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A STUDY OF THE RELATIONSHIP BETWEEN NASION PERPENDICULAR AND
THE TRUE VERTICAL LINE

by

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A THESIS

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A STUDY OF THE RELATIONSHIP BETWEEN NASION PERPENDICULAR AND THE TRUE VERTICAL LINE

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DEPARTMENT OF ORTHODONTICS

ABSTRACT

The purpose of this study is to assess the relationship between Nasion perpendicular and the true vertical line between patient groups using cephalometric analysis. **Materials and Methods:** Ninety-six adolescent patients comprised the sample for this study. Subjects were between 10 and 18 years old, with no major craniofacial deformity. Three groups of patients were divided in to three groups (Class I, Class II and Class III) based on their skeletal antero-posterior relationship. Pre-treatment lateral cephalometric radiographs were taken with the Orthoceph® OC100 D. Using Dolphin Imaging™ software, the necessary anatomic landmarks were located and points were plotted. The angular difference between Nasion perpendicular and the true vertical line was calculated for the sample, and differences described between the different patient groups (Class I, II, and III). **Results:** Malocclusion class has a significant effect on the VFA ($p < 0.05$). All three groups showed a mean negative angle, becoming more negative from Class II (-0.21°), to Class I (-2.1°), to Class III (-3.8°). In post-hoc tests, significant differences were observed between every class. Greater significance was displayed when comparing Classes I and III versus Class II, with much less significance between Class I and Class III. The difference between II and III was the most significant (-3.8° vs -0.21°). **Conclusions:** The anteroposterior jaw relationship does have a significant effect on the VFA when observed between Class I, II, and III groups. When the VFA differs significantly from the mean, measurements using NaPerp as a reference line will often

indicate an unrealistic U1 position. The differences among different skeletal malocclusions must be taken into account when using the vertical reference plane NaPerp to assess U1 position.

Keywords: Cephalometrics, Nasion perpendicular, True Vertical line

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LIST OF ABBREVIATIONS

AP.....	Anterior -posterior
STCA.....	Soft Tissue Cephalometric Analysis
Na Perp.....	Nasion Perpendicular
TVL.....	True Vertical Line
CL I.....	Class one
CL II	Class two
CL III	Class three
FH.....	Frankfort Horizontal
FMA.....	Frankfort to Mandibular Plane angle
SN.....	Sella – Nasion
ANB.....	A-point – Nasion – B-point angle
Sn.....	Subnasale
NHP.....	Natural Head Position
NHO.....	Natural Head Orientation
U1.....	Upper incisor
U1 Most Labial.....	Upper Incisor’s most labial point
VFA.....	Vertical Facial Angle

CHAPTER 1

INTRODUCTION

Background

Orthodontics has historically been focused on the achievement of occlusal and facial harmony. The order of importance, however, has not always been clear. Going back to the days of Edward Angle, emphasis was placed on achieving a good occlusion with the thought that facial harmony would follow suit. The profession would go on to develop cephalometric standards that related teeth to the bones of the face and skeleton. This was done with the idea that if these dentoskeletal standards were followed as treatment goals, facial harmony would exist [17].

As the importance of facial esthetics has become more prominent, the relationship of teeth to dentoskeletal standards is no longer the only focus. This shift has been due, in part, to the variability discovered within hard tissue-based analyses. The idea of using soft tissue landmarks to supplement traditional analyses has given a new angle on diagnosis and treatment planning as soft tissue landmarks could be used to establish vertical reference planes in order to evaluate tooth positions, and plan movements, similar to traditional analyses. The main difference between hard and soft tissue analyses is that the latter use a natural head orientation, a concept used since the 1950's by Downs (1956), Bjerin (1957), and Moorrees and Kean (1958) [8,5,13]. Regardless of the analysis used, orthodontic results today rely heavily on planning the upper incisor position (PIP). This has been shown to be an important part of achieving dentofacial esthetics [35].

Many reference planes and analyses exist to assess and plan upper incisor (U1) position, but this study will focus on 2 methods. The first reference plane, Nasion

Perpendicular (Na Perp), uses dentoskeletal standards as treatment goals. The plane is established using intra-cranial landmarks that are determined by the patient's individual anatomy. The second reference plane, True Vertical Line (TVL), is part of a soft tissue analysis and uses soft tissue anatomy and natural head position to establish treatment goals. These 2 planes were chosen for comparison because of their popularity in use, but also because they often give conflicting information regarding patient diagnosis. The present day use of two common reference planes of very different foundation (hard vs. soft tissue) begs the question about their relationship to each other among patients. An objective of this study is to establish data regarding the differences between these 2 planes in patients presenting with various antero-posterior (AP) skeletal discrepancies.

Statement of the problem

In the current era of evidence-based orthodontics, there is a need for reliable, reproducible facial planes in order to diagnose and plan treatment. It seems that often times orthodontists can agree on treatment objectives (balanced profile, good occlusion, lip support, etc.), but the standards used to assess these elements are often not agreed upon. This can create a situation in which the goals strived for are not being met.

The vertical reference planes of Na Perp and TVL are often both used to assess maxillary incisor position. In the "ideal" patient, the U1 would be located approximately 4 mm anterior to Na Perp and -9 mm posterior to TVL [12,29]. For this scenario, it is assumed that these lines are roughly parallel (Fig. 1), making their measurements both reliable. The U1 in figure 1 is described as being in a good position according to the norms for both reference planes. However, we find that often times Na Perp is far from parallel to TVL (Fig. 2), meaning the use of one of the two references is inaccurate.

Figure 2 shows a scenario where Na Perp describes the U1 as retrusive (normal is 4mm +/- 1.5mm anterior to Na Perp), but TVL describes it as protrusive (normal is 12mm posterior to TVL for males). In this scenario, the U1 is obviously in a protrusive position, but we have one analysis giving an accurate description, and another giving conflicting information.

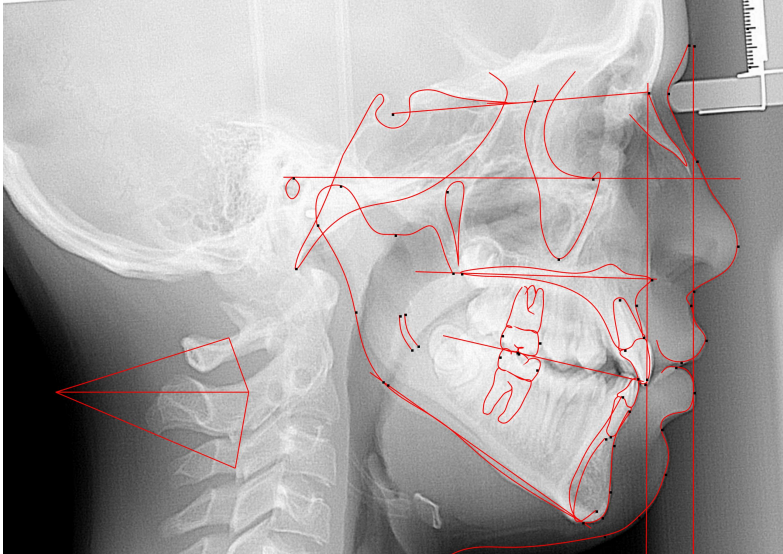


Figure 1. Na Perp coincident with TVL



Figure 2. Disagreement between Na Perp and TVL

As a result, the use of reference planes that are established in very different ways will often give conflicting information on a given patient. This situation creates a lack of consistency in cephalometric numbers that confuses practitioners. For this reason many orthodontists no longer rely on cephalometrics as a tool in diagnosis and treatment planning.

There is no wrong or right analysis. However, information describing how these analyses differ and relate to each other will help with these problems. This research will help establish a relationship between 2 commonly used facial planes, and assess a correlation between skeletal patterns.

Purpose of the Study

The objectives of the study are to:

1. Assess the relationship between TVL and Na-perp.
2. Investigate the correlation of this relationship with the various AP skeletal discrepancies.

Null Hypotheses

1. There is no significant difference in the angle formed between Nasion perpendicular and the true vertical line (vertical facial angle).
2. There is no difference in the vertical facial angle value between patients of class I, II, and III skeletal patterns.

Definition of Terms

Landmark- a point or line on a cephalometric radiograph that represents anatomy.

Nasion – the intersection of the internasal and frontonasal sutures in the midsagittal plane [15].

Subnasale – the point in the midsagittal plane where the base of the columella of the nose meets the upper lip [15].

Nasion Perpendicular – a reference plane perpendicular to Frankfort horizontal, through Nasion [12].

True vertical line - a line that parallels the head's frontal plane in NHO and passes through the subnasale [29].

Vertical Facial Angle – the angle formed between the 2 planes, Nasion perpendicular and the true vertical line.

Natural Head Orientation – the head orientation of the subject perceived by the clinician, based on general experience, as the natural head position in a standing, relaxed body and head posture, when the subject is looking at a distant point at eye level; same as adjusted natural head position and upright head position [10]

Natural Head Position – a standardized and reproducible orientation of the head when the subject is focusing on a distant point at eye level. Clinically, established by asking a patient to look at his/her own eyes in a small mirror at eye level [19].

CHAPTER 2

REVIEW OF THE LITERATURE

Cephalometric History

In 1931, a new technique for the study of malocclusion and skeletal disproportions was introduced to the world of dentistry. Though described decades earlier, the credit for description of modern day cephalometric radiography is owed to Birdsall Holly Broadbent Sr. in the United States, and to H. Hofrath in Germany. They simultaneously defined a way to capture the cephalometric radiograph, in a standardized, somewhat repeatable fashion. It was the introduction of the cephalometer by Broadbent in 1936, however, that marked the beginning of the technique in earnest. This provided an instrument for accurate placement of the head relative to the film and x-ray source. Interestingly, cephalometric radiography was developed purely for Broadbent's personal interest in the study of craniofacial growth. The first cephalometric analysis was introduced by William Downs in 1948 [20]. Other analyses soon followed, the purpose of all being to characterize patient's skeletal, dental and soft tissue relationships and compare them to population norms.

Craniofacial Reference Planes

Current day cephalometric analysis in orthodontics is based on comparing elements of the craniofacial complex to selected reference planes. An ideal cephalometric reference plane/system should have the following features: good reliability (low method error), good intra-individual reproducibility, low inter-individual variability, and a true representation of the true horizontal and/or vertical [38]. The effort to locate these planes, some would say, began at the world congress in 1884.

Even prior to the use of cephalometrics in orthodontics, Frankfort Horizontal

(FH) was used as the standard horizontal reference plane. Anthropologists at the world congress in 1884 determined it to be the best estimate of the true horizontal. Two major problems with the use of FH are its inter-individual variability, and lack of true horizontal representation. In 1956, Downs showed the inter-individual variation of FH to be $+9^\circ$ to -7° , and a standard deviation of 5° . In terms of FH and its representation of a true horizontal, it is on average 2° - 5° off of true horizontal. Studies by Downs, Moorrees, Lundström, Cole, and others confirm these findings [8, 13, 10, 6]. Despite this data, FH is used to diagnose and treatment plan orthodontic cases

A few decades later, another commonly used craniofacial reference was developed. The Sella-Nasion plane (SN) was developed by Broadbent in 1931. SN gained popularity among orthodontists largely due to the fact that it is easy to locate, fairly reliable, and a good representation of the anterior cranial base. Similar to FH, however, it has been shown to have large inter-individual standard deviations of up to 7° and a 2° - 9° average orientation from the true horizontal [8,13,10,6]. The reasons for these variations result mainly from the difference in anatomy between individuals. The foundation of these planes are subject to extreme biologic variability. This makes applying population standards for cephalometric analysis very difficult. For these reasons the validity of SN and FH as craniofacial reference planes is highly questionable. [6].

Natural Head Position

Traditional cephalometric reference planes, as discussed above, are developed by connecting intra-cranial landmarks. These images are taken with the patient assuming an arbitrary head posture. This often results in extremely unnatural head positions.

Although this does not affect the cephalometric numbers, it makes assessment of the patient's features difficult [43].

A different approach is the use of Natural Head Position (NHP) in order to overcome this problem. Introduced to orthodontics in the 1950s, NHP is a standardized position of the head in an upright head posture with the eyes focused on a point in the distance at eye level [19,13]. Clinically, it is registered by having subjects stand in an upright position and look into their own eyes in a mirror. Some clinicians recommend having the patient perform a series of neck flexion exercises prior to this [21]. "True" vertical and horizontal lines can then be placed on an image taken with this technique, and used as reference planes.

There are two key advantages to the use of NHP. The first is its good intra-individual reproducibility to a vertical plumb line. Lundstrom and Lundstrom first investigated this by transferring a vertical plumb line from pre-treatment photographs taken in NHP to lateral cephalograms [9]. The NHP reproducibility between 2 photographs of a given patient was shown to be 2°. The study was able to look at the variation of intra-cranial reference planes at the same time, showing the following standard deviations: Basion-Nasion (SD of 4.5 -5.0), Sella-Nasion (SD. 5-5.6), and Porion-Orbitale (SD of 4.7-5.3) [9].

This intra-individual reproducibility of NHP has been supported over both short and long time intervals by several research works, especially the longitudinal serial studies of Cooke et al. [22]. Their findings showed the method error of NHP to be 1.9° after 1-2 hours. At the 5-year interval and 15-year interval of their longitudinal study, the method error of NHP was found to be 3.04° and 2.2°, respectively. This makes the

variance of NHP at 1-2 hour, 5 year, and 15 year intervals to be 3.61 °, 9.24 °, and 4.8 °, respectively. Therefore, the variability of NHP registrations are far less variable than the 25 ° – 36 ° variability range of intra-cranial reference planes [7,22,23].

The second advantage is that NHP represents the true-life appearance of a patient [43]. After all, when a patient is treated in order to make some improvement in the soft tissue profile, it should be in reference to a head position most similar to a real life posture, as opposed to internal anatomical landmarks. The goal of NHP is to capture the profile in a posture that is closest to a real life presentation of the patient, but also to be reproducible. Multiple studies have proven the reproducibility of NHP [7,9,13,22-24]. However, its use in cephalometrics is not uniformly embraced. Possible reasons may be confusion over terminology, technical aspects of the process, or just fear of change.

Natural Head Orientation

Patient positioning in the cephalostat in NHP is sometimes challenging, due to a multitude of factors that include patient discomfort in the cephalostat, operator –related errors due to poor patient positioning or improper technique for achieving NHP by the operator, etc. The end result can be an unnatural head position on the cephalometric radiograph when compared to the normal head posture observed by the clinician in real life interactions. To overcome these limitations, Lundstrom and Lundstrom introduced a second concept, Natural Head Orientation (NHO), in 1995. NHO is defined as the head position adjusted from the registered NHP to a position judged to be the natural head orientation by the orthodontist. It can also be defined as the head position evaluated as “natural” by observers [10].

Due to the fact that clinical judgment is used, the possibility for error exists. Despite this, research has shown that the differences between clinicians' judgments for the NHO of a given patient are very small. Lundstrom and Lundstrom tested the inter-observer error by having assessors position lateral cephalograms at 3-week intervals. Similar to studies testing the variation of NHP, the differences in head position are observed by measuring changes in the angle between SN and a vertical plumb. This resulted in an inter-observer method error of 1.6 °. Other studies have shown the same outcome. [9,24,25] These results have supported the idea that NHO is a more reliable reference than registered NHP [25,45].

Importance of planned incisor position

One of the most common chief complaints of patients reporting for orthodontic treatment is unacceptable maxillary incisor position in the sagittal plane. Planned Maxillary Incisor Position (PIP) is thus one of the requirements to achieve ideal orthodontic results [35]. This position is affected by both anterior-posterior position and inclination of the incisor. Different cephalometric and non-cephalometric methods have been used to assess the maxillary incisor sagittal position / inclination in the literature, however among cephalometric methods, two of the widely used reference planes are Na Perp and TVL. The 2 analyses that use these planes each will be detailed in sections below.

Traditional vertical reference planes

Cephalometric reference planes can be used to assess the patient's skeletal, dental and soft tissue profile relationships. Vertical reference planes are used to assess the antero-posterior (AP) dimension of the patient. As described above, one of the most important aspects of this for orthodontics is the diagnosis and treatment planning of the upper incisors in the AP dimension.

Cecil Steiner [27] was the first to advocate using cephalometrics for treatment planning in orthodontics. Prior to his recommendation, cephalometric analyses were only a diagnostic tool. He utilized the planes Nasion-A point (NA) and Nasion - B point (NB) to assess the AP position of the upper and lower incisor, respectively. The norms for the upper and lower incisor's position anterior to these lines were calculated at 4mm each. The positions of these planes rely on a combination of cranial base and jaw orientation. Ricketts [28] developed his analysis in 1979, suggesting a plane from A point to Pogonion (A-pog) as a line to which the upper incisor should related. His clinical norm is 3.5 +/- 2.3mm anterior to this line.

James McNamara [12], in 1984, suggested the use of a plane called Nasion Perpendicular, or McNamara's Line, which passes through Nasion and is perpendicular to the FH plane. He suggested this as a critical plane for measuring the distance from the upper and lower jaws, but also the incisor positions. The McNamara analysis uses a norm of 4 mm +/- 1.5mm anterior to Na Perp for the U1. This became a popular analysis for assessment of the upper incisor, and is still widely considered valid today.

All of the above analyses have similar foundations in that they use intra-cranial landmarks as their points of reference. For many years, these vertical reference planes have been used for diagnosis and treatment planning of the upper incisor. However, they

do not always coincide with facial esthetics, and they also show a tendency toward inter-individual discrepancy [8,13,10,6].

Paradigm shift

Though used with much success, the shortcomings of these traditional vertical reference planes led some clinicians to explore the use of soft tissue landmarks for assessing the A-P position of the upper incisor. Sarver et al. describe the orthodontist's task as being one that must satisfy both occlusal and facial demands to achieve success. Clinicians have begun to place more importance on the soft tissues of the face as the limitations of orthodontic treatment. This change in philosophy places greater emphasis on soft tissue function and esthetics than ever before [44]. This paradigm shift from intra-cranial to extracranial structures has happened for 3 main reasons:

The first reason is the glaring unreliability of craniofacial reference planes founded on intra-cranial landmarks (i.e. FH and SN) [8]. Large standard deviations between individuals in these planes frustrate clinicians when the numbers don't match up with what they see clinically. For example, a protrusive upper incisor can be described by an analysis as retrusive, simply because the FH plane is canted.

The second reason is the consistency and predictability of using soft tissue landmarks in conjunction with natural head position. Obviously, all techniques have their inherent error, but relative to the alternative of intra-cranial reference planes, extracranial references are more consistent. This will be discussed in further detail below.

A third reason for this paradigm shift is the increased emphasis on facial esthetics in society [44]., It makes sense to relate tooth position to landmarks that closely affect this facial outcome. Arnett and Bergman describe 19 soft tissue landmarks in their

“Facial Keys” that serve as tools for improved facial and dental results. With such an increased emphasis on facial and soft tissue esthetics, they suggest relating dental and skeletal points to references that are closer to these features. For these reasons, soft tissue landmarks of the lips, nose and forehead have proven to be useful [2,3].

Soft tissue vertical reference planes

Many authors have suggested utilizing soft tissue as a foundation for reference planes for incisor position over the years (Burstone, 1958, 1967; Legan and Burstone, 1980; Holdaway, 1984). However, the soft tissue aspects of their studies did not catch on in terms of treatment planning for incisor position.

William Arnett [29], in 1999, developed his Soft Tissue Cephalometric Analysis (STCA). He pointed out that occlusal correction does not always lead to correction, or even maintenance, of facial esthetics [2]. He sought to utilize the soft tissue profile as a guide to tooth placement and occlusal correction. The goal, essentially, was to achieve optimum facial harmony along with occlusal correction. As he put it, “the bite indicates a problem; the face indicates how to treat the bite”. Thus, a reference plane located on the face would be important. As its primary reference plane, this analysis uses the True Vertical Line (TVL) to assess positions of hard and soft tissue in the esthetic zone. This line runs vertically through subnasale, a soft tissue point. The orientation TVL ignores all intra-cranial planes (ie. FH, SN) and is assumed as a “true” vertical reference based on NHP. Though originally for surgical treatment planning, Arnett and McLaughlin [26] advocated the use of TVL and the STCA in orthodontics, and have made its use popular

with the McLaughlin analysis. The cephalometric database for this analysis places the incisor at -9mm and -12mm posterior to TVL for females and males, respectively.

The use of TVL in treatment planning has value for several reasons. In comparison to reference planes, such as Nasion Perpendicular, NA, NB, and N-Pog, that use the skeletal base for a reference, TVL has been shown to be much less variable (standard deviations of approx. 2° compared to 5°-9° for FH and SN). Another advantage over other skeletal base associated references is its location. The plane is placed very close to the upper incisor, which is the area of interest. Planes that have their foundation in intra-cranial landmarks very distant from the U1 have a type of “lever arm” effect on the vertical reference plane. Slight variation at the landmark level, can equal a much larger discrepancy at the location of the distant U1. However, TVL uses the point Subnasale as its landmark. As a result, even if the NHP is recorded incorrectly, the effect at the level of the U1 is much less dramatic for TVL due its proximity. [2,3,29]

Specific aims of this study

For many years, the importance of soft tissue facial analysis has been considered secondary and dentoskeletal relationships have been the deciding factor in diagnosis and treatment planning. Now with at least some shift towards soft tissue relationships to the dentition, we have both philosophies in use for PIP. For many patients, using either TVL or Na-perp as reference plane will yield similar data, but for some patients, these planes are highly non-parallel, and therefore give inconsistent data on incisor assessment, leading to ill-advised planning. This study looks to assess the relationship between TVL and Na-Perp (VFA), and investigates the correlation between the VFA and various antero-posterior skeletal discrepancies.

CHAPTER 3

MATERIALS AND METHODS

This is a retrospective investigation based on pre-treatment cephalometric radiographs of patients seeking orthodontic treatment at the UAB School of Dentistry Orthodontics Department. The sample consisted of 54 males and 42 females with an average age of 12.3 years old.

Subject Selection Criteria

Subjects for the study were selected from the database of patients at the University of Alabama School of Dentistry Orthodontics Department. 96 subjects were evenly divided into 3 groups of 32 based on A-P relationships of the skeletal bases. The 3 groups were made of Class I, Class II, or Class III patients, as determined by the Wits and ANB measurements. Both measurements had to agree on the patient's skeletal pattern to include the subject in the study. Pre-treatment cephalometric radiographs were obtained for each patient included in the study. Prior to initiating this study, approval was granted from the Institutional Review Board for Human Use.

3 groups:

- Class I skeletal pattern (ANB 0-3°, Wits -2 to 1mm)
- Class II skeletal pattern (ANB >3°, Wits >1mm)
- Class III skeletal pattern (ANB <0°, Wits < -2mm)

Inclusion Criteria

- Subjects between the ages of 10-18 years

- Class I , II, III skeletal patterns based on Wits and ANB values
- Normodivergent skeletal pattern (FMA of 25° +/- 5°)

Exclusion Criteria

- Presence of any craniofacial anomalies
- Patients currently undergoing orthodontic treatment

Data Collection

The cephalometric images for all subjects were obtained on the Orthoceph® OC100 D machine (Instrumentarium, Milwaukee, WI) at the UAB SOD Orthodontics department. After collecting the cephalograms, each image was digitized using the UAB Dolphin Imaging software (Dolphin Imaging & Management Solutions, Chatsworth, CA). Necessary points for the McNamara and Arnett/McLaughlin analyses were identified and plotted. All radiographs were digitally traced in Dolphin Imaging by one operator (J.S.). Images that displayed a head position that was deemed as unnatural were adjusted to NHO by the first observer. A second observer (N.S.) later reviewed the original images and made positional changes, as deemed necessary. Any disagreement between the 2 examiners for either resulted in registration of the average head position between the 2 assessments. Assessments were also made for intra- and inter- observer reliability for films that needed adjustment. TVL was then established as a vertical line parallel to the edge of the film, through subnasale. Na Perp was established as a 90° angle to FH, through Nasion. Points whose location was sensitive to the eventual placement of Na Perp, such as Porion, Orbitale, and Nasion, were also checked by the second observer

(N.S.). A summary of cephalometric landmarks and planes used can be found in Table 1. After establishment of Na Perp and TVL was complete, the images were available for measurement and statistical analysis.

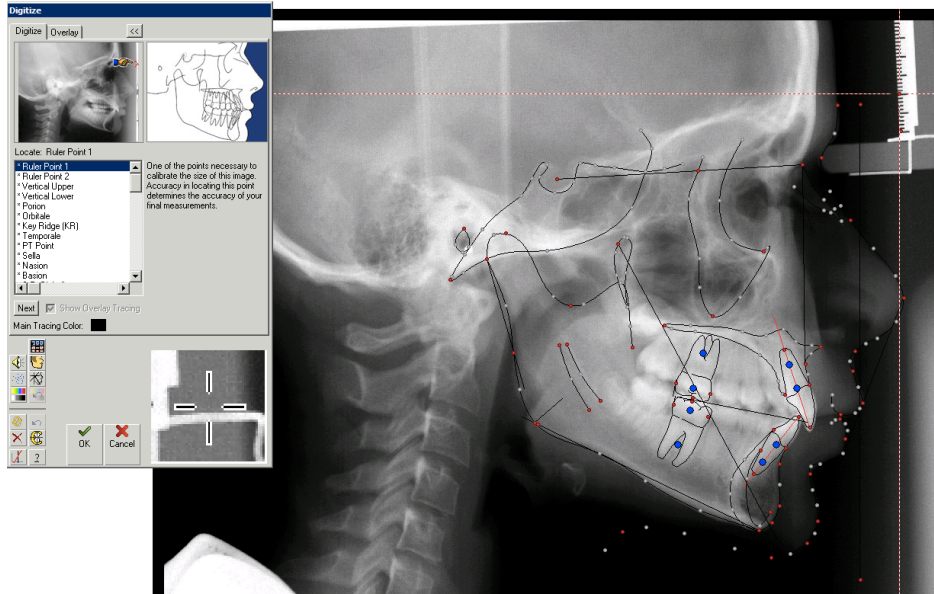


Figure 3. Establishing Na Perp and TVL

Parameters Measured

In order to measure the angular difference between the 2 reference planes, Na Perp and TVL, a custom measurement was created for the study by Dolphin Imaging (Fig. 3). This is called the Vertical Facial Angle (VFA). The VFA was the main parameter measured in this the study. The other parameter taken from the cephalometric analysis was U1 to Na Perp. Table 2 provides a summary of the measurements used in the custom cephalometric analysis.



Figure 4. Vertical Facial Angle (VFA)

Statistical analysis

Mean, Standard Deviation, Variance, Minimum & Maximum value and Range were calculated for each variable for each subject. VFA was calculated for each subject in each group. Statistical comparisons of the VFA in subjects in different malocclusion groups were compared using one-way analysis of variance (ANOVA), as well as pair-wise post hoc tests utilizing the Tukey method. A p-value <0.05 was considered statistically significant. Intra-rater and inter-rater reliability were assessed using an ICC (intra-class correlation) score. The ICC score is defined as the ratio of the variance between subjects to the total variance estimated using a two-way mixed effect model (the raters are fixed and patients are random). To assess the intra-rater reliability associated with digitizing and measurements, 30 radiographs were selected randomly for

examination. All procedures such as landmark identification, tracing, and measurement were repeated on these 30 radiographs 3 weeks after the first examination, by the same investigator. The T1 and T2 measurements were compared using the ICC score. In the same manner, inter-rater reliability for head position evaluation was tested by comparing the VFA differences between rater 1 and rater 2. As the head position changes based on estimation, the VFA changes as well. VFA differences were compared for those patients whose head position was different between rater 1 and rater 2. SAS v9.4 was used for all analyses (SAS Institute Inc., Cary, North Carolina).

Table 1

Cephalometric Landmarks and Reference Planes

Landmarks	Abbreviation	Definition
A-point	A	The deepest (most posterior) midline point on the curvature between the ANS and Prosthion.
B-point	B	The deepest (most posterior) midline point on the bony curvature of the anterior mandible, between Infradentale and Pogonion.
Gonion	Go	The most posterior inferior point on the outline of the angle of the mandible.
Menton	Me	The most inferior point of the mandibular symphysis, in the midsagittal plane.
Nasion	N	The most anterior point on the frontonasal suture in the midsagittal plane
Orbitale	Or	The lowest point on the inferior rim of the orbit
Porion	Po	The highest point on the upper margin of the external auditory meatus
Subnasale	Sn	The point in the midsagittal plane where the base of the columella of the nose meets the upper lip
Nasion	N	The most anterior point on the frontonasal suture in the midsagittal plane
Upper Limit	UL	Upper point that establishes vertical in NHP
Lower Limit	LL	Lower point that establishes vertical in NHP
Upper 1 Most Labial	U1-most labial	Most labial surface of the upper central incisor
Upper 1	U1	Incisal tip of the upper central incisor
Reference Planes		
Frankfort Horizontal Plane	FH	The line connecting Po and Or

Nasion Perpendicular Plane	Na Perp	A vertical reference plane created by dropping a line perpendicular to Frankfort horizontal through Nasion
True Vertical Line	TVL	A vertical plane established in a natural head posture, through Subnasale

Table 2

Measurements Used in Custom Cephalometric Analysis

Measurement	Abbreviation	Definition
Vertical Facial Angle	VFA	The angle formed between Na Perp and the TVL
Upper incisor – Nasion Perp (mm)	U1-NaPerp	Horizontal measurement for the position of the upper incisor measured as the distance from the upper incisor’s most anterior surface to Na Perp

CHAPTER 4

RESULTS

The study was conducted on 96 subjects (3 groups of 32 each) with mean age of 13.2 ± 2.1 , 12.8 ± 1.7 , and 13.7 ± 1.8 years old for the Class I, II, and III groups, respectively. Table 3 shows descriptive statistics for each parameter, stratified by malocclusion. These include age, ANB, Wits, FMA angle, U1-NaPerp.

Table 3

Mean values and standard deviations for age, ANB, Wits, and FMA in patients with Class I, II, and III malocclusions.

Variable	Mean (SD)		
	<i>Class I</i> (<i>n=32</i>)	<i>Class II</i> (<i>n=32</i>)	<i>Class III</i> (<i>n=32</i>)
Age	13.1 (2.1)	12.8 (1.7)	13.7 (1.8)
ANB (°)	1.4 (0.7)	5.4 (1.4)	-1.7 (1.5)
Wits Appraisal (mm)	-0.31 (0.9)	3.7 (2)	-5.5 (2.2)
FMA (MP-FH)(°)	24.1 (3.5)	26.8 (4.1)	23.2 (4.5)
U1 - NaPerp (mm)	5.7 (1.8)	4.2 (2.2)	6.3 (2.5)
VFA (°)	-2.1 (2.9)	-0.21 (3)	-3.8 (2.5)

The measurement for the angular difference between Na Perp and TVL, known as VFA, was evaluated. Table 4 shows the mean and standard deviations for the VFA of each group, as well as comparison of these values between groups. VFA values were negative (angle was divergent in an inferior direction) for all 3 groups. The Class II group was very close to parallel (value of 0) on average, with a slightly negative value of -0.21° . The Class I and III groups had a much more negative value for VFA. P-values from ANOVA and post-hoc comparison are shown. P-values indicated significant differences for the ANOVA comparison of all 3 classes. Post-hoc comparison p-values were also significant for each comparison; however, it was clear that a greater

significance was displayed when comparing Classes I and III versus Class II, with much less significance between Class I and Class III.

Table 4
Comparison of groups with ANOVA and pair-wise post-hoc test.

Variable	Mean (SD)			<i>p</i> -value	p-value for Post-hoc Comparison ¹		
	Class I (<i>n</i> =32)	Class II (<i>n</i> =32)	Class III (<i>n</i> =32)		I vs II	I vs III	II vs III
Age	13.1 (2.1)	12.8 (1.7)	13.7 (1.8)	0.15	0.69	0.48	0.13
ANB (°)	1.4 (0.7)	5.4 (1.4)	-1.7 (1.5)	<.0001*	<.0001*	<.0001*	<.0001*
Wits							
Appraisal (mm)	-0.31 (0.9)	3.7 (2)	-5.5 (2.2)	<.0001*	<.0001*	<.0001*	<.0001*
FMA (MP- FH)(°)	24.1 (3.5)	26.8 (4.1)	23.2 (4.5)	0.002*	0.025*	0.65	0.002*
U1 - NaPerp (mm)	5.7 (1.8)	4.2 (2.2)	6.3 (2.5)	0.001*	0.016*	0.5	0.0004*
VFA (°)	-2.1 (2.9)	-0.21 (3)	-3.8 (2.5)	<.0001*	0.018*	0.04*	<.0001*

*Denotes statistical significance at $p < 0.05$

¹Tukey method

Table 5
Box plot for VFA divided by class

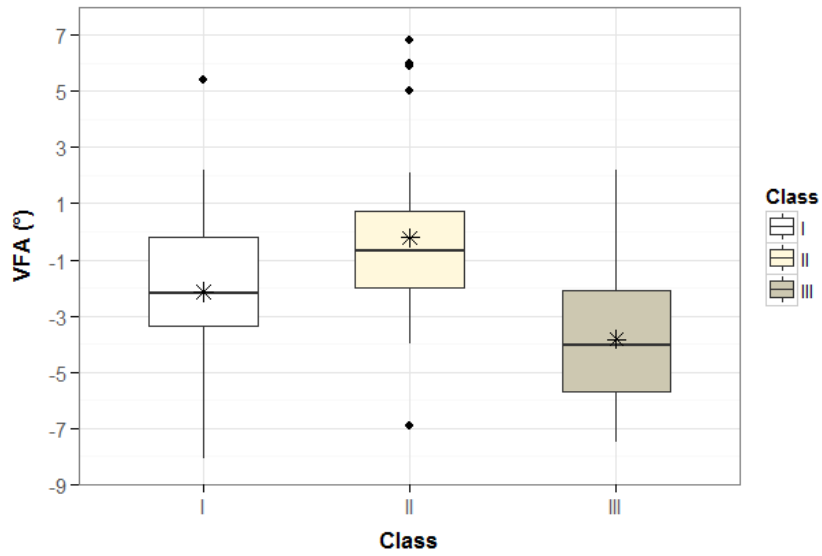
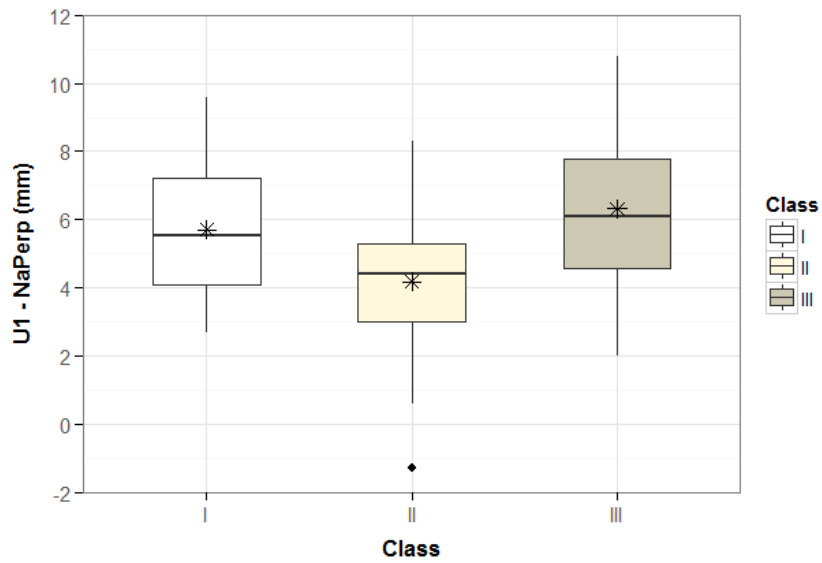


Table 6
Box plot for U1 - NaPerp (mm) divided by class



Intra-rater and inter-rater reliability was measured by ICC score (Intra-class correlation) is summarized in Table 7. An ICC score of 0.75 or higher was considered an acceptable reliability.

Table 7

Intra-rater and inter-rater reliability

Intra-rater reliability		Inter-rater reliability	
Variable	ICC	Variable	ICC
ANB	0.996	VFA	0.932
Wits	0.998		
FMA	0.994		
U1-NaPerp	0.975		
VFA	0.935		

CHAPTER 5

DISCUSSION

Previous studies have compared cephalometric reference planes to gather insightful information, however, most of these have focused on comparison of intracranial horizontal reference planes such as S-N, FH, Ba-N, etc. This study focused on comparing a vertical reference plane based off intracranial landmarks, Na-Perp, to an extracranial reference plane, TVL. As is known, variability of intracranial reference planes can create problems for the clinician when using cephalometric norms to diagnose and treatment plan. While extracranial references used with NHO have their own inherent error, it has been shown to be much less than intracranial references [9,10].

Comparison of malocclusion groups

Results of the ANOVA testing show that the antero-posterior skeletal discrepancy does have a significant effect on the VFA ($p < 0.05$). All three groups showed a mean negative angle, becoming more negative from Class II, to Class I, to Class III. In post-hoc tests, significant differences were observed between every class. A difference between II and III was the most significant (-3.8° vs -0.21° , $p < .0001$, a difference of 3.59° , $p < .0001$).

Intra- and inter-rater reliability

Previous studies testing the consistency when estimating NHP have shown little difference between raters. Studies agree on an inter-observer method error below 2° [9,24,25]. These results have supported the idea that NHO is a more reliable reference than registered NHP [25,45], which is a main reason it was used for this study. In this study, inter-rater reliability for head position evaluation was tested by comparing the

VFA differences between rater 1 and rater 2. As the head position changes based on estimation, the VFA changes as well. VFA differences were compared for those patients whose head position was different between rater 1 and rater 2. An ICC score of 0.75 or higher was considered an acceptable reliability. Table 7 displays the inter-rater reliability is 0.93; its 95% CI is (0.9, 0.96). This shows a reliability consistent with previous studies [9,24,25].

To assess the intra-rater reliability for the primary operator (JS) associated with digitizing and measurements, 30 radiographs were selected randomly for examination. All procedures such as landmark identification, tracing, and measurement were repeated on these 30 radiographs 3 weeks after the first examination, by the same investigator. The T1 and T2 measurements were compared using the ICC score. All ICC scores were above the 0.75 value for acceptability, showing reliability for the digitizing and measurements for operator 1 (JS).

Differences in VFA between groups

Reasons for the change in VFA from one class to another can be due largely to the variation seen in FH orientation to the true horizontal [8, 13, 10, 6]. An excessive upward inclination of FH due to anatomy will cause NaPerp to become more parallel to TVL. This is what is seen with the Class II group, with a VFA very close to parallel. An excessive downward inclination will make the VFA become more negative, as seen in the Class III group.

Although there is no norm for VFA, it is helpful to relate the VFA to an average as a reference. To decide what can be considered an average VFA, 2 elements can be considered: the average of this study and the findings from previous studies on the angle

between FH and a true horizontal. On average, FH is has been shown to be -1° to -5° , off of the true horizontal [8, 13, 10, 6]. Our measurement of the VFA is analogous to that angle, as NaPerp is perpendicular to FH and TVL is perpendicular to a true horizontal. Using these studies, one could consider that a normal range for VFA. Our mean for all subjects was $-2.1^{\circ} \pm 2.6$. Taking this range into consideration, our findings for the Class I and III group agree with this range, with a VFA of -2.1° and -3.8° , respectively. The outlier of the 3 groups is shown to be the Class II group, at -0.21° . Ultimately, a study using a larger sample group population would be needed to develop a true VFA norm.

Clinical Implications

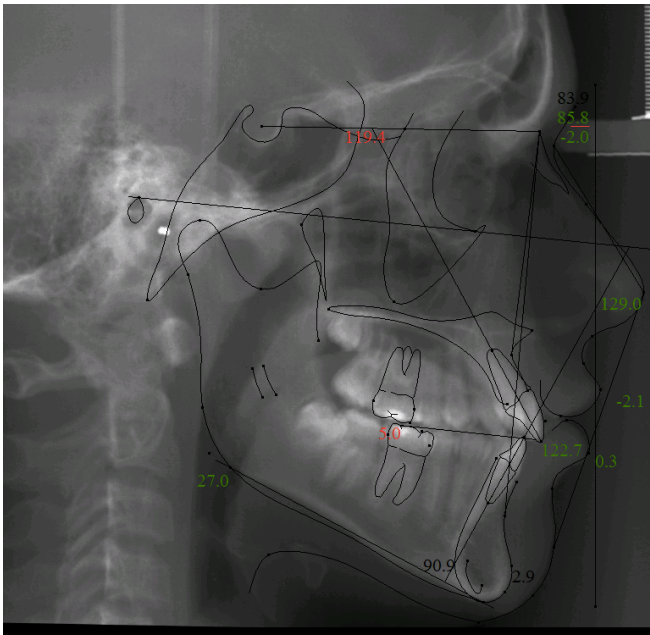
The knowledge that VFA differs between malocclusion classes has several implications. First of all, a varying VFA will have an impact on the U1 assessment to NaPerp or TVL, which we use for diagnosis and treatment planning. The effect that the correlation between malocclusion and VFA has on the U1-NaPerp reading can be seen when comparing the box plots in Table 5 and 6. The VFA and U1-NaPerp value are inversely related. Comparing the plots, one can see the U1-NaPerp assessment becomes protrusive as the angle becomes more negative (as in Class III group), and retrusive as the angle becomes closer to 0° (as in Class II group).

While these assessments of the upper incisor may be accurate, it stands to reason that patients with a VFA well outside a normal range can give inaccurate values for U1 evaluation. For example, the Class III group had an average VFA of $-3.8^{\circ} \pm 2.5$. The patients in this group that were outside 1 standard deviation in a negative direction had the following U1-NaPerp assessment: 6.9mm, 6.1mm, 7.0mm, 10.8mm, 9.5mm, 10.3mm, and 6.1mm. This describes these patients as having significantly protrusive incisors,

however, the incisors were typically in good position as seen in Fig 5, or even retrusive in some cases. Fig. 5 shows an example of a patient with an U1 that most would not consider protrusive, but because of the large VFA angle, it gives an extremely protrusive U1-NaPerp measurement. It seems that the significant effect that malocclusion has on the VFA is of particular importance in Class II and III patients as they were on either end of the study's average, which is where the variation in NaPerp position most drastically effects measurements to the U1. For a Class II patient, the tendency will be for the incisor to be deemed as retrusive. For a Class III patient, the tendency will be for the incisor to be deemed as protrusive. Having the VFA value in mind could be helpful when assessing these patient's upper incisors cephalometrically.

Fig 5

Normal U1 position with abnormally negative VFA



Another clinical use of this study is that it gives us average that we can expect to see between these 2 planes. It can be likened to the 8° difference seen on average between S-N and FH [39]. This number is referred to often during treatment planning to assess if one of the planes is abnormally placed. If the difference between S-N and FH is much greater or less than 8° we know that the numbers associated with one, or both, of the planes may be inaccurate. Using the VFA, one could be alerted that either the FH or the head position in the film are in error. An average VFA of $-2.1^{\circ} \pm 2.6$ was seen in our sample, but this included patients with different malocclusions. A larger and less variable sample would be needed to confirm this preliminary norm for the VFA.

The function of vertical cephalometric reference lines is to accurately describe the patient's craniofacial complex and dentition. No single reference line will completely satisfy all purposes, and avoid all errors. The intent of this study was not to advocate the use of one reference line over the other. However, previous studies suggest the greater reliability of NHO and an extracranial reference to accurately represent these structures. The results of this study show a relationship between NaPerp and TVL that is significantly affected by malocclusion class. When the VFA differs significantly from the mean, measurements using NaPerp as a reference line will indicate abnormal U1 position, even if it is normal. Assuming a correct head position, those measurements using TVL will still provide accurate information. Thus, one must be aware of the VFA if NaPerp is used for reference. This should encourage clinicians to use the U1-NaPerp measurement with caution in these cases.

Possible limitations of the study include the inherent operator error in identification of landmarks, head position. Possibilities of inaccuracy of the VFA due to

error in FH tracing and/or NHO estimation are possible. Best efforts were made to reduce and test this error.

Future studies could attempt to develop a norm for VFA. A large sample size with ideal occlusion, profile, etc. could be used to develop this norm. This would be helpful in giving the clinician a sense of how abnormal a given VFA is when compared to a norm.

CHAPTER 6

CONCLUSION

- Significant differences among skeletal malocclusions were observed for the VFA.
- A difference in VFA between Class II and Class III skeletal discrepancies was the most significant (-3.8° vs -0.21° , $p < .0001$).
- When the VFA differs significantly from the mean, measurements using NaPerp as a reference line will often indicate an unrealistic U1 position.
- The differences among different skeletal malocclusions must be taken into account when using the vertical reference plane NaPerp to assess U1 position.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL

DATE: 2/19/15

MEMORANDUM

TO: Nada Souccar
Principal Investigator

FROM: Cari Oliver, CIP 
Assistant Director
Institutional Review Board for Human Use (IRB)

RE: Request for Determination—Human Subjects Research
**IRB Protocol #N150216002 – A Study of the Relationship Between Nasion
Perpendicular and the True Vertical Line**

A member of the Office of the IRB has reviewed your Application for Not Human Subjects Research Designation for above referenced proposal.

The reviewer has determined that this proposal is **not** subject to FDA regulations and is **not** Human Subjects Research. Note that any changes to the project should be resubmitted to the Office of the IRB for determination.