisal edge was determined to be 29.2mm (Std Dev= 3mm, 95% CI: 28.3mm to 30mm). The mean distance between mid hamular notch and mid incisal edge was 58.5mm (Std Dev.= 3.2, 95% CI: 57.6mm to 59.4mm). The angle between the HNI plane and the occlusal plane was determined to be 15.5$^{o}$ (Std Dev= 2.7$^{o}$, 95% CI: 14.7$^{o}$ to 16.2$^{o}$). The mean angle difference between the Frankfort Horizontal and occlusal planes was determined to be 9.7$^{o}$ (Std Dev= 5.6$^{o}$, 95% CI: 8.1$^{o}$ to 11.3$^{o}$). The angulation difference between Camper's and occlusal plane was 6$^{o}$ (Std Dev= 3.2$^{o}$, 95% CI: 5.0$^{o}$ to 6.9$^{o}$) (Table 3).

Figure 2 showed the linear measurements from mid hamular notch and ANS to the anterior determinant of the occlusal plane. The angulation difference between HNI and the occlusal planes was illustrated in Figure 3. Boxplots in Figure 2 and 3 were calculated using quartile percentages and median values.

**Table 1**: List of inclusion and exclusion criteria.

| Inclusion Criteria: | Exclusion Criteria |
|---|---|
| | |
| Patients were between the ages of 21 to 50 years old*** | Patients who have had full mouth rehabilitation |
| Patients with 28-32 natural teeth | Patients who have had orthognathic repositioning surgery |
| | Patients who have severe skeletal Class II and Class III malocclusion |

***21 years of age was chosen to ensure that the patients have completed their growth process and 50 years old was an arbitrary cut off age.

**Table 2:** Anatomical structures and dental landmarks.

| Anatomical Structures | Dental Landmarks |
|---|---|
| Left and Right Porions | Incisal Edge of Central Incisors |
| Left and Right Orbitales | Mesiolingual Cusps of Maxillary 1$^{St}$ Molars |
| Left and Right Hamular Notches | |
| Anterior Nasal Spine (ANS) | |

**Table 3:** Mean distances and angulations between landmarks and reference planes.

| Variables: | Mean Values (Std Dev) | 95% CI |
|---|---|---|
| ANS to Mid Incisal Edge (mm) | 29.2 (3) | 28.3 – 30.0 |
| Mid Hamular Notch to Mid Incisal Edge (mm) | 58.5 (3.2) | 57.6 - 59.4 |
| Angle between HNI and Occlusal planes ($^o$) | 15.5 (2.7) | 14.7 - 16.2 |
| Frankfort Horizontal to Occlusal plane ($^o$) | 9.7 (5.6) | 8.1 - 11.3 |
| Camper's plane to Occlusal plane ($^o$) | 6 (3.2) | 5.0 - 6.9 |

**Figure 1:** Simplant Orthodontics and Orthognathics software was used to identify anatomical and dental landmarks. This software provides sagittal, coronal and axial cross-sections in addition to the 3D imaging, enabling precise location of anatomical landmarks. It was used to locate bony structures, to draw a line between two points, to determine a plane between three points and to calculate the distances and angulations between lines and planes.

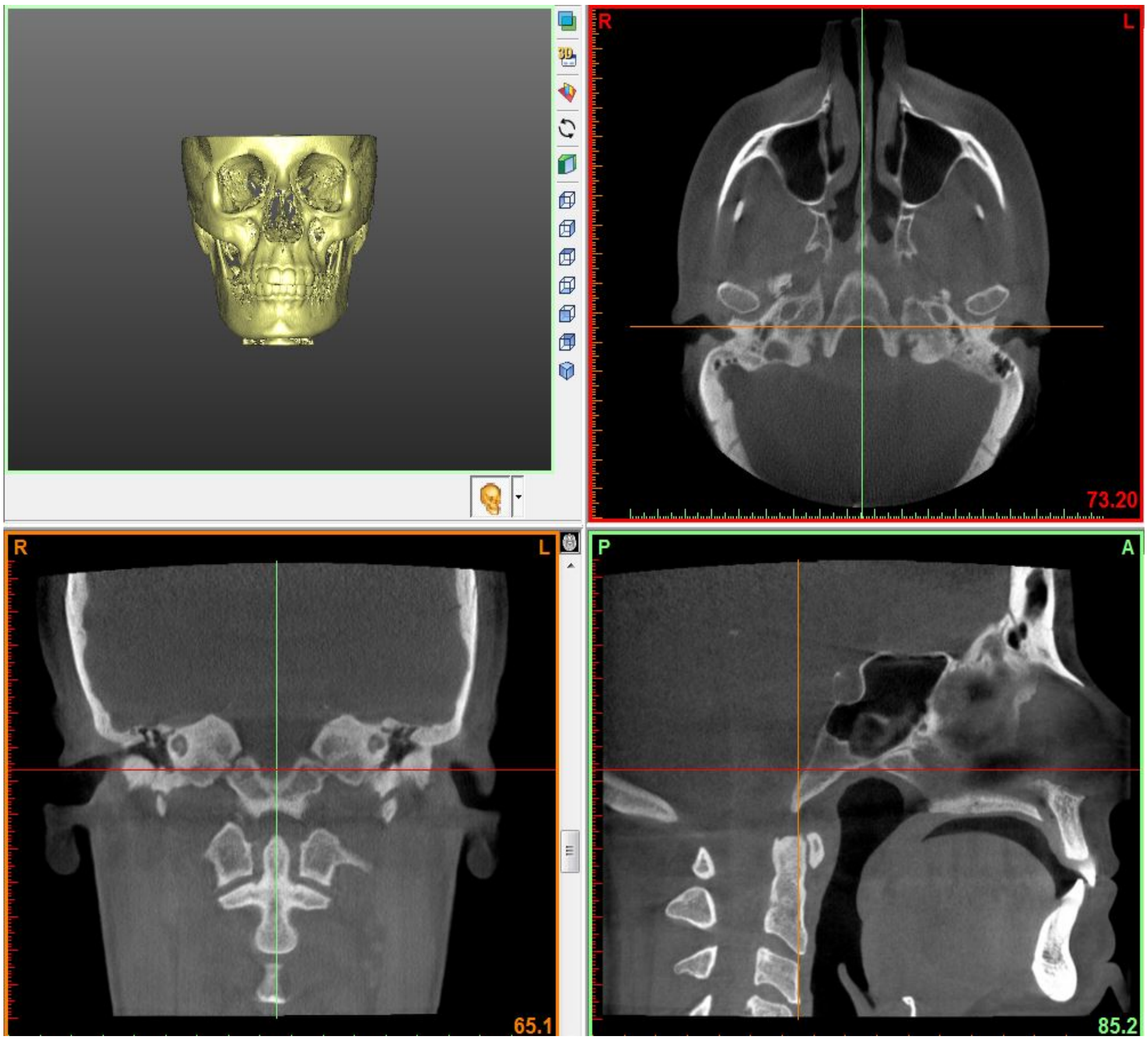


**Figure 2:** Distance (in mm) between line mid hamular notch and line mid incisal edge of maxillary central incisors (left). Distance (in mm) between anterior nasal spine (ANS) to line mid incisal edge of maxillary central incisors (right).

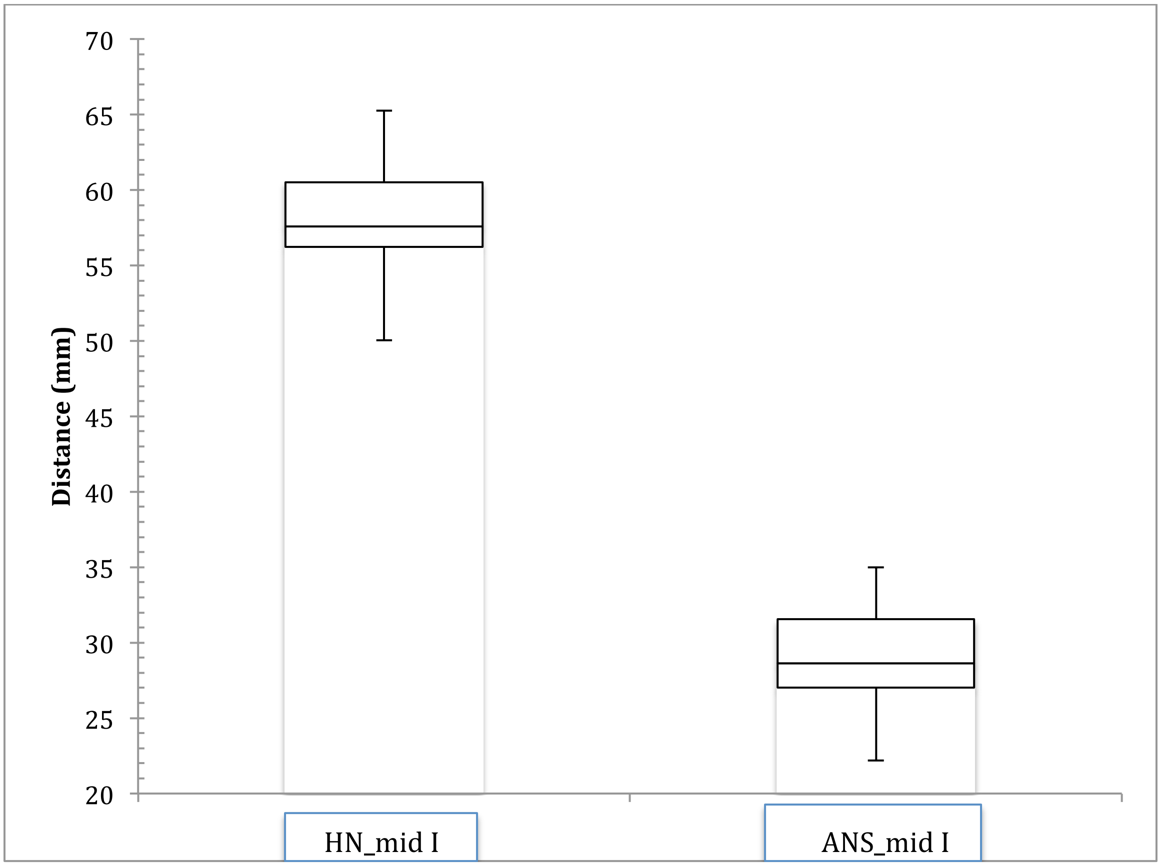


**Figure 3:** Angulation (in degrees) between HNI and occlusal planes.

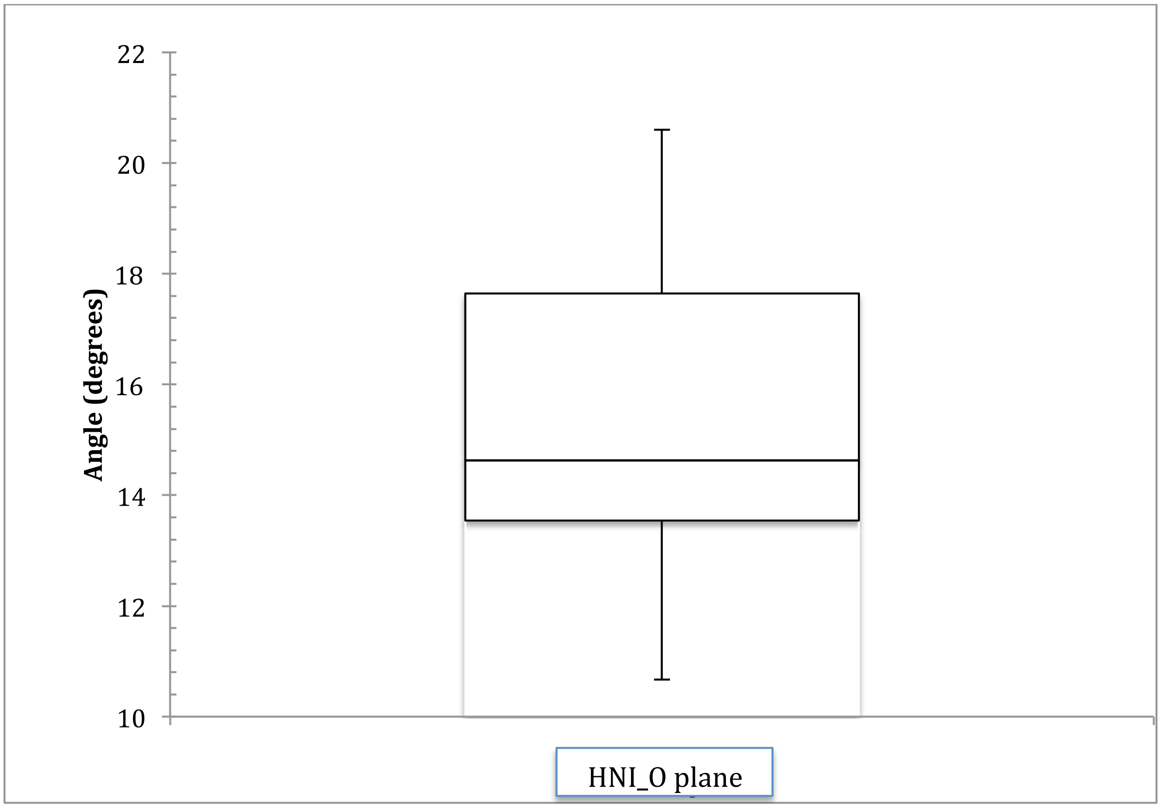
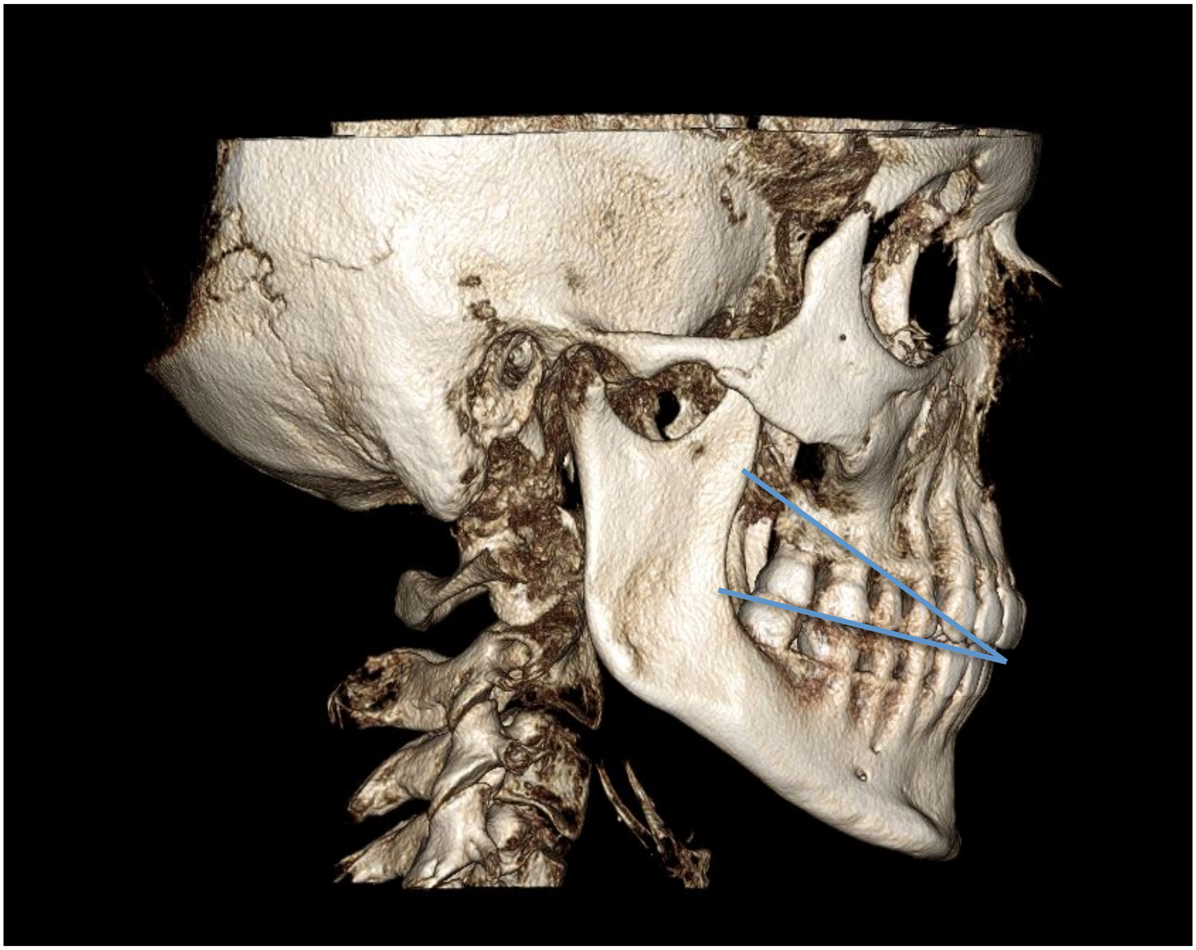


**Figure 4:** The angulation difference between HNI and natural occlusal planes.



# DISCUSSION

The occlusal plane is defined as "the average plane established by the incisal and occlusal surfaces of the teeth" and it is highly significant in achieving esthetics, phonetics and re-establishment of lost vertical dimension (27). The reconstruction of natural occlusal plane in edentulous mouth restores the normal function of cheeks, tongue muscles and other surrounding structures (28, 29). Without proper orientation, the task of locating the occlusal plane is challenging, especially in a digital environment. This study offers an alternative method to determine the location of the occlusal plane through the use of CBCT scans. Using data collected from 50 anonymous CBCT scans, the angulations and linear relationships between anatomical structures and dental landmarks were determined. The incisal edge of the occlusal plane is established by a linear measurement from ANS to mid Incisal edge of maxillary central incisors; this distance has a mean value of 29.2mm with a standard deviation of 3mm. The angle of the natural occlusal plane is $15.5^{o}$ with a standard deviation of $2.7^{o}$, from the HNI plane (Figure 4).

In addition to determining the location of occlusal plane in relation to bony landmarks, this study also investigated the angulation difference between occlusal plane and Camper's and Frankfort Horizontal planes. In this study, the mean angle difference between Frankfort Horizontal and Occlusal planes was determined to be $9.7^{o}$, which was corroborated by previous studies by Seifert et al. (27) where they determined that the difference between the occlusal plane-FH plane was 11.42° in dentulous subjects. Celebic et al. determined an angulation of 9.43° in dentulous and 8.53° in edentulous subjects (30). The angular difference between Camper's and natural occlusal plane was to be 6.0° in this study. Van Niekerk *et al*. conducted a cephalometric study on 33 edentulous patients and found the angulation difference between occlusal plane and Camper's plane to be 3.45°. However Koller *et al*., and Karkazis and Polyzois reported it as 7.00° and 10.00° respectively (31, 32, 33).

The data from this study provided the linear and angular dimensions needed for the establishment of natural occlusal plane and it afforded an alternate method to locate the occlusal plane in-leu of using analog face-bow transfer. The precise measurement acquired from CBCT scans enabled dentists and technicians to locate the occlusal plane for digital denture fabrication in a digital environment.

The limitation of this research project may be due to its sample size of 50 patients. Further verification of these angulations and linear measurements need to be performed through a larger sample size of CBCT data of adults who are free of dental and skeletal pathology or temporomandibular disorder.

# CONCLUSIONS

With the current paradigm shift in dentistry from analog to digital setting, the ability to identify the location and angulation of natural occlusal plane digitally is critical to digital denture fabrication. Distance and angulation relationships between stable anatomical structures and dental landmarks will provide dentists with the ability to locate the position and orientation of a patient's natural occlusal plane without the use of stone models and analog face-bow. The results of this study can provide dental clinics and laboratories the ability to fabricate digital dentures in a true digital environment.

Published studies have measured angulation relationships between Frankfort Horizontal or Camper's plane and the occlusal plane, which could be used to establish the orientation of a patient's occlusal plane, especially in edentulous patients. However, these studies have illustrated a large variance in the degrees of angulation. The angulation relationship between the hamular notch-incisal edge (HNI) plane and the occlusal plane established in this study provide another modality for orientation of occlusal plane. This angle is confined within the skull and has a low variance. It appears to be a relatively stable and reliable angle of reference in establishing proper orientation of the occlusal plane.

Current advancement in technology has equipped the dental community with innovative approach to streamline clinical and laboratory procedures. The anthropomorphic averages of incisal edge location and angulation of natural occlusal plane when integrated with implant planning software could offer dentists and technicians the proper location of occlusal plane in edentulous mouth. The technical and clinical importance of this study findings could be extrapolated to virtual teeth set-up in a digital wax-up, the establishment of occlusal plane in prosthodontically driven surgical guide and the re-establishment of occlusal plane in full mouth rehabilitation. Hence, minimizing the guesswork from prosthodontics reconstruction procedures and improving patient care.

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