3-DIMENSIONAL REPRODUCIBILITY OF NATURAL HEAD POSITION

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DEDICATION

This thesis is dedicated to my family. My parents' hard work and dedication to our family have always been an inspiration to me. No matter what, they have stuck by me and offered me advice unconditionally. My parents and my husband have supported me and given me the strength to complete my education and training throughout dental school and orthodontic residency. JR, my son, is so fun, full of energy and a great kid to be around. He is a delight and the apple of my “eyeball.” Alexa, my daughter, is beautiful and good natured. She is always laughing and smiling, which would be the highlight of anyone's day. Finally, my Heavenly Father, who has given me the strength to persevere and pursue my dreams.

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ABSTRACT

Objective: During orthodontic treatment, photographs or radiographs of patients are typically utilized to evaluate soft tissue growth and treatment change. As a means of assessing these changes, direct superimposition of images taken at different time points is traditionally accomplished. This study was accomplished in order to determine the reliability of using True Sagittal, Coronal and Frontal reference planes for image superimposition, based on a patient's Natural Head Position (NHP). The study was designed to evaluate the reproducibility of NHP over time in all planes of space using three-dimensional imaging. It was hypothesized that a patient's NHP is reproducible in the Sagittal, Coronal and Frontal dimensions over time. **Methods and Materials:** The experimental design included 28 adult subjects, 18-40 years of age. Two fixed laser lines (iCAT® , Imaging Sciences International, Hatfield, PA), oriented horizontally and vertically, were used as a reference to record NHP after a patient was asked to look into their own eyes in a mirror and assume a stable position after a series of oscillations. The patient's NHP was recorded using semi-permanent markers (Sharpie®, Newell Rubbermaid Office Products, Oak Brook, IL) placed on four points, coincident within the laser lines, on the head for registration. Using a 3-dimensional camera system (3dMD®, Atlanta, GA), photographs were taken to capture the orientation of the respective points. By superimposing each of the five photographs on stable anatomic surfaces, changes in the position of the markers were recorded and then assessed for parallelism using 3dMDvultus® (3dMD, Atlanta GA) and Dolphin Imaging™ (Dolphin Imaging and Management Solutions, Chatsworth, CA) software packages. These systems allowed for quantification of angular differences. One subject was used to verify the reproducibility of the method and angles were calculated ten times at each time point and in all three angles.

Results: A 0.10° deviation or operator error was found. No statistically significant differences were observed between the angular measurements in any plane of reference over time ($p>0.05$). In the sagittal plane, a mean deviation of 1.5 degrees was observed from baseline to the four hour time point, 1.7 degrees was observed at both eight and twenty-four hours and a 1.8 degree difference was observed at one week. In the coronal plane, a mean deviation of 0.5 degrees was observed at four and eight hours, 0.55 degrees at twenty-four hours, and 0.73 degrees at one week. In the frontal plane, a deviation of 1.0 degree was observed at four and eight hours, and 1.3 degrees at both twenty-four hours and one week. A statistically significant difference ($p<0.05$) was observed between the mean deviations of three reference planes ($p<0.05$), with a hierarchy of reproducibility established as Coronal > Frontal > Sagittal.

Conclusions: Within the parameters of this study, Natural Head Position was found to be reproducible within a clinically acceptable range, in the sagittal, coronal and frontal planes of space. The coronal plane was observed to be the most reproducible of the planes, followed by the frontal and finally the sagittal plane.

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I. BACKGROUND AND LITERATURE REVIEW

A. Introduction

Historically, natural head position (NHP) had been recognized by artists and sculptors who attempted to capture the essence of the individuals they were portraying as they accurately tried to replicate the face. As more emphasis was placed on the evolutionary development of human beings, anthropologists began to study the cranium in the subject's natural head position. In order to standardize the position of the skull in space and compare individuals, a craniometer was invented by Teodor Kocher (Schueltke, 2009) to standardize measurement of the cranium. The craniometer was used to compare cranial morphology of individual specimens and races for anthropometric analysis utilizing a standardized head positioning technique that simulated NHP.

Contemporary orthodontic diagnosis is based on a comprehensive evaluation of facial and dental esthetics. Subsequent orthodontic treatment planning is directed toward positioning skeletal and dental structures in the most ideal position to support optimal facial esthetic, dental function, and stability the hallmarks of orthodontic treatment. The search for a logical diagnostic and treatment planning point became important in defining a specific structure within the skull which could be used as a common reference point from which to measure and compare individuals. The majority of these norms were reference planes that were traditionally used for anthropometric studies of dried skulls, the conventional being Frankfort Horizontal. It was agreed upon in the “Frankfort Agreement” of 1884 to utilize a point inferior to the orbit as well as the external auditory meatus to achieve a uniform horizontal axis (Garson, 1885). When radiographic imaging of live patients became possible with the development of the Bolton Cephalostat, the logical reference plane to use was Frankfort Horizontal (Broadbent et al., 1975). Since the development of the cephalometric head film technique introduced by Broadbent in the United States and Hofrath in Germany, orthodontists have been guided to develop norms for dental and skeletal positioning. These radiographs allowed orthodontists to evaluate changes in live individuals over time as a result of either growth or active treatment by superimposing successive cephalograms on relatively stable reference planes such as Frankfort Horizontal (external auditory meatus to the lower border of the orbit), or Sella Nasion (spatial midpoint of Sella Turcica to the point of juncture of the Frontal and Nasal bones) (Downs, 1956; Bjoerk, 1951). Frankfort Horizontal was soon followed by numerous other internal reference planes based on radiographic hard tissue landmarks. Some orthodontists, including Downs (1956), who discussed discrepancies between cephalometric facial typing and photographic facial typing, recognized the limitations of Frankfort horizontal in living individuals. Despite his efforts, Frankfort Horizontal continued to be utilized in establishing a horizontal axis for reference and as a diagnostic tool.

Traditionally, natural head position has been utilized as a reference and orientation position for the evaluation of craniofacial morphology with several publications referencing it (Downs, 1956; Bjerin, 1957; Downs, 1952; Arnett, 1999; Andrews, 2001). As stated by Lundstroem, “Natural head position provides the key for meaningful analysis because external cranial reference lines can be used as opposed to intracranial reference lines, which can have considerable biological variation in their inclination" (Lundstroem, 1995). Intracranial reference lines have been described as inconsistent by many researchers (Downs, 1955; Moorrees, 1995) and therefore, utilizing natural head position provides a more consistent method of reference than utilizing conventional anatomic planes. Additionally, natural head position describes a more accurate true-life appearance that can be more consistently replicated for determination of a true vertical reference plane that has been proven to be essential for the esthetic assessment of facial profile, particularly when diagnosing a surgical treatment option (Cooke and Wei, 1988).

B. Internal Reference planes

It is often difficult to choose whether to use internal or external reference planes when reorienting a patient during the course of treatment. Internal reference planes vary among individuals and change constantly as a patient grows (Baumrind, 1976). Whereas, some argue that the use of internal reference planes make orientation of the head simple and reliable (Lundstroem et al, 1995). Emphasis has been historically placed on using osseous internal landmarks for cephalometrics during diagnosis, as opposed to soft tissue or other methods of evaluation. (Andrews, 2008)

Investigators have attempted to establish reference planes that would be suitable for evaluation of treatment and growth changes. These reference planes include:

Frankfort Horizontal: Porion to Orbitale plane

Sella-Nasion: Sella to Nasion plane

Korkhaus: the Nasion-Tragion plane

Broadbent: the Nasion-Bolton plane.

Brodie: the Nasion-Sella turcica plane (Bjerin, 1957)

Campers: the anterior nasal spine to center of bony external auditory meatus

These planes each have inherent limitations, and therefore the search for a more reliable means of orientation has continued.

Historically, the reference planes utilized to orient the anterior-posterior and transverse positions of the head include the external auditory meati, interocular line, interpupillary line, orbits, and medial canthi (Moorrees, 1958; Feuer, 1974). It is often difficult to locate many of these anatomical landmarks and to determine a relationship of the patient's natural head position to these reference planes. There are errors of identification between points and among clinicians. In Baumrind's study (1971), five 1st year graduate students were given sixteen points to locate on 122 cephalometric radiographs. The best estimate/fit for the landmark oriented to the Sella-Nasion line of each point was placed on a scattergram. The degree of deviation between the students varied according to the specific landmark, with Gonion deviating by 5.21mm, followed by Point B (1.97mm) and Orbitale (1.91mm).

Nasion, the anterior reference for establishment of the Sella-Nasion plane, deviated by 1.46 mm.

Current cephalometric technique relies on internal landmarks for much of the diagnosis and treatment planning of orthodontic patients. Downs (1955), Tweed (1946), Steiner (1960), Ricketts (1981), and McNamara (1974) have created analyses based on internal reference points. Downs, Tweed, and McNamara created analyses based on Frankfort Horizontal, whereas Steiner used Sella-Nasion (SN). Using a constructed anterior reference plane to quantify measurements for optimal facial esthetics, such as in the McNamara analysis, has been advocated; however, since it is a constructed perpendicular to Frankfort Horizontal it can suffer from landmark identification errors as well as deviations for the patient’s true horizontal. Several studies have assessed the reliability of these head film measurements and have found that not all measurements can be reproduced due to variation in biology and difficulty in finding individual landmarks (Moorees, 1995; Baumrind, 1971). Growth also has different patterns dependent on which facial type a patient possesses and therefore osseous changes may be present and difficult to replicate (Proffit, 2000).

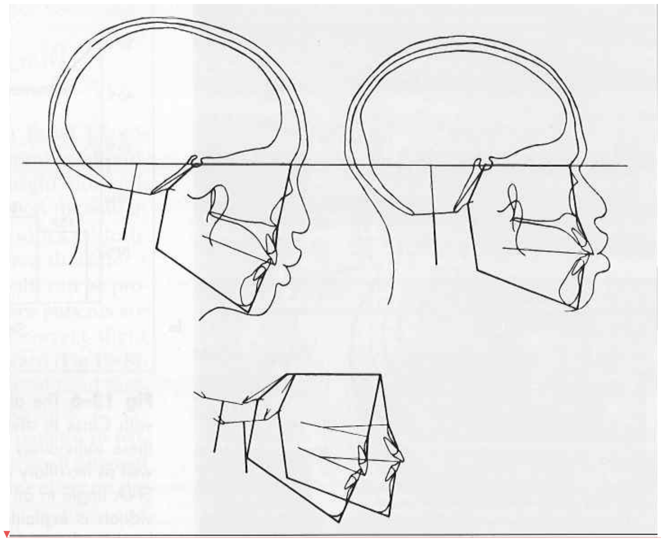
Natural head position has been used in the study of craniofacial growth and treatment of orthodontic patients since studies began to support its reproducibility, with typical variation measuring between 1.5-2 degrees (Lundstroem et al, 1995; Moorrees, 1958; Cooke, 1990; Peng, 1999; Vig, 1980). Since the 1950s, its stability and reproducibility have been investigated in depth by a variety of investigators; however, the majority of clinicians are still taught to use internal reference planes for most cephalometric studies.

1. Sella-Nasion

Sella-Nasion, SN, described by Broadbent (1931), has been found to be biologically reliable in representing anatomic positions of the anterior cranial base; however, it has been found to have a large variation in reproducibility when compared to true horizontal. Bjern (1957) studied the deviation of SN in comparison to a true horizontal based on NHP and found that there was an average deviation of 4.3 degrees with a standard deviation of 3.99 degrees. In the current literature, the mean standard deviations of the SN plane have ranged from 2 to 9 degrees of deviation as compared to deviation in true horizontal (Madsen, 2008).

In a study by Bjork (1951), two Bantu subjects with similar facial profiles (Figure 1), but who differed in low and high inclination of the Sella-Nasion lines were presented. Although there was much variation in cranial base inclination, the two individuals demonstrated similar degrees of prognathism when using natural head position as a reference. This demonstrated that basing measurements from SN can lead to possible inappropriate diagnosis and treatment planning.

Figure 1: Changes in Cranial Base Inclination



(Jacobson, Alexander. Radiographic Cephalometry: from basics to videoimaging. Quintessence Publishing Co, Inc. Chicago, 1995.)

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2. Frankfort Horizontal

Bjern (1957) found that Frankfort Horizontal also deviated from a true horizontal based on NHP by 1.8 degrees with a standard deviation of 4.6 degrees when they investigated 35 subjects who were standing and sitting. Lundstroem et al. (1995) described that Frankfort Horizontal displayed large variability between 1 and 5 degrees in relation to true horizontal. (Downs, 1956, Lundstroem, 1995; Moorrees, 1958; Cooke, 1990; Peng, 1999; Vig, 1980) Ferrario, et al (1994) demonstrated that when an individual is standing, the angle between Frankfort Horizontal and true horizontal deviated on average of 13 degrees; whereas, when in the sitting position only a 5 degree deviation from true horizontal was demonstrated (Ferrario, 1994).

Additionally, reference planes such as Sella-Nasion or Frankfort Horizontal, which include the external auditory meatus or any part of the eyes/orbits have flaws due to the difficulty in locating these landmarks and the possibility of abnormal rotations of the head (Brode, 1971; Jacobsen, 1975; Madsen, 2008; Cuccia, 2009). Downs (1955) suggested that using Frankfort Horizontal for patients with low set ears would result in a patient looking towards the floor, which would distort his/her natural position if it were relied upon to be the horizontal reference and could lead to unrealistic treatment goals. Clinically, detrimental effects could occur if a patient were treatment planned as if Frankfort Horizontal was parallel to the floor and it deviated from that position. A patient may be diagnosed as being retrognathic as opposed to having a straight facial profile which may influence the treatment plan for the patient, and may even include a surgical treatment option when one was not indicated (Downs, 1955). Arnett (1993) suggested that, since patients do not walk around with Frankfort Horizontal parallel to the floor and that natural head position should be considered when diagnosing a patient.

Lundstroem, et al (1995) also stated that Frankfort Horizontal was an inferior reference plane to even Sella-Nasion and can be constructed with less reliability due to the difficulty in locating Porion (Po). These reference structures make analyses based upon them misleading with serious implications for orthodontic and orthognathic surgical treatment plans. Many of these problems can be avoided by using natural head position and relating measurements to the true horizontal, not to arbitrarily assigned intracranial hard tissue landmarks, which also require a radiograph (Lundstroem et al, 1995; Arnett, 1993).

C. Natural Head Position

The description of natural head position has also been an area of debate in orthodontics over the past fifty years, with several investigators advocating its use, with a variety of methods utilized to orient the face (Downs, 1956; Bjerin, 1957). As a result, there are numerous descriptions of ways in which to orient the head in NHP. Natural head position was first investigated in 1862 by Broca, who defined it as the position “when a man is standing and his visual axis is horizontal…” (Broca, 1862). Moorees defined it further as “a standardized and reproducible orientation of the head in space when one is focusing on a distant point at eye level,” eg. sitting on the beach watching a sunset, (1995).

Natural head position was first introduced into orthodontics by Downs (1955) and it was subsequently refined and used by Bjern (1957). Moorrees and Kean (1958) further defined natural head position, capturing it while the subject was in the walking position, and termed it natural head posture or “orthoposition”; the first step from standing to walking (Moorrees and Kean, 1958). As a result of his research on the subject, Moorrees proposed not utilizing ear posts when positioning the patient for cephalometric radiographs, which he believed caused an appearance of asymmetry or altered the subjects’ natural head posture.

Solow and Tallgren (1971) described the typical method for registering natural head position, in which 120 subjects were asked to stand in an “ortho-position” and look into their own eyes in the mirror after a period of oscillations, raising and lowering the head multiple times, with decreasing amplitude until a comfortable position was reached. The mirror position was compared to the “self-balance position” where the subject has their own feeling of natural head balance or comfort. They found that the self balance position was less reliable (Standard deviation=2.48 degrees) than the mirror guided position (standard deviation=1.43 degrees).

Feuer (1974) defined natural head position as the “usual, balanced position of the head which is adopted for viewing the horizon or an object at eye level.” He determined that natural head position was useful when reconstructing the face in art, forensics, orthodontic diagnosis and treatment planning for surgical management.

In two studies, Cooke and Wei (1988) (1990) defined natural head position as “the natural, physiologic position of the head that is assumed when a relaxed subject looks at a distant reference point.” They looked at the clinical reproducibility of natural head posture utilizing ear posts, mirror, gender, and time. Establishing their definition of natural head posture as the previously described “ortho-position,” taken as an individual takes his/her first step as he/she begins to walk. In their study 217 Chinese children were cephalometrically radiographed in that position and the results showed that natural head position was highly reproducible.

Cooke et al. (1990) further investigated natural head posture. They described natural head posture as being “a less variable reference plane than conventional cephalometric reference planes.” They also concluded that natural head posture was more reproducible and less variable than intracranial reference planes with respect to the vertical. In their study, 618 Chinese children were cephalometricaly radiographed in the “ortho-position.” Only a mirror was used as an eye reference while the patients were standing. The results showed that again natural head position was highly reproducible with the error ranging from 1.88 degrees after 4-8 minutes to 3.04 degrees at 5 years (Cooke et al., 1990).

Natural head position has also been compared with natural head orientation which is defined as the head orientation of the subject based on the perception of the clinician, as an individual is focusing on a distant point at eye level. It is also known as natural head estimation. Moorrees and Kean (1958) were the first to utilize natural head orientation to correct the head position of those who were tense. Lundstroem and Lundstroem (1995) defined natural head position as “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” (Lundstroem, 1995). This technique was later described as natural head orientation, where the “unnatural” natural head positions could be corrected by the clinician. Natural head orientation has been found to be reproducible when a subject is focusing on a distant point at eye level and therefore the visual axis is horizontal. By orienting a subject in natural head position, extra-cranial reference lines, such as true vertical and true horizontal, can be utilized as a reference to determine that a patient is in the same position (Lundstroem and Lundstroem, 1995).

TABLE 1: Definitions of Head Position

Definitions of Head Position

Natural Head Position	Also known as Registered Natural Head position. A standardized and reproducible orientation of the head when the subject is focusing on a distant point at eye level and the visual axis is horizontal*
Natural Head Posture	Also known as "ortho-position" when a subject is taking the first step from standing to a walking position **
Natural Head Orientation	Also known as “estimation,” that position perceived by the clinician, as the natural head position when the subject is focusing at a distant point***

*Jacobsen (1995)
**Solow and Tallgren (1976)
*** Lundstroem and Lundstroem (1995)

D. Natural Head Positioning techniques

Registration of natural head position has been documented in the anterior-posterior direction in four distinct ways within the last fifty years (Lundstroem and Lundstroem, 1995). First, lateral head radiographs were taken in the sitting or standing positions. Second, lateral photographs were taken sitting or standing in natural head position. (Solow, 1971) Third, subjective estimation was used to orient a head in a natural head position (Lundstroem and Lundstroem, 1995) (Andrews, 2000). In this method, conventional cephalograms and lateral photographs were taken and then rotated to their natural position by an experienced specialist. And fourth, a combination of radiographic registration and subjective estimation was used to correct gross errors known with the registered natural head position (Lundstroem and Lundstroem, 1995). In this method, a plumb line or true vertical was used as a registration point in the radiographs and photographs.

Lundstroem and Lundstroem (1995) defined the natural head orientation of the individual as the adjustment of the patient's natural head position by the experienced practitioner. They observed the reliability of the Natural head orientation using profile photographs of 27 orthodontic patients who were instructed to stand relaxed in front of a mirror and look at their reflection. Each of the four assessors positioned the profile of the subject into a natural head "orientation." A line was marked on a cephalogram from soft tissue nasion and soft tissue pogonion on a white piece of paper. The procedure was repeated three weeks later. The mean differences in natural head orientation for the three week period varied between 0.1 and 2.9 degrees. Angles between points were measured from the two occasions and the results showed a high correlation (r=0.82-0.96) between assessors for deviations from natural head position in estimating natural head orientation. There was also a high correlation between the two photographic registrations (r=0.9). Lundstroem and Lundstroem found a 1.4 degree difference between the estimated and registered natural head positions. They concluded that an experienced clinician is able to reproducibly adjust natural head orientation to correct for errors that are perceived to be unnatural by the practitioner. It was concluded after comparing the estimated natural head position and the registered natural head position and seeing a strong correlation that both techniques can be used with similar reproducibility. Lundstroem and Lundstroem found a 1.4 degree difference between the estimated and registered natural head positions.

Jiang and Xu (2007) found that there was a strong correlation between both registered natural head position, where a patient naturally oriented their head prior to practitioner adjustment, and estimated natural head position. They also suggested that utilizing a mirror for orientation of registered natural head position is crucial for validity and accuracy in the use of natural head position.

Natural head position registrations have been calculated in the anterior-posterior direction with a 1.5-2.5 degree differential when measured at various time points (Cooke, 1988; Moorrees, 1958). Cooke and Wei measured a 1.9 degree of method error while using a mirror for 618 Chinese children at age 12 years. When the procedure was repeated 3-6 months later a 2.4 degree of error was found (Cooke, 1988). These deviations represent small differences when compared to the large variations of cranial anatomy when using intracranial reference lines, such as Frankfort Horizontal or Sella-Nasion.

Fifteen years later, twenty adults in Hong Kong, who were initially irradiated at age 12 years, were followed and had repeated cephalgrams. The original subjects were re-evaluated in natural head position an 2.2 degree method of error was found (Peng and Cooke, 1999).

Usumez and Orhan (2001) used two inclinometers, tilt sensors, attached to a pair of eyeglass frames. One inclinometer recorded pitch (sagittal plane) and the other recorded roll (frontal plane). Three cephalgrams were obtained, the first two with eyeglasses and the third without the eyeglasses. The technique was found to be highly reproducible with only 0.6 and 0.7 degrees of error.

E. Soft tissue reference planes utilizing natural head position as a basis

Historically, there have been predominately four soft tissue analyses developed utilizing natural head position for patient evaluation (Holdaway, 1983). The four analyses are Ricketts's "E-line" (Ricketts, 1981), Steiner's "S-shaped curve", Holdaway's "H-angle", and Merrifield's "Z-angle." All four of these analyses focus on the position of the lips. Many of these analyses were based specifically on Caucasian male norms, and therefore are only pertinent for a handful of patients. Recently, Proffit has described a new approach to treatment planning based on soft tissue analysis. He states that "esthetic concerns are paramount" for orthodontic treatment planning and should assessed by way of evaluation of the patient in natural head position. (Proffit, 2000)

Arnett and Bergman

The Soft tissue Cephalometric Analysis was described by Arnett and Bergman (1999) to determine facial balance and harmony for treatment planning and diagnosis. They described nineteen facial keys necessary in orthodontic diagnoses and treatment planning and based assessment of these on reference planes established with patients in natural head position. They recognized that tooth movement could negatively affect facial esthetics if used improperly. They described their analysis as an adjunctive treatment planning tool to differentiate between facial and dental keys to proper occlusion.

Andrews

Andrews et al (2000) developed the “Six Elements to Orofacial Harmony”. He advocated using his Element II Analysis with natural head orientation for treatment planning, since “it has been demonstrated that internal landmarks were not relevant clinically and do not always correlate with pleasing facial features” (Baumrind, 1971) Andrews stated that external reference planes such as true vertical lines (TVL) and true horizontal lines (THL) can be utilized, as opposed to internal reference planes, when assessing growth changes over time or differences between individuals. Additionally, he states that natural head position and orientation are useful for photographic and soft tissue profile analysis.

Extra-cranial landmarks may be better suited for initial diagnosis and treatment planning based on soft-tissue results and demonstrating change/progress of a growing patient undergoing significant remodeling of internal hard tissue structures. Since the soft tissue does not stop growing even after growth ceases, soft tissue planes based on anatomic structures again have limitations (Proffit, 2000).

F. Biologic Considerations to Natural Head Positioning

Natural head position is dynamic and varies depending on biologic, physiologic and environmental changes. The use of Natural head position for establishment of reference planes relies on the subject's ability to place he/her head in the same position consistently. Interestingly, the biology of what causes an individual to place his/her head in a specific orientation has been studied well, using a variety of techniques (Brodal, 1972).

One technique uses a visual cue such as a mirror to help the patient orient his/her head while another asks them to find a "self-balanced" reference position. It has been demonstrated that if a patient is required to look into his/her own eyes with the aid of a mirror, an orientation can be established in a transverse dimension. (Downs, 1956; Lundstroem, 1995) Mirror orientation as a means to attain natural head position with the patient looking into their own eyes during the registration is the standard (Bjerin, 1957; Cooke, 1988). According to Listing's Law, eyes are capable of moving along three axes in response to vestibular stimulation. (Kunin, 2007) Head positions, however, do not follow Listing's Law. Fjellvang and Solow (1986) investigated 30 blind individuals from birth and showed that the blind individuals demonstrated more variation in head posture than the controls. The blind individuals tilted their heads 4.3 degrees more toward the floor.

Alternatively, reports in otolaryngology state that damage to vestibular hair cells can cause postural instability and chronic disequilibrium. If the damage is repaired or the semicircular canals are plugged, the vestibulo-ocular reflex for head rotation around the axis of rotation in any of the 3-dimensions of space is restored, thus allowing an individual to replicate his/her normal head position (Santina, 2010). Positioning can involve proprioception from internal ear, eye, muscles, bones and tendons. Physiologic, psychologic, and pathologic factors can also influence a subject's natural head position (Lundstroem, 1981).

It has also been proposed that there is an influence from the cervical column to a patient's head orientation. These factors include visual and vestibular systems, muscular and articular neck proprioceptors, hyoid bone position, masticatory system and neuromuscular activity (Brodal, 1972). It has been proposed that abnormal positioning of the head has become more common due to the increased bad posture from computer use, video-gaming, carrying heavy backpacks, and possible trauma from car accidents (Cuccia, 2009). Much research has also been completed relating cranio-cervical posture to temporomandibular disorders, neck pain, headache, dentofacial structures, mandibular length, mandibular position, mandibular divergency and overjet (Cuccia, 2009).

Achilleos (2000) found that natural head position changes post-orthognathic surgery, particularly with a BSSO setback. The nasopharyngeal airway size is reduced and as a result there is an increase in head extension when compared with pre-surgical head orientation. Phillips, et al. (1991) saw a significant increase in head flexion with natural head position after a combination of maxillary impaction and mandibular advancement within the first year post-operatively. By one year post-surgery, natural head position was the same as it was pre-operatively.

Vig et al. (2004) described three experiments to analyze cranial posture. Total nasal obstruction, visual feedback deprivation, and a combination of the two were studied relative to a true vertical reference plane. It was found that total nasal obstruction resulted in an extended neck position. They concluded that there is an adaptation of head posture to respiratory needs, which may play a role in growth and dental morphology.

G. Photography

Although the benefits of internal land marking are important in the diagnosis of skeletal anatomy and relationships of the teeth and jaws, there are limitations regarding the use of radiographic cephalometry in craniofacial research, especially as reducing exposure to radiation is becoming more important. Taking 2-D photographs have provided clinicians with increased diagnostic information. Photography has become a crucial piece in diagnosis and treatment planning. These photographs are needed to complete the orthodontic diagnosis to adequately evaluate the soft tissues.

Lundstroem and Lundstroem (1995) first described combining a 2-dimensional photographic technique with natural head position and then transferred natural head position to a lateral cephalometric film. 52 subjects were asked to look into a mirror and a plumb line was used to display true vertical. A horizontal line was drawn perpendicular to the vertical plumb line and transferred from the photograph to the corresponding lateral head film. Lundstroem and Lundstroem found that using natural head position from photographs could be used to improve orthodontic diagnosis and treatment planning. This combination of angular and linear measurements allowed the clinician to quantify changes in position of the head.

Two-dimensional photography has also been utilized by several investigators (Ferrario (1994); Pereira (2010); Xia (2009)) to quantify natural head position. Unfortunately, only one plane of space can be examined per photograph; therefore, multiple photographs are required to gain information in more than one dimension.

Efforts to improve on the information gained from 2-dimensional photography led to the use of stereophotogrammetry and video-imaging. These techniques were utilized in the past as an attempt to evaluate soft tissue views, utilizing a grid. In fact, the earliest use of stereophotogrammetry was reported by Thalmann-Degan in 1944 who researched the affect of orthodontic treatment on facial morphology (Hajeer, 1944). Continued improvements have been made and stereophotogrammetry has allowed for quantification of patients' soft tissue structures. Consequently, facial analysis continues to evolve.

The orthodontic profession has entered a pivotal period in which biotechnology continues to be advanced from 2 to 3-dimensional imaging and the limitations of 2-dimensional usage have been well noted in the literature (Franklin, 1952). Improvements in imaging over the past decade have led to the use of 3-dimensional photography as a means of soft tissue analysis rather than using traditional two-dimensional photography (Bister, 2002). Todd et al. (2005) investigated the differences between 3D and 2D images. He found that 3-Dimensional images can cue providers to certain facial proportions and features which could improve facial esthetics. This finding is represented well in the work of Incrapera (2010), who found that the facial three-dimensional image capture allowed for more information to be gained than a two-dimensional image.

3-D imaging has added a new dimension to the orthodontic profession. It has provided a more-ideal means to measure angles, distances, and proportions that can be utilized for improved soft tissue norms to accompany the long-established cephalometric norms. 3-D imaging has also been used by plastic surgeons and orthodontists to determine growth patterns and evaluate the affect of growth deformities on facial appearances (How, 2006). Therefore, applications for 3D imaging continue to increase in number, providing an enhanced focus on soft-tissue morphology and more complete method to address psychosocial issues influenced by appearance.

H. Recording natural head position 3-dimensionally

Much of the emphasis on natural head position in the past, as it pertains to orthodontic treatment, has focused on the anterior-posterior dimension, with little known regarding reproducibility in the transverse or coronal planes. However, with the advent of 3-dimensional photography, such as 3dMD™ and use of specialized software, superimposition of certain areas of the face can be superimposed to determine the reproducibility of natural head position in all three planes of space. This can be accomplished without specialized techniques that are time consuming and cumbersome.

Several methods to record natural head position have been suggested in the literature to record natural head position in 3-dimensions, including registration jigs, eyeglasses, and 3-dimensional laser scanners. Schatz et al. (2010) suggested using a gyroscope assembly including a face-bow transfer and bite jig. Xia et al. (2009) used natural head position to orient patients with craniofacial and developmental deformities, since common cephalometric landmarks may be missing and planes cannot be used to orient these individuals. Xia et al. utilized two methods. First, a 3-dimensional laser surface scanner was used to capture the soft tissue and then was matched to a composite skull model. The second technique used a digital gyroscope attached to a face bow to capture the roll, pitch, yaw angulations of the head. This information was then used to reorient the composite skull model to the patient's natural head position and then used to create stereolithographic skull models.

Soncul and Bamber (2000) advocated using a facial laser scanner, head rest, and spirit level in relationship to Frankfort Horizontal, not natural head position, to determine the reproducibility of the head position in 3-dimensions. They found that this technique was highly reproducible.

Koerich de Paula et al. (2012) tested the use of mini sensors as an aid to reproduce natural head position. Twenty individuals were studied with four 3dMD photographs. The first was taken in an unrestrained head position, the photograph was then repeated. A headset was placed with tracking sensors in the third photograph and then repeated. They found that even with sensors, roll, pitch, and yaw were controlled independently of the sensors. There were differences in head position which required additional registration procedures of the 3-dimensional photographs.

It has been demonstrated that the brow and the infraorbital regions are the most stable soft-tissue areas of the face. These landmarks are minimally influenced by hydration, are the thinnest areas to the skull, and have minimal distortion in animation or repose. Therefore, use of these anatomical areas has been shown to be the most appropriate for superimposition of 3-dimensional photographs (Incrapera et al, 2010).

Due to the limitations in conventional methodology, previous studies have not looked at natural head position in three planes of space, although many have studied the anterior-posterior position. Therefore, the present study adds to the discussion of Natural Head Position in 3 dimensions and seeks to assess its suitability for diagnosis, treatment planning, and evaluation of growth and treatment effects in all planes of space.

I. OBJECTIVES

A. Overall Objective

The goal of this study was to determine if natural head position is reproducible over time in the sagittal, coronal and frontal planes of space

B. Specific Hypothesis

It is hypothesized that individuals are able to position their heads in the same 3-dimensional orientation at various time intervals, with a clinically insignificant range of difference.

C. Null Hypotheses

1. There is no difference in natural head position, measured in 3 planes of space at various time points.
2. There is no difference between the mean deviations measured in the individual planes of space over time.

II. MATERIALS AND METHODS

A. Subjects

Twenty-eight adult active duty military personnel, aged 18-50 years of age, were invited to participate in this longitudinal study conducted at the 3-D imaging department at the Tri-Service Orthodontic Program, Lackland AFB, San Antonio, TX. Approval for this study was obtained from the Wilford Hall Ambulatory Surgical Center IRB. In addition, informed consent, HIPAA authorization and photographic release documents were obtained from all study participants.

B. Data Capture Technique

A studio was created to facilitate standardized light conditions and support all necessary equipment. The subjects were asked to sit in an iCAT® (Imaging Sciences International, Hatfield, PA) 3-D CBCT imaging system machine (see Figure 2). No imaging scans were performed on the subjects. The iCAT® was only used as a reference to place points on the face using the machine's laser light beam. The laser beam was FDA-approved as being minimal risk, equivalent to the lasers that are typically used in a CT scanner, in which there is no heat transfer to the body to cause harm. Adjustments to seating heights were made to assist the subjects in achieving proper placement of the laser lines on the face.

The patients were asked to close their eyes, tilt their head forward and backwards with decreasing amplitude until they came to a comfortable position and a natural head balance was reached. Once they were comfortable they were asked to open their eyes, look directly into their eyes in a mirror, which was mounted on a door directly in front of them, and finalize their head position.

Figure 2-Subject sitting in i-CAT® machine

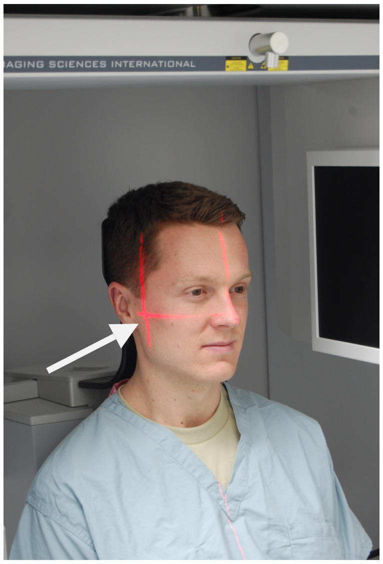


Figure 3-Laser lines in true vertical and horizontal axis

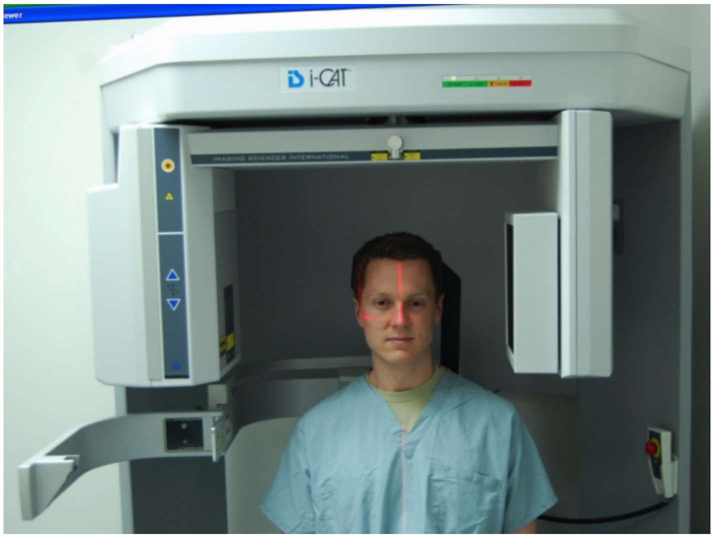


Figure 4- Front view of subject sitting in the i-CAT® machine

Using semi-permanent Sharpie ® (Newell Rubbermaid Office Products, Oak Brook, IL) markers, four ink dots were placed along the laser light beams (Figure 3, 4)—two dots in the vertical plane along the forehead and on the mid face including the tip of nose; two dots were then placed in the horizontal plane, on the pre-auricular and infrazygomatic areas (Figure 5, 6). After the reference points were placed on the subject's face, the subject was escorted to the photographic area for facial imaging with the 3dMD® stereo-photographic imaging system (Figure 7, 8). If it was perceived that the subjects moved during the photograph, the photograph was retaken. Photographs were taken at five time points, an initial photograph, then four hours, eight hours, 24 hours, and one week later. Each time the patient came in, the process was repeated; placing dots to register natural head position, followed by a 3-dimensional photograph. The dots differed in color and corresponded to a specific time point. Black was chosen for time point initial, red was used for time point four hours, followed by purple at time point eight hours, blue for time point 24-hours, and green for time point one week (Table 2).

Table 2- Dot colors at each time point

	Dot colors
Initial	**Black**
4 hours	**Red**
8 hours	**Purple**
24 hours	**Blue**
1 week	**Green**

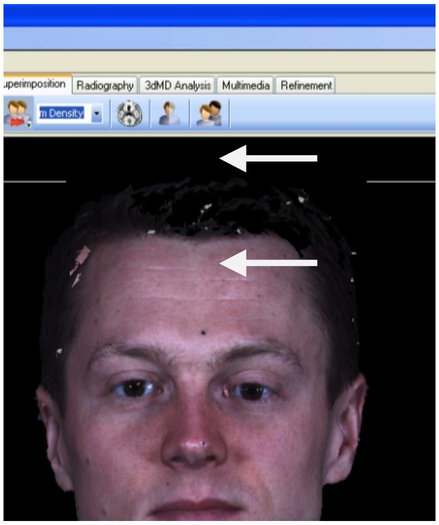


Figure 5– Dot placement in Frontal view

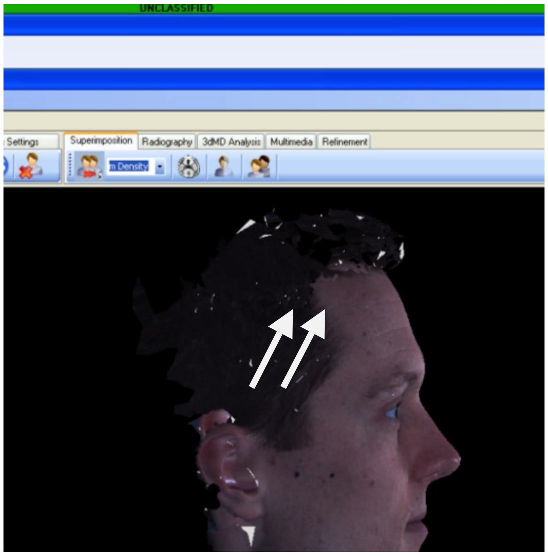


Figure 6– Dot placement in A-P view

Figure 7- 3dMD® photography unit

Figure 8- 2 camera pods with 4 cameras per pod

C. Three-Dimensional Imaging System

3D surface images were obtained using the 3dMD Face® multi-camera system (3dMD, Atlanta, GA). The 3dMD® stereophotography unit uses four cameras positioned on either side of the subject. The 3dMD® covers a 180-degree face capture (ear-to-ear). The camera has a capture speed of only 1.5 milliseconds at highest resolution and is reported to have a clinical accuracy of 1.5% of total observed variance. One continuous photograph was produced from the multiple stereo camera viewpoints.

D. Data Processing of the Whole Face

All photographic images were exported as .tbs files and imported into 3dMDvultus® (3dMD, Atlanta GA) imaging software in which polygon meshes, accurate freeform, non-uniform rationale B-spline surfaces, and geometrically accurate solid models were created. Utilizing the Vultus® software program, the initial images (T1) were oriented using the axial and sagittal reference planes (Figure 9, 10). The Coronal plane was established as the resultant perpendicular to both axial and sagittal planes.

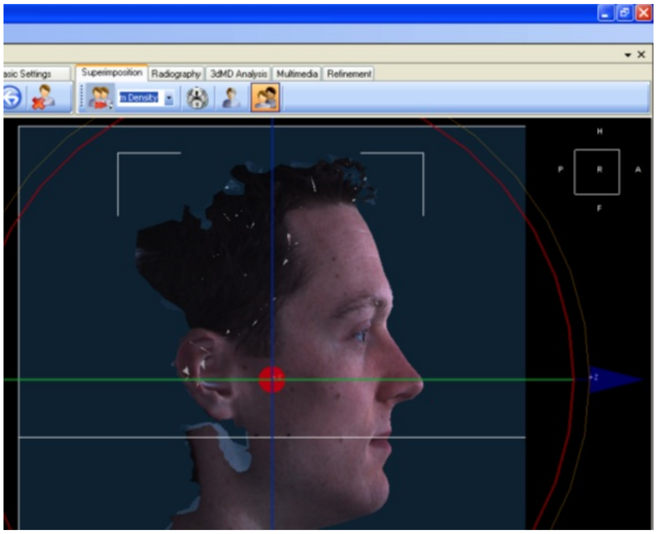


Figure 9- A-P orientation

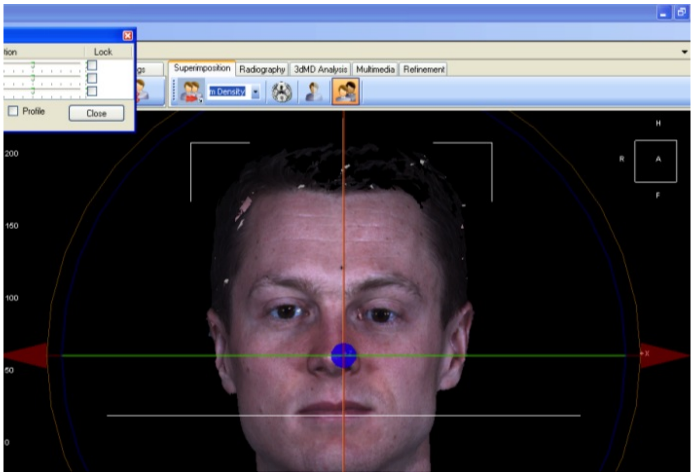


Figure 10- Frontal orientation

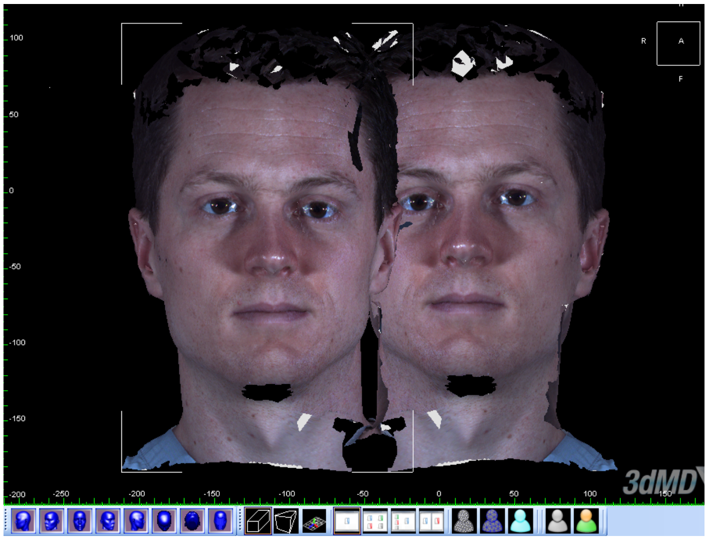


Figure 11- Two photos for superimposition

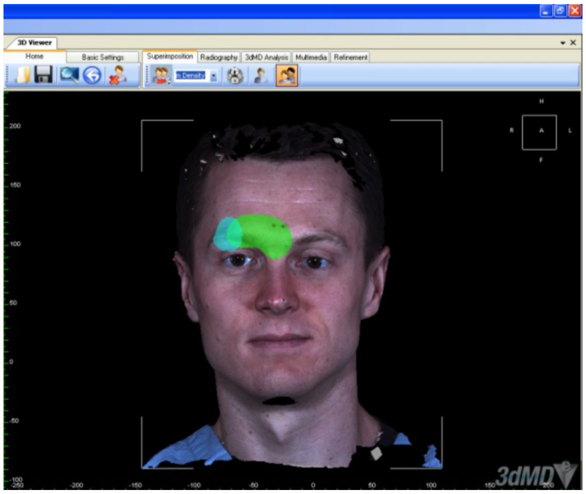


Figure 12- Demonstration of superimposition

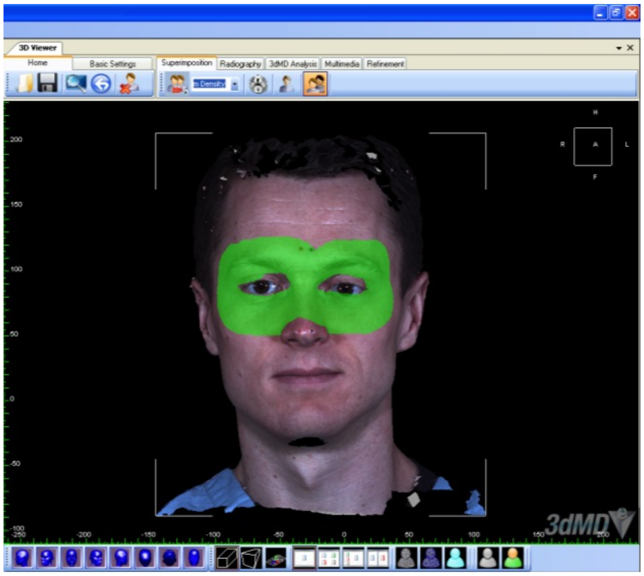


Figure 13- Superimposition mask complete

Individual whole faces of subjects were superimposed over one another to determine changes in all three dimensions of space that occurred between T1, T2, T3, T4, and T5. Using Voltus$_{TM}$ imaging software, a systematic process was utilized by manually aligning the facial photographs on their forehead (brow area) and under their eyes (Figure 11), as described by Incrapera et al.,(2010). The figures were superimposed using the broadest area of the anterior position of the forehead, including soft tissue glabella, soft tissue nasion, and bridge of nose to incorporate a regional fit environment (Figure 12). Each individual time point image was superimposed on T1 using this method; T2 on T1, T 3 on T1, T 4 on T1, T5 on T1. Neon dots were digitally placed over the Sharpie® color dots on the vertical and horizontal positions using the land marking tool in the Vultus® software program (Figure 13, 14).

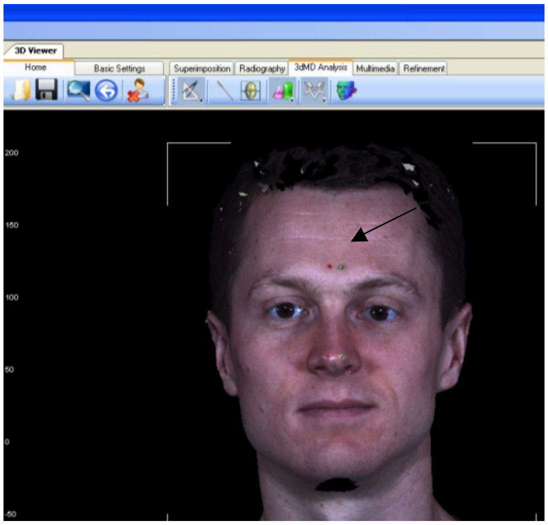


Figure 14- Neon dots placed

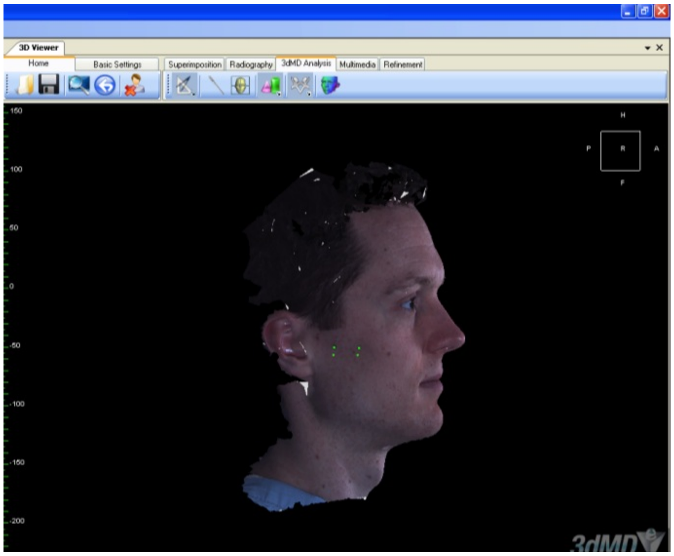


Figure 15- Neon dots in from T1 and T2

The screen was captured in the saggital plane with the four points digitized, two points for each time point. The screen capture was then saved as a .jpeg file and imported into Dolphin™ Imaging software to calculate an angle utilizing the 4-points (Figure 15, 16). Since Voltus® software did not include a tool to allow measurements of angular differences between 2 closely parallel lines, the Dolphin software allowed calculation of the resulting 4-point angles. Each measurement was compared to the initial time point (T1) and recorded for each superimposition.

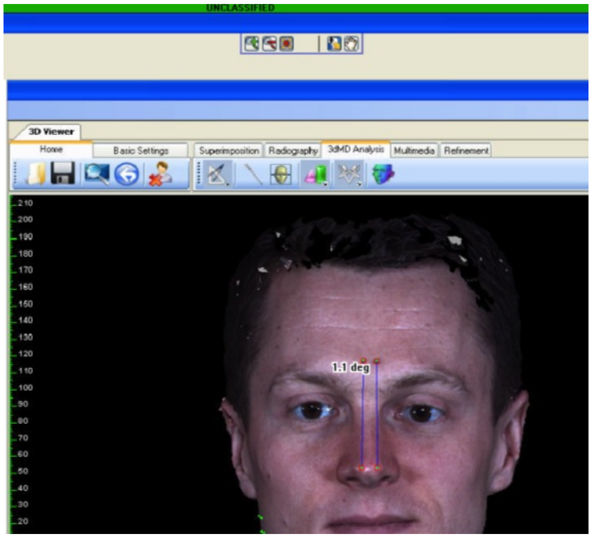


Figure 16- Angle utilizing 4-points calculated within Dolphin Imaging™

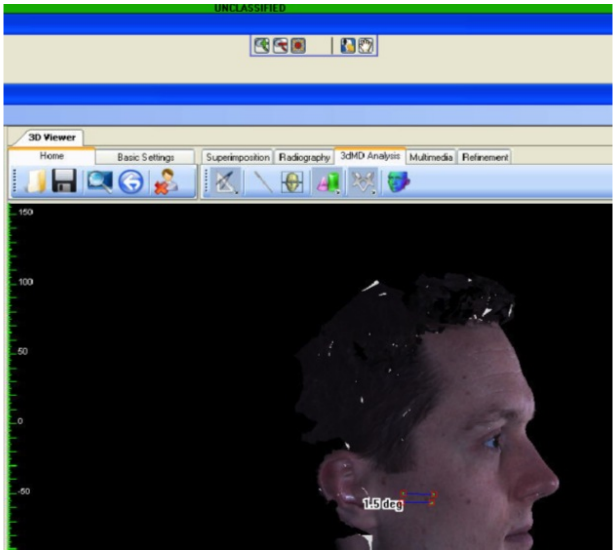


Figure 17- Angle utilizing 4-points in A-P plane

In order to obtain the coronal axis, the axial and saggital planes were locked in place, utilizing the reference plane tool in the Vultus® software and two fiducial markers were set on soft-tissue coronally, perpendicular to the midsagittal plane. The coronal position was then locked to the sagittal and axial planes (Figure 17). Images for time points T2-T5 were also set, locked, and superimposed on the initial time point (T1) for comparison. The coronal position was screen captured with all four points (Figure 18). The photo was again saved and exported as a .jpeg file and downloaded into the Dolphin™ Imaging software to calculate an angle utilizing the 4 points in the coronal plane (Figure 19). The deviations from parallelism to the T1 planes were compared and analyzed by the PI (DW) for the three planes of space.

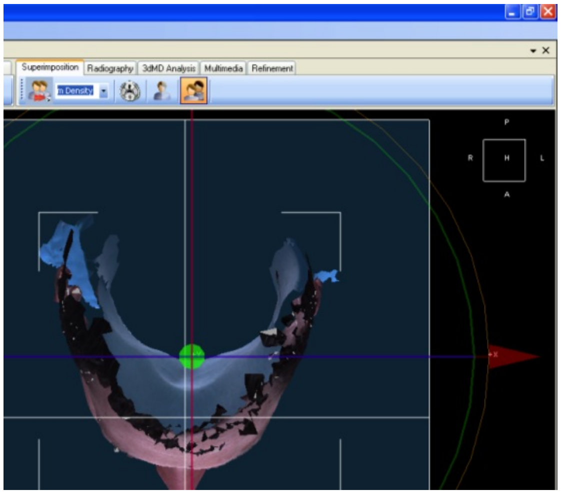


Figure 18- Coronal segmentation

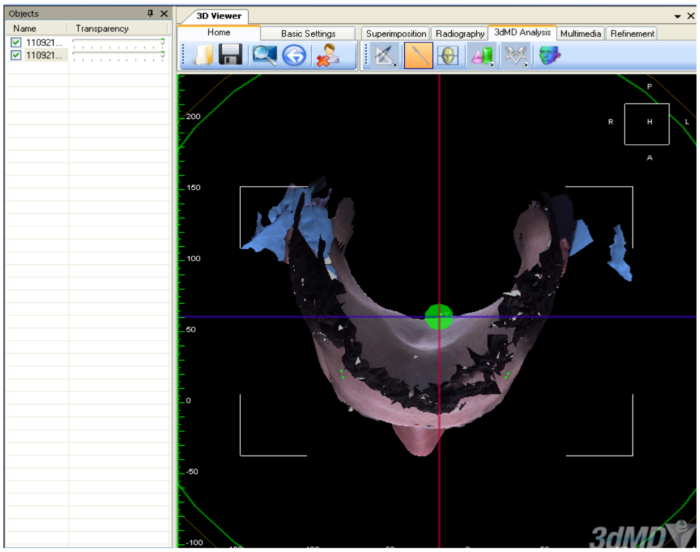


Figure 19- T1 and T2 marked in coronal view

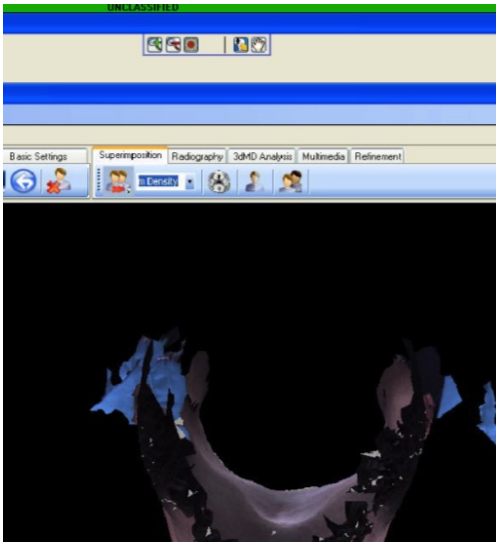


Figure 20- Angle utilizing 4-points on coronal axis

C. Statistical Management of Data

An a *priori* power analysis demonstrated that a sample size of 28 participants with 15 observations per participant (five time points and three planes) provided a statistical power of 99% with a small effect size of 0.25 (approximately 0.52 standard deviation) and an alpha (probability of type I error) equal to 0.05 (p=0.05).

Observation times: The mean time periods from T1 photograph to T2 photograph were initial and 4 hours later, respectively. The mean time periods from T1 photograph to T3 photograph was initial and 8 hours, respectively. T4 photograph was 24 hours from initial and T5 photograph was 1 week from initial. It can be assumed that Natural Head Position registrations at T5 were not influenced by the registration at T1.

One subject was used and five time points were compared on each of the three planes. The angle was repeated ten times and standard deviation calculated.

Means and standard deviations were calculated for each time point and then analyzed and compared statistically. The study design was repeated measure and a parametric analysis was used to analyze the data. The data was also analyzed by using a repeated measure analysis of variance with repeated measures with Bonferroni correction over five time points for three planes.

III. RESULTS

The degree of difference between each individual at various time points was placed on a scatter plot. The points were identified differences of initial and four hours, initial and eight hours, initial and twenty-four hours, and initial and one week (Figures 21, 22, 23). One subject was used and five time points were compared on each of the three planes. The angle was repeated ten times. The reliability was calculated using standard deviation and a 0.10° deviation or operator error was found.

FIGURE 21- A-P Scatter Plot

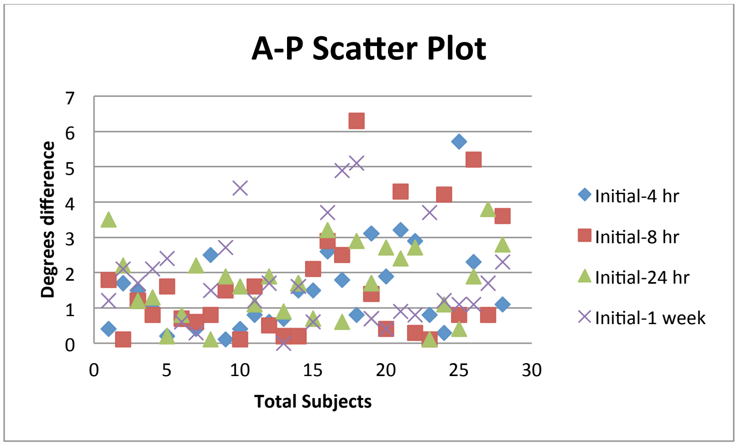


FIGURE 22- Frontal Scatter Plot

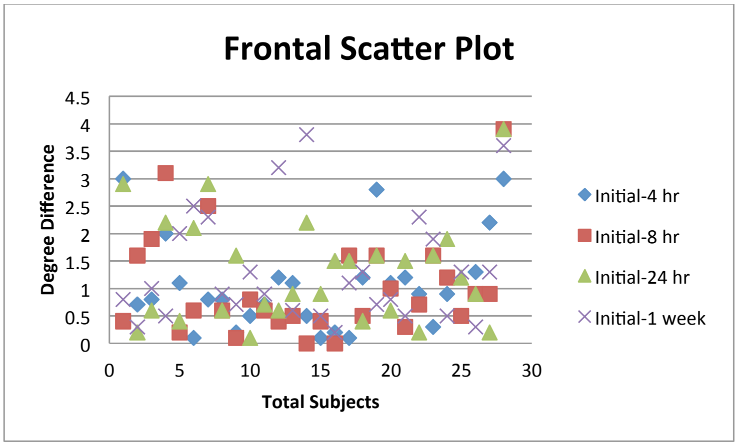
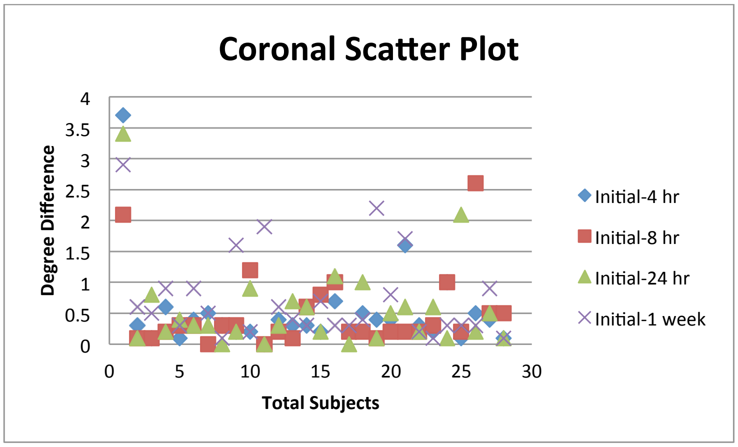


Figure 23- Coronal-Scatter Plot



Means and standard deviations were recorded for each time period and each of the three planes (Table 3). In the Sagittal plane, a mean deviation of 1.48° was found between initial (T1) and the four-hour (T2) time-point. A 1.66° deviation was observed between initial (T1) and eight hours (T3), a 1.70° deviation was observed between initial (T1) and twenty-four hours (T4), and a 1.85° difference was observed at one week (T5). In the Coronal plane, a mean deviation of 0.50° was observed at four hours, 0.49° was observed at eight hours, 0.55° was observed at twenty-four hours, and 0.73° at one week. In the Axial plane, 1.05° of deviation was observed at four hours, 1.01° at eight hours, 1.28° at twenty four hours and 1.33° at one week .

Table 3: Descriptive Statistics

Descriptive Statistics

	Group	Mean Angle (°) Difference	Std. Deviation	N
Initial-4 hr	Sagittal	1.475	1.2376	28
	Axial	1.046	.8417	28
	Coronal	.500	.7029	28
	Total	1.007	1.0250	84
Initial-8 hr	Sagittal	1.664	1.6707	28
	Axial	1.014	.9380	28
	Coronal	.493	.6122	28
	Total	1.057	1.2444	84
Initial-24 hr	Sagittal	1.700	1.0456	28
	Axial	1.282	.9503	28
	Coronal	.554	.7147	28
	Total	1.179	1.0211	84
Initial-1 week	Sagittal	1.846	1.3823	28
	Axial	1.325	1.0065	28
	Coronal	.725	.7053	28
	Total	1.299	1.1513	84

Comparison of means via a repeated measures test was completed, which revealed no statistically significant differences between the measured deviations over time ($p>0.05$). Additionally, pairwise comparisons with Bonferroni correction, of time points revealed no significant differences ($p>0.05$) between T1 - T2, T1 - T3, T1 - T4, and T1 - T5 (Table 4).

Table 4: Time Pairwise Comparisons

Pairwise Comparisons

Measure:Time_period

(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.050	.148	1.000	-.449	.349
	3	-.171	.129	1.000	-.519	.176
	4	-.292	.155	.385	-.712	.129
2	1	.050	.148	1.000	-.349	.449
	3	-.121	.134	1.000	-.483	.240
	4	-.242	.152	.699	-.654	.170
3	1	.171	.129	1.000	-.176	.519
	2	.121	.134	1.000	-.240	.483
	4	-.120	.140	1.000	-.498	.258
4	1	.292	.155	.385	-.129	.712
	2	.242	.152	.699	-.170	.654
	3	.120	.140	1.000	-.258	.498

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Comparison of these means was with an ANOVA with Bonferroni correction revealed a statistically significant difference between all three planes ($p<0.05$) (Table

5). The Coronal plane had less variation than the Frontal plane. The Sagittal plane had the most variation (Figure 20).

Table 5: Pairwise Comparisons

Pairwise Comparisons

Measure:Time_period

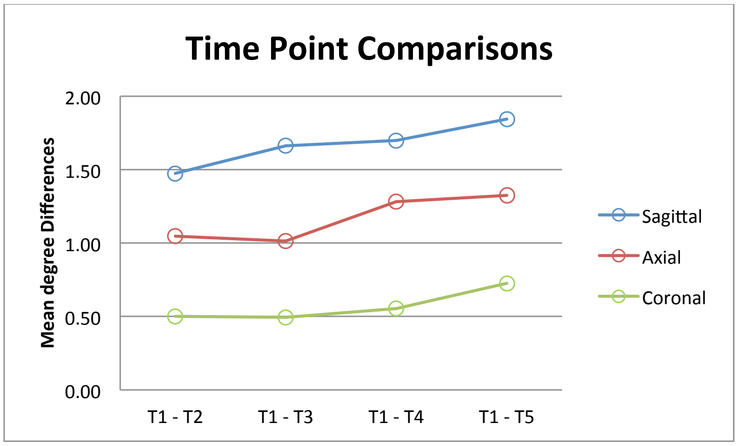
					95% Confidence Interval for Difference[a]	
(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
Sagittal	Axial	.504*	.172	.013	.084	.924
	Coronal	1.104*	.172	.000	.684	1.524
Axial	Sagittal	-.504*	.172	.013	-.924	-.084
	Coronal	.599*	.172	.002	.179	1.019
Coronal	Sagittal	-1.104*	.172	.000	-1.524	-.684
	Axial	-.599*	.172	.002	-1.019	-.179

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Figure 24: Profile Plot



IV. DISCUSSION

The results in this project show that Natural Head Position is reproducible over time in the 3 planes of space. In the population studied, there was no significant difference between the mean Natural Head Position at any of the time points measured when compared to the initial time-point, a finding that is consistent with the published literature pertaining to the Sagittal plane. Natural head position registrations have been measured in the Sagittal plane with 1.5-2.5° of deviation when compared at various time points (Cooke, 1988; Moorrees, 1958). Cooke and Wei (1988) measured a 1.9° method error when using a mirror after 4 to 10 minutes and comparing this value to measurement taken one to two hours later. When the procedure was repeated at 3-6 months, a 2.4° method of error was found. Peng and Cooke (1999) in a longitudinal study radiographed 20 of the original subjects and found a 2.2° method of error after 15 years, compared to a 3° method of error at 5 years. The results of this study are consistent with Cooke and Wei's findings for the short term; however, time points past one week were not included in the present study to compare with their 3-6 month, 5 year, or 15 year results.

In the present study of the Sagittal plane, a trend of increasing deviation was observed from the initial time point to one week, although very slight and not statistically or clinically significant. As noted by previous authors, Moorrees and Kean (1958), subjects may experience occasional tenseness that may result in unnatural tilting of the head. Moorrees and Kean recommended using natural head orientation to correct the head position if the subject's head position is deemed unnatural by the clinician. This was not done in the current study; although it should be considered to improve natural head position in future studies.

The trend of increasing deviation was not observed in the Coronal and Axial planes. Natural head position was again found to be reproducible with even smaller deviations in these two planes. The Coronal plane had less deviation than the Axial plane. The Axial plane was more accurate than the Sagittal, but had more deviation than the coronal. The Sagittal plane had the most deviation of the three planes evaluated.

Biological factors may provide an explanation as to why the Coronal plane had the least deviation, followed by the Axial, and finally the Sagittal plane. The deviation of the Coronal plane may exhibit the least error simply due to the head being centered vertically and positioned on its axis. Using the analogy of a 2-Liter bottle balanced on its top, if you rotate the bottle, positional deviation will occur, but the bottle remains balanced on its central vertical axis. Likewise, when measuring Coronal plane deviations associated with a patient's NHP, the head is balanced by large muscle groups offering only slight flexion or extension across a central vertical axis. As the subject is asked to look directly into their own eyes, the subject has a visual cue that is framed by the obvious protrusions of the brow and the nose which guide repositioning and prevent subtle flexion or extension. Vestibulo-ocular and vestibulo-spinal reflexes as well as inner ear otolithic gravitational responses provide an interface between eye position, head position and muscle interaction that influences the movement and positioning of the head in relation to the spine, and support maintaining visual fixation on objects of interest. If the eyes deviate from a target, the muscle receptors in the eye will result in conjugate contraction and relaxation of the ocular muscles in both eyes, as in the saccade movement of the eye during positioning. The image from the object of interest is brought onto the fovea and the eyes stabilize on their target. Nasal offset occurs if the eyes are not focused directly on the target, which will result in differential retinal input corrected by a change in posture or rotation of the head. Lateral movement of the head in the coronal plane causes lateral spinal flexion, unequal contraction and support of smaller, more easily fatigued muscle groups, and differential firing of the inner ear otolithic organs, the saccule and utricle, that cause dissonance prompting immediate feedback to correct the tilted position, or making it more difficult to maintain that position over time. Biologically speaking, the Coronal axis provides more clues to the subject attempting to duplicate head position and hence is the simplest axis for reliability of position repetition.

As opposed to the six muscles of the eye, as the head moves from side to side (as in Axial plane deviations) or in varying oscillations up and down (as in Sagittal plane deviations), twenty muscles within the neck are triggered to respond (Flint et al., 2010). Maintaining a consistent head position becomes more complicated when the trunk and lower extremities become involved in maintaining the body in balance. Physiologically, there are two reflexes that patients utilize to help stabilize their head. The first is the vestibulocollic reflex, where the muscles of the neck respond to vestibular input. The second reflex, the cervicocollic reflex, governs the response of the neck to stretch receptors. Maintaining positional stability in Sagittal plane requires a combination of positional memory, muscle tone, muscle memory, as well as visual response as a person sits or stands in the same position. Some past researchers have used a visual cue such as a mirror to help a subject orient his/her head, while others have asked them to find a “self-balanced” reference position. It has been demonstrated by a variety of investigators that if a patient is required to look into his/her own eyes with the aid of a mirror, an orientation can be established in a sagittal dimension (Downs, 1956; Lundstroem, 1995). Mirror orientation as a method to attain natural head position with the patient looking into their own eyes during the registration is the standard (Bjerin, 1957; Cooke, 1988). The weight of the head may be a significant factor in the finding that there is more deviation in the Sagittal plane in natural head position, since gravity is working against the individual when the head is not balanced and aligned with the spine. Additionally, patients may be more tolerant of deviation in the Sagittal plane based on daily movements. For instance, individuals typically position their heads downward while working on a computer or reading a newspaper which may lead to habitual, tolerated unbalanced positioning of the head in the Sagittal plane.

Natural head positioning in the Axial plane may rely heavily on inner ear balance from stimulation of the vestibular system, muscle balance and visual input. According to Brodal (1972) the vestibular system plays a significant role in terms of its response to motion and spatial orientation of the head. The vestibular system works with visual stimulation to stabilize an image on the retina as the head moves in space. The ear contains two structures, the utricle and saccule as well as three semicircular canals, all of which are fluid filled. The cilia in the ear become stimulated or polarized by the fluid as the head moves in any direction. The three-coordinate system, made up of the semicircular canals oriented in the sagittal, axial and coronal planes, allows any direction of rotation to be recognized when the discharges from the three canals are combined. Motions provide reflexive coordination of eye movements to maintain visual focus on a subject. The tilt of the head from side to side stimulates movement of hair bundles and the individual would receive input to refocus the eyes opposite to the movement. The tilt of the head from left or right may also be a protective instinct to maintain head center of gravity over the axis of the spine to prevent fatigue or injury from walking around with their head offset from its point of stability. This function is coordinated by the otolithic organs which are gravitationally based and responsive to linear rather than angular acceleration. As an example of this phylogenetically protective mechanism, cradling a phone between your head and your shoulder, may give way to a “kink” in your neck with your neck muscles signaling that the interference should be corrected.

The 3-dimensional technique utilized in this study provides a variety of benefits to observing progress or change for the growing patient. A major advantage in this study is the use of photographs, which don’t require repeated radiation exposure. Since the subject is not exposed to radiation, a sequence of photographs can be taken and superimposed. Using this technique to generate external reference planes based on NHP may be better suited for initial diagnosis and treatment planning; especially, in an effort to provide a soft-tissue focus. One may argue that if an orthodontic patient has mild crowding and a pleasing facial profile, a cephalometric radiographic procedure may not be necessary.

In the non-growing patient, intracranial references, however, may be well suited to show treatment progress or change via superimposition, since S-N or Porion to Orbitale will be relatively stable. Extra-cranial (photographic) orientation via Natural Head Position may be better suited for initial diagnosis and treatment planning based on soft tissue emphasis and may also demonstrate the changes, progress for growing patients which undergo significant remodeling of internal hard tissue structures.

The current study was beneficial in helping to determine if natural head position could be utilized and examined in three planes of space. Although natural head position could have been examined using a 3-dimensional cone beam CT unit, the findings of this study may eliminate the risk of radiation. This study demonstrated that a simplified technique can be used in evaluating three planes, sagittal, axial, and coronal, in natural head position. Not only does it eliminate the need for radiation, but it can be subsequently combined with information gained from 3-dimensional radiography to glean even more information. While a patient is in treatment, the 3-dimensional photograph can be integrated with a CBCT to improve the diagnosis and treatment planning of a patient. For complete diagnosis, the

3dMD® photo could be superimposed on the CBCT data to evaluate underlying skeletal and dental structures concurrently and provide an accurate 3-dimensional digital reconstruction of the patient's craniofacial complex.

This study evaluated the reliability of NHP over a period of one week in an exclusively adult population. A future study would benefit from the addition of subsequent time-points and the inclusion of groups of subjects who are actively growing or undergoing orthodontic treatment to analyze alterations of NHP precipitated by growth or treatment effects.

V. CONCLUSION

Within the parameters of this study, it can be demonstrated that natural head position is reproducible in the three planes of space over time. The three planes were not equally reproducible and demonstrated a statistically significant hierarchy with the Coronal plane demonstrating the least variation over time, followed by the Axial then the Sagittal in order of increasing variability. Additionally, it is suggested that the use of True Vertical, Horizontal and Frontal external reference planes, based on Natural Head Position, would improve the esthetic focus of orthodontic diagnosis and treatment planning, as well as provide reproducible planes of reference for evaluation of facial growth and treatment effects over time.

Appendix A: Raw Data

Table 6- Sagittal Raw Data

Sagittal	Initial-4 hr	Initial-8 hr	Initial-24 hr	Initial-1 week
1	0.4	1.8	3.5	1.2
2	1.7	0.1	2.2	2.1
3	1.5	1.2	1.2	1.7
4	1	0.8	1.3	2.1
5	0.2	1.6	0.2	2.4
6	0.7	0.7	0.8	0.6
7	0.4	0.6	2.2	0.3
8	2.5	0.8	0.1	1.5
9	0.1	1.5	1.9	2.7
10	0.4	0.1	1.6	4.4
11	0.8	1.6	1.1	1.2
12	0.6	0.5	1.9	1.7
13	0.7	0.2	0.9	0
14	1.5	0.2	1.7	1.6
15	1.5	2.1	0.7	0.6
16	2.6	2.9	3.2	3.7
17	1.8	2.5	0.6	4.9
18	0.8	6.3	2.9	5.1
19	3.1	1.4	1.7	0.7
20	1.9	0.4	2.7	0.4
21	3.2	4.3	2.4	0.9
22	2.9	0.3	2.7	0.8
23	0.8	0.1	0.1	3.7
24	0.3	4.2	1.1	1.2
25	5.7	0.8	0.4	1.1
26	2.3	5.2	1.9	1.1
27	0.8	0.8	3.8	1.7
28	1.1	3.6	2.8	2.3
Mean	***1.475***	***1.6642857***	***1.7***	***1.846428571***
STD DEV	***1.23756781***	***1.6707094***	***1.045625809***	***1.382290676***

TABLE 7- AXIAL RAW DATA

Axial	Initial-4 hr	Initial-8 hr	Initial-24 hr	Initial-1 week
1	3	0.4	2.9	0.8
2	0.7	1.6	0.2	0.3
3	0.8	1.9	0.6	1
4	2	3.1	2.2	0.5
5	1.1	0.2	0.4	2
6	0.1	0.6	2.1	2.5
7	0.8	2.5	2.9	2.3
8	0.8	0.6	0.6	0.9
9	0.2	0.1	1.6	0.7
10	0.5	0.8	0.1	1.3
11	0.7	0.6	0.7	0.9
12	1.2	0.4	0.6	3.2
13	1.1	0.5	0.9	0.6
14	0.5	0	2.2	3.8
15	0.1	0.4	0.9	0.5
16	0.2	0	1.5	0.2
17	0.1	1.6	1.5	1.1
18	1.2	0.5	0.4	1.3
19	2.8	1.6	1.6	0.7
20	1.1	1	0.6	0.8
21	1.2	0.3	1.5	0.5
22	0.9	0.7	0.2	2.3
23	0.3	1.6	1.6	1.9
24	0.9	1.2	1.9	0.5
25	0.5	0.5	1.2	1.3
26	1.3	0.9	0.9	0.3
27	2.2	0.9	0.2	1.3
28	3	3.9	3.9	3.6
Mean	***1.0464286***	***1.01428571***	***1.28214286***	***1.325***
STD DEV	***0.8417276***	***0.93797034***	***0.95026451***	***1.00650661***

TABLE 8- CORONAL RAW DATA

Coronal	Initial-4 hr	Initial-8 hr	Initial-24 hr	Initial-1 week
1	3.7	2.1	3.4	2.9
2	0.3	0.1	0.1	0.6
3	0.1	0.1	0.8	0.5
4	0.6	0.2	0.2	0.9
5	0.1	0.3	0.4	0.3
6	0.4	0.3	0.3	0.9
7	0.5	0	0.3	0.5
8	0.3	0.3	0	0.1
9	0.2	0.3	0.2	1.6
10	0.2	1.2	0.9	0.2
11	0	0	0	1.9
12	0.4	0.2	0.3	0.6
13	0.3	0.1	0.7	0.4
14	0.3	0.6	0.6	0.3
15	0.2	0.8	0.2	0.7
16	0.7	1	1.1	0.3
17	0.2	0.2	0	0.3
18	0.5	0.2	1	0.4
19	0.4	0.1	0.1	2.2
20	0.4	0.2	0.5	0.8
21	1.6	0.2	0.6	1.7
22	0.3	0.2	0.2	0.2
23	0.2	0.3	0.6	0.1
24	1	1	0.1	0.3
25	0.1	0.2	2.1	0.3
26	0.5	2.6	0.2	0.3
27	0.4	0.5	0.5	0.9
28	0.1	0.5	0.1	0.1
Mean	**0.5**	**0.4928571**	**0.553571429**	**0.725**
STD DEV	**0.70290403**	**0.612178**	**0.714652022**	**0.705336799**

Table 9: Multivariate Tests

Multivariate Tests[c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Time	Pillai's Trace	.052	1.458[a]	3.000	79.000	.232
	Wilks' Lambda	.948	1.458[a]	3.000	79.000	.232
	Hotelling's Trace	.055	1.458[a]	3.000	79.000	.232
	Roy's Largest Root	.055	1.458[a]	3.000	79.000	.232
Time * Group	Pillai's Trace	.012	.165	6.000	160.000	.986
	Wilks' Lambda	.988	.163[a]	6.000	158.000	.986
	Hotelling's Trace	.012	.160	6.000	156.000	.987
	Roy's Largest Root	.008	.203[b]	3.000	80.000	.894

a. Exact statistic

b. The statistic is an upper bound on F that yields a lower bound on the significance level.

c. Design: Intercept + Group
Within Subjects Design: Time

Table 10: Mauchly's Test of Sphericity

Mauchly's Test of Sphericity[b]

Measure:Time_period

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	.940	4.927	5	.425	.964	1.000	.333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept + Group
Within Subjects Design: Time

Table 11: Tests of Within-subjects Effects

Tests of Within-Subjects Effects

Measure:Time_period

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Time	Sphericity Assumed	4.296	3	1.432	1.663	.176
	Greenhouse-Geisser	4.296	2.891	1.486	1.663	.178
	Huynh-Feldt	4.296	3.000	1.432	1.663	.176
	Lower-bound	4.296	1.000	4.296	1.663	.201
Time * Group	Sphericity Assumed	.780	6	.130	.151	.989
	Greenhouse-Geisser	.780	5.781	.135	.151	.987
	Huynh-Feldt	.780	6.000	.130	.151	.989
	Lower-bound	.780	2.000	.390	.151	.860
Error(Time)	Sphericity Assumed	209.257	243	.861		
	Greenhouse-Geisser	209.257	234.146	.894		
	Huynh-Feldt	209.257	243.000	.861		
	Lower-bound	209.257	81.000	2.583		

Table 12: Tests of Within-Subjects Contrasts

Tests of Within-Subjects Contrasts

Measure:Time_period

Source	Time	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	Linear	4.170	1	4.170	4.306	.041
	Quadratic	.104	1	.104	.127	.723
	Cubic	.022	1	.022	.028	.868
Time * Group	Linear	.144	2	.072	.074	.928
	Quadratic	.172	2	.086	.105	.901
	Cubic	.464	2	.232	.292	.748
Error(Time)	Linear	78.449	81	.969		
	Quadratic	66.332	81	.819		
	Cubic	64.475	81	.796		

Table 13: Tests of Between-Subjects Effects

Tests of Between-Subjects Effects

Measure:Time_period
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	433.161	1	433.161	262.094	.000
Group	68.368	2	34.184	20.684	.000
Error	133.868	81	1.653		

Table 14: Overall Mean

1. Grand Mean

Measure:Time_period

		95% Confidence Interval	
Mean	Std. Error	Lower Bound	Upper Bound
1.135	.070	.996	1.275

Table 15: Group Means

Estimates

Measure:Time_period

			95% Confidence Interval	
Group	Mean	Std. Error	Lower Bound	Upper Bound
Sagittal	1.671	.121	1.430	1.913
Axial	1.167	.121	.925	1.409
Coronal	.568	.121	.326	.810

Table 16: Univariate Tests

Univariate Tests

Measure:Time_period

	Sum of Squares	df	Mean Square	F	Sig.
Contrast	17.092	2	8.546	20.684	.000
Error	33.467	81	.413		

The F tests the effect of Group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Table 17: Time means

Estimates

Measure:Time_period

Time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	1.007	.104	.800	1.214
2	1.057	.127	.805	1.309
3	1.179	.100	.980	1.377
4	1.299	.117	1.067	1.531

Table 18: Multivariate Tests

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.052	1.458[a]	3.000	79.000	.232
Wilks' lambda	.948	1.458[a]	3.000	79.000	.232
Hotelling's trace	.055	1.458[a]	3.000	79.000	.232
Roy's largest root	.055	1.458[a]	3.000	79.000	.232

Each F tests the multivariate effect of Time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

Table 19: Group Time comparisons

4. Group * Time

Measure:Time_period

Group	Time	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Sagittal	1	1.475	.180	1.116	1.834
	2	1.664	.219	1.228	2.101
	3	1.700	.173	1.356	2.044
	4	1.846	.202	1.445	2.248
Axial	1	1.046	.180	.687	1.405
	2	1.014	.219	.578	1.451
	3	1.282	.173	.938	1.626
	4	1.325	.202	.923	1.727
Coronal	1	.500	.180	.141	.859
	2	.493	.219	.056	.930
	3	.554	.173	.210	.897
	4	.725	.202	.323	1.127

Table 20: Post-Hoc Test

Multiple Comparisons

Time_period
Bonferroni

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Sagittal	Axial	.504*	.1718	.013	.084	.924
	Coronal	1.104*	.1718	.000	.684	1.524
Axial	Sagittal	-.504*	.1718	.013	-.924	-.084
	Coronal	.599*	.1718	.002	.179	1.019
Coronal	Sagittal	-1.104*	.1718	.000	-1.524	-.684
	Axial	-.599*	.1718	.002	-1.019	-.179

Based on observed means.
The error term is Mean Square(Error) = .413.
*. The mean difference is significant at the .05 level.

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