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# Effects of Functional Appliances on the TMJ and Mandibular Length of Skeletal Class II Patients: A Cone Beam Computed Tomography Study

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LOMA LINDA UNIVERSITY
School of Dentistry
in conjunction with the
Faculty of Graduate Studies

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# Effects of Functional Appliances on the TMJ and Mandibular Length of Skeletal Class II Patients: A Cone Beam Computed Tomography Study

by

David C. Lee

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A thesis submitted in partial satisfaction of
the requirements for the degree of
Master of Science in Orthodontics and Dentofacial Orthopedics

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September 2009

Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree Masters of Science.

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# ABBREVIATIONS

| | |
|---|---|
| C | Superior point of condyle |
| CBCT | Cone-Beam Computed Tomography |
| DICOM | Digital Imaging and Communications in Medicine |
| FH | Frankfurt Horizontal |
| GF | Superior point of glenoid fossa |
| Gn | Gnathion |
| IMP | Incisor mandibular plane angle |
| MARA | Mandibular Anterior Repositioning Appliance |
| Me | Menton |
| MRI | Magnetic Resonance Images |
| Na | Nasion |
| Po | Porion |
| PtM | Pterygomaxillary fissure |
| S | Sella |
| T1 | Pre-treatment |
| T2 | Progress |
| T3 | Post-treatment |
| TMJ | Temporomandibular Joint |
| 2D | Two-dimensional |
| 3D | Three-dimensional |

# ABSTRACT OF THE THESIS

# Treatment Effects of Functional Appliances on the TMJ and Mandibular Length of Skeletal Class II Patients : A Cone Beam Computed Tomography Study

by

David C. Lee DDS

Master of Science in Orthodontics and Dentofacial Orthopedics
Loma Linda University, September 2009
Dr. Kitichai Rungcharassaeng, Chairperson

**Introduction:** Functional appliances have been efficiently used in the treatment of Class II malocclusions caused by retrognathic mandibles. Cone beam computed tomography has enabled us to make more accurate linear measurements by eliminating superimposition of other structures and to analyze skeletal anatomic detail in all three planes of space. This retrospective study evaluated the osseous changes in the temporomandibular joint (TMJ) and length of the mandible in skeletal Class II malocclusion patients treated with the fixed functional appliances and compared measurements with Class I malocclusion patients treated with orthodontic mechanics that did not alter skeletal relationships.

**Materials and Methods:** Twelve patients (10 male, 2 female; mean age, 15.1 years) who were treated with the fixed functional appliance therapy until Class I molar occlusion was achieved and had the pre-treatment (T1) and progress (T2) CBCT images available were included in the study as functional appliance group. The control group included twelve gender-and age-matched patients (10 male, 2 female; mean age 15.3 years) who completed treatment for Class I malocclusion with orthodontic mechanics without orthopedic effects and had the pre-treatment (T1) and post-treatment (T3) CBCT images available. Newtom NNT imaging software measurements of the TMJ and mandibular osseous changes were compared in each treatment modality. The glenoid fossa location was determined by measuring from the most superior point of the glenoid fossa (GF) to porion (Po) and pterygomaxillary fissure (PtM). The length of the mandible was measured from the superior point of the condyle (C) to gnathion (Gn)[1] and from GF to Gn. Corrections achieved through dental changes were measured by comparing the incisor mandibular plane angle (IMP). The data at different time intervals and between groups were analyzed using paired and independent t-tests at the significance level of $\alpha=0.05$ respectively.

**Results:** In the functional appliance group, GF-Gn, C-Gn and GF-Po at T2 were significantly greater than those at T1 ($p < .05$); IMP at T2 was significantly higher than T1 ($p < .05$); whereas no statistically significant difference in GF-PtM between T1 and T2 ($p = .067$). In the control group, Gf-Gn. C-Gn, and GF-Po at T3 were significantly greater than those at T1 ($p < 0.05$). However, there was no statistically significant difference between T1 and T3 of IMP ($p=0.078$) or GF-PtM ($p=0.957$). When comparing the changes achieved between experimental and control group, no statistically significant difference was found between any of the measurements ($p > 0.05$).

**Conclusions:** Evaluating three-dimensional cone-beam computed tomography allows for improved reliability over two-dimensional radiographs in landmark identification as well as linear and angular measurements. The results of this study seemed to validate the motion that functional appliance therapy corrects Class II malocclusion by increasing the length of the mandible, anterior repositioning of the glenoid fossa, and proclination of the mandibular incisors.

# CHAPTER ONE

# REVIEW OF THE LITERATURE

## The Controversy Behind Functional Appliances

There have been many techniques used by orthodontists to treat Class II malocclusions. In addition to various types of headgears, magnets, and elastics, a range of removable and fixed functional appliances have been used to influence occlusion and the growth of the mandible to possibly avoid surgery for patients with Class II malocclusion resulting from mandibular retrognathism. Functional appliances are appliances that alter the posture of the mandible by holding it in a more protruded position. They transmit the forces that are created by the resulting stretch of the neuromuscular environment to the dental and skeletal tissues. While there were several landmark studies demonstrating reproducible skeletal changes in the Temporomandibular Joint (TMJ) with functional appliances in animals[2] [3] [4] [5] [6], their clinical use in orthodontics is controversial because human studies remain inconclusive.

There are several factors that have led to the inconsistencies found in human studies. First, studies have used inappropriate landmarks, such as articulare (Ar) and condylion (Co), to measure horizontal growth of the mandible, which has been shown to affect the results. Significant differences in growth measurements were obtained when Ar was used as the posterior end point in measuring mandibular length than when Co was used. Although Ar can be located with a better reproducibility when compared to Co, it is affected more by changes in the growth of the skull, which makes it a less reliable landmark. Second, there are variations in treatment times with the appliance as well as duration between follow-up appointments. Third, studies utilizing histomorphometry have experimental flaws in the design and methodology. For example, it is impractical to analyze several sections from each condyle and therefore a subjective bias is added when specific sections are chosen to be most representative. Finally, the lack of normalization of the data in recent studies results in data that does not take into account the different sizes of the condyles in the study.[7]

In addition to these inconsistencies, there are several variables that are to be considered when analyzing the results. While many of the authors report a statistical difference in changes of mandibular length with functional appliance treatment, it is important to take into account the possible areas of inaccuracy. Most cephalometric studies do not consider the rotation of the condyle during growth, which would most likely underestimate the growth of the mandible. It is also common to disregard the direction of condylar growth. This leads to the speculation that the rotation of the condyle could actually be neutralized by the remodeling of the condylar head in a posterior direction which would appear to result in lengthening of the mandible. Thus, the variability of growth is an important factor to consider when linear measurements between specific landmarks are being made.[1] In addition to this, the age and sex of the individuals being studied should also be taken into account. The reason for this is the different periods of growth including the timing of peak height velocity (PHV) will have a sizeable effect on the results collected from the data. Many studies utilized children that had yet to reach their PHV, which would have led to an underestimation of the skeletal changes.[7]

## Effect of Functional Appliances on the TMJ

The efficacy of removable and fixed functional appliances have been attributed to their ability to enhance mandibular growth, and for this reason are considered to be an alternative to orthognathic surgery in borderline skeletal Class II cases.[8] There are three adaptive processes in the TMJ that are thought to result in protrusion of the mandible during treatment: 1) increased condylar growth, 2) anterior displacement of the glenoid fossa, and 3) anterior positioning of the condyle in the fossa.[9] While much speculation still exists in the effectiveness of this method of treatment, functional appliances remain widely used in the United States.

Pancherz and Ruf utilized Magnetic Resonance Images (MRI) to analyze the effect of the Herbst appliance on the three adaptive processes thought to take place in the TMJ. Condylar remodeling was seen on the posterior superior border in 29 of the 30 condyles after 6-12 weeks of treatment. Later treatment stages revealed glenoid fossa changes at the anterior surface of the postglenoid spine. Both of these mechanisms were associated with the increase in mandibular prognathism resulting from the Herbst appliance, but condyle fossa relationship appeared to have no significant effect.[10]

Stimulation of condylar growth with functional appliances remains a controversial issue. Biomechanical forces produced by these appliances have been shown to produce cellular and molecular changes within the condyle. In a recent article, the authors stated that this cascade of molecular responses stimulated the proliferation and maturation of chondrocytes as well as their transition into osteogenesis.[11] In another study by Rabie et al[12], he again showed that the expression of Sox 9 and type II collagen was accelerated with forward mandibular positioning. Sox 9 is a transcription factor that controls the differentiation of mesenchymal cells into chondrocytes. No significant difference was found in new bone formation in the post treatment phase after the removal of the appliance when compared to natural growth. This showed that the results were not temporary and there was a resulting enhancement of chondrocyte differentiation and collagen matrix formation, which indicated a possibility of true enhancement of growth in the condyle.[12] However, this study along with many others took into account only the experimental period that they were observing. While the gene expression was actually altered with treatment, the changes appeared to be only temporary. Although this does not discount the results of this experiment, it causes speculation to still persist regarding the mechanisms by which these changes occur. Some reason that these appliances only accelerate growth without increasing their genetic potential while others maintain that actual growth of the mandible can be stimulated.[1 7 13]

## Role of the Glenoid Fossa

Giuntini et al[14] measured the glenoid fossa position in skeletal and dental Class II Malocclusion patients and compared them to patients with Class I malocclusion. The location of the glenoid fossa was measured from its most superior point (GF) to three different landmarks: sella (S), pterygomaxillary fissure (PtM), and frontomaxillonasal suture (FMN). In the Class II group, the average distance from GF to FMN was 3.5 mm greater than that of the Class I group. This showed that GF was in a more posterior anatomical position in the Class II group, and that the position of the glenoid fossa may be a factor in skeletal Class II patients.[14]

Anterior displacement of the glenoid fossa during treatment with functional appliance has been noted in several studies. Some animal studies have shown that forces created by masticatory muscles stretching the tissues in the TMJ have resulted in changes of the sagittal and vertical position of the glenoid fossa.[15] A recent article by Liu et al evaluated the morphologic and histologic response of the glenoid fossa in rats to the lateral shift in the mandible. They concluded that there was a shift in the location and shape of the glenoid fossa as well as new bone formation in the posterior region of the fossa. When the mandible was shifted to the left, the result was a shallower fossa on the left that was positioned relatively backward, upward, and outward. In comparison, the contralateral side was relocated relatively downward and forward. In addition, histologic analysis revealed that there were enhanced metabolic activity in the anterior part of the fossa and synthesis of cartilage matrix in the posterior part of the fossa.[16]

Wadhawan et al evaluated MRI before (T1) and after functional appliance therapy (T2) and at completion of treatment (T3) on 12 children between the ages of 10 and 14.[17] They found that the distance from the external auditory meatus to the post-glenoid spine was 1.3 mm forward at T3 compared to T1. They concluded that this anterior repositioning of the glenoid fossa was the main contributor to the correction of the malocclusion.[17]

In human studies, the changes are only noted immediately after treatment and are usually not sustained for long periods of time.[18] However, this does not rule out the possibility that the glenoid fossa contributes to mandibular advancement. Studies have reported no significant difference in the measurement between porion and the posterior aspect of the glenoid fossa, which could imply that it is being held from its natural downward and backward direction of growth.[27]

## The Herbst Appliance

One appliance that has been shown to have a high clinical success in accelerating mandibular growth in Class II treatment is the Herbst appliance.[1] Emil Herbst first introduced the Herbst appliance in the early 1900's, and Pancherz repopularized the appliance in the 1970's.[19] Dischinger modified the appliance in 1989 by attaching two telescopic tubes to stainless steel crowns on the first molars instead of bands in order to provide superior retention when protruding the mandible. It has been chosen for many research studies involving functional appliances because it eliminates the need for patient compliance and maintains an impressive clinical record.[20]

The Herbst Appliance has corrected Class II patients to Class I malocclusion with high predictability.[9] In growing patients, this is thought to be accomplished by repositioning the glenoid fossa in a more anterior positioning and stimulating growth of the condyle.[16] Some studies have also noted a headgear effect where the maxilla was actually moved into a more posterior position.[21 45] In a study comparing the longitudinal growth changes of Class II Div 1 malocclusion cases with Class I cases, Stahl et al searched through the University of Michigan Growth Study and Denver Growth Study to find untreated subjects with either malocclusion that had lateral cephalograms of the 6 stages in cervical vertebral maturation. Patterns of craniofacial growth were generally similar between the two groups except for the significantly smaller increase in mandibular length at the growth spurt (CS3-CS4).[22] While functional appliances have been thought to be most effective when taking advantage of the pubertal growth spurt of the growing patient, a recent study has shown that the Herbst appliance is effective in treating adults as well. Via cephalometric analysis, adult Herbst treatment achieves Class II correction by 87% dental changes and 13% skeletal changes.[23]

Recent studies have shown that the predictability and success of treatment with the Herbst appliance is as high as it is for surgery. Even though a considerable amount of the correction is obtained via dental changes, the Herbst was able to obtain normal overbite and overjet in all studied cases. Thus, in borderline Class II cases functional appliances should be considered as a predictable alternative treatment to surgery when large facial esthetic correction is not a major goal.[24]

### Mandibular Anterior Repositioning Appliance

Introduced in 2003, the Mandibular anterior repositioning appliance (MARA) is a tooth borne functional appliance that is used to correct Class II malocclusions. It has been shown to produce very similar treatment effects as the Herbst. Comparative differences that were noted include the MARA's lack of maxillary molar intrusion as well as less proclination of the mandibular incisors. The most significant difference is seen in the restrictive effect that the Herbst exerts on the maxilla, which is absent in the MARA. The dental changes that are seen with the MARA include distalization of the upper molar, forward movement of the mandibular molar and incisor, and proclination of the lower incisors.[25]

## Shortcomings of 2-Dimensional (2D) Radiograph Analysis

Previous studies involving functional appliance treatment generally measured growth of the face and jaws with cephalometrics in two dimensions.[9 18 19 23] However, these 2D measurements are now perceived to be inadequate in measuring the structural changes at distinct positions.[26] The limitations of conventional cephalometrics stem from the difficulty of distinguishing between superimposed structures and of determining landmarks used in measurement analysis. Also, lateral cephalometrics assume a linear relationship between skeletal structures, which creates an inaccurate interpretation of measurements regarding osseous changes.[27] In addition, there are also the inherent image distortion and the possibility of anatomical differences of the left and right side. A definite lack of accuracy and validity exist in studies that utilized cephalometric analysis to determine short and long term effects of treatment with functional appliances.

## 2D vs. 3D Imaging

A recent study examined the difference in accuracy between CBCT images and digital cephalometic radiographs.[28] Ten linear dimensions were measured between eleven anatomical landmarks in order to analyze different TMJ measurements including the size of the condyle and mandibular length on 25 dry human skulls. No measurement made with the CBCT differed significantly from the physical measurements whereas in this study conventional cephalograms produced measurements that were significantly greater than the anatomic physical measurements even after calibration. CBCT is capable of accurately depicting and measuring the TMJ structures with great reproducibility and is significantly more reliable than cephalograms.[28] A number of studies evaluating the TMJ consider CBCT to be the best examination tool due to its ability to show the details of bone and its 100% agreement between images and surgical findings.[29]

The advent of three-dimensional craniofacial imaging has provided us with a valuable tool to help us advance our understanding of treatment mechanisms and assessment of skeletal changes associated with growth and treatment. It has allowed researchers to analyze the data by rendering 3D models, which can be automatically superimposed via graphic overlays. By utilizing these tools, it is possible to accurately measure the outcome of the treatment.

Magnetic Resonance Imaging (MRI) and Cone Beam Computerized Tomography (CBCT) are both used to depict osseous morphology. MRI is particularly useful in analyzing fossa-disc and disc-condyle relationships as well as identifying any pathological changes to the TMJ. With their 3D measurement capabilities, a more accurate depiction of linear measurements of landmarks located in different planes of space can be obtained. However, when compared to tomographs and CBCT, MRI has been shown to produce less accurate images of osseous anatomy.[30] This can be attributed to incorrect interpretation of artifacts as bone deposition.[27]

## Biological Landmarks to Measure Growth and Treatment Changes

A study of Cevidanes et al defined ten biological landmarks in each plane of space (coronal, axial and sagittal) that were specifically related to the growth of the mandible.[26] Since measurements were based on landmark displacements from other landmarks, they were particularly significant because they determine the studied effects of growth and treatment. Since the cranial base is not developmentally related to mandibular growth, it was their belief that landmarks measuring changes in the mandible should be made at the condyle and the greater wing of the sphenoid. This would allow comparisons to be made of the mandible relative to its equivalents in the upper face structure.[26]

Griener et al utilized lateral cephalograms and two groups of macerated skulls to compare the changes in porion (Po) location during growth. Utilizing sella (S) and nasion (Na) as landmarks of the cranial base, the perpendicular distance from the sella-nasion (SN) line and Po was measured. They concluded that the vertical postion of Po remained virtually constant as the posterior reference point with respect to the anterior cranial base.[31]

Palomo et al compared changes of the maxilla, mandible, midface, and cranial vault in untreated Class I and Class II samples at ages 6,11, and 15. While Class II skeletal discrepancies were not evident at age 6, both the mandible and maxilla were found to be responsible at later ages. Compared to the Class I sample, the Class II group had more protrusive maxillary landmarks and a more inferior and retrusive mandible at all ages which revealed a more vertical growth pattern. The rate of shape change was very similar for both Class I and Class II at all ages, which showed that change occurs at the same rate but in different directions.[32]

Gu et al studied the longitudinal cephalometric records of 20 subjects from the Matthew and Ware implant study[33] where tantalum implants were placed in the mandible of children as reference points. Fifteen of the subjects showed a Class I molar relationship, and five presented with a Class II molar relationship. Cephalograms at each of the six consecutive stages of cervical vertebral maturation were available (CS1 through CS6). The greatest amount of increase in mandibular length occurred during the growth interval CS3 to CS4, at ages 11.7 to 13.0 respectively. There was more growth posteriorly than anteriorly and no visible remodeling occurred at the anterior border of the symphysis.[34]

# CHAPTER TWO

# EFFECTS OF FUNCTIONAL APPLIANCES ON THE TMJ AND MANDIBULAR LENGTH OF SKELETAL CLASS II PATIENTS: A CONE BEAM COMPUTED TOMOGRAPHY STUDY

## Introduction

While Class II malocclusions can arise from derivations in both skeletal and dental origins, growing patients exhibiting mandibular retrognathism would benefit most from orthopedic correction aimed at stimulating mandibular growth to achieve skeletal and dental harmony.[35] The efficacy of removable and fixed functional appliances has been attributed to their ability to enhance mandibular growth.[1 8] Therefore, they are considered to be an alternative to orthognathic surgery in borderline skeletal Class II cases.[8] However, fixed functional appliances have the distinct advantage of eliminating patient compliance. There are three adaptive processes in the TMJ thought to facilitate the protrusion of the mandible during treatment: 1) increased condylar growth, 2) anterior displacement of the glenoid fossa, and 3) anterior positioning of the condyle in the fossa.[9]

Despite the widespread use of functional appliances in modern orthodontic therapy, there continues to be much controversy regarding their use, mode of action, and effectiveness. Previous studies involving functional appliance treatment have measured growth of the face and jaws with cephalometrics in two dimensions and are now perceived to be inadequate and inaccurate in measuring the structural changes at distinct positions.[9 19 23 26 40] The limitations of conventional cephalometrics stem from the difficulty of distinguishing between superimposed structures and of determining landmarks used in measurement analysis. Also, lateral cephalometrics assume a linear relationship between skeletal structures, which creates an inaccurate interpretation of measurements regarding osseous changes.[27]

With the introduction of CBCT as part of the armamentarium in dental research, better methods have been introduced to include the aspect of growth and rotation of the condyle by selection of more meaningful skeletal landmarks. It is important to take each subject's age and sex into account to rule out variability of growth during PHV. Further research with an experimental design that eliminates previous sources of ambiguity should be carried out to determine the actual mechanism by which functional appliances correct Class II malocclusions. The advent of three-dimensional craniofacial imaging has provided us with a valuable tool to help us advance our understanding of treatment mechanisms and assessment of skeletal changes associated with growth and treatment.

Although numerous studies have been conducted on the effects of functional appliances, no comparison using cone-beam computed tomography (CBCT) has been performed. This retrospective study used the CBCT data to evaluate the effects of fixed functional appliances on the osseous changes in the temporomandibular joint (TMJ) and the length of the mandible in skeletal Class II malocclusion patients. The changes were also compared with those observed in Class I malocclusion patients treated with orthodontic mechanics that did not alter skeletal relationships.

## Materials and Methods

This study was approved by the Institutional Review Board of Loma Linda University, Loma Linda, CA. All patients involved in this study received orthodontic treatment at the Graduate Orthodontic Clinic, Loma Linda School of Dentistry. The functional appliance group consisted of twelve skeletal Class II patients, who received fixed functional appliances as part of their comprehensive orthodontic treatment. To be included in the study, the patient was required to have pretreatment (T1) and progress (T2) CBCT images available. The T1 images were obtained before orthodontic treatment and the T2 images were obtained after a minimum of seven months of functional appliance therapy and after Class I molar relationship had been achieved. For the control group, pretreatment (T1) and post-treatment (T3) CBCT images of 12 age and gender-matched patients with class I malocclusion treated with orthodontic treatment mechanics that would not alter the position or posture of the mandible were included.

General information about each patient including gender, age at start of treatment, and duration of treatment were collected from the patient's record. The CBCT scans were collected using the Dental Volumetric Tomograph Newtom 3G (AFP Imaging, Elmsford, NY) (Figure 1), which acquires 360 individual xrays in 36 seconds with Safebeam technology that varies radiation dosage based on the patient's age and size. A personal computer which used Windows NT operating system (Microsoft Corporation, Redmond, WA) controlled the scanner, and the raw image data were transferred to a workstation.

Figure 1. Newtom 3G Unit

## Acquisition of the Images

Using filtered back projection techniques, the primary reconstruction of the raw data was then completed in order to record and store as digital imaging and communications in medicine (DICOM) format. The secondary reconstruction with axial slice thickness at 0.3 mm intervals and isotropic voxels was performed with multiplanar formatting allowing the operator to obtain image slicing in any 3D direction.

For intra-rater reliability, a single observer repeated landmark identification of 8 anatomic points 30 times at intervals of at least 6 hours. By selecting the appropriate landmarks, Newtom NNT software analysis was used to compute linear and angular measurements with an accuracy limited to the 0.3 mm voxel size. Although it has been shown that alterations in skull position during image acquisition did not affect the accuracy of linear measurements, the 3D image was reoriented in both the sagittal and coronal projection so that Frankfurt horizontal plane paralleled the lower border of the screen.[36]

## Locating the Landmarks in 3 Planes of Space

With axial, coronal, and sagittal views of the 3D rendering, 12 landmarks were selected from criteria that were established for each landmark by defining anatomic identifications in the X, Y, and Z coordinates (Table 1).[37] [38] The Newtom NNT imaging software allowed multiple planes in the same window views as well as enlarged single plane views to aid in confirming landmark position with a cursor-driven pointer (Figure 2), and these craniometric points were used to determine linear and angular measurements. The difference between T1 and T2 measurements of patients undergoing functional appliance treatment and between T1 and T3 measurements of the control group were calculated, and comparisons were made between and within the two groups.

To locate the superior point of the glenoid fossa (GF), on the axial view, using the secondary study reconstruction mode, cross sectional cuts were made from the lateral pole to the medial pole of the condyle to create cross sectional images with a width of 50 mm and a thickness of 1 mm in the sagittal plane (Figure 3). By viewing both the axial and sagittal planes on the same screen, the middle of the glenoid fossa was located on a specific cut in the axial view and the most superior point of the glenoid fossa in the corresponding sagittal cross sectional view was marked using marking tool on the NNT imaging software as GF (Figure 4). On the scout view, an axial plane that most closely corresponded to Frankfurt Horizontal (FH) was selected as the reference plane. The reference plane was then scrolled up and down until GF was identified on the axial image. The reference plane was then scrolled down to locate the first sign of cortication of the condyle within the glenoid fossa on the axial plane. Once, identified the point was marked as the superior point of the condyle (C) (Figure 5). This procedure was performed to determine GF and C on both the left and right side.

To locate Gnathion (Gn), an axial plane from the scout view that most closely corresponded to the occlusal plane was selected as the reference plane. Scrolling down from this plane on scout view, the most anterior-inferior point of the contour of the bony chin was identified and the corresponding axial view was used to mark as Gn on the middle of the bony chin.

To locate Porion (Po), cross sectional images were made with a width of 50 mm and a thickness of 1 mm and parallel to the external auditory meatus. While viewing the axial and sagittal planes on the same screen, the latero-superior most point of the external auditory meatus at the first sign of complete cortication was marked on the sagittal cut. (Figure 6). On the scout view, an axial plane that most closely corresponded to Frankfurt Horizontal (FH) was selected as the reference plane. The reference plane was then scrolled up and down until Po was identified on the axial image, and the steps were repeated for the opposite side.

To locate the pterygomaxillary fissure, an axial plane was selected from the scout view that most closely corresponded to Frankfurt Horizontal. The reference plane was scrolled down the lateral image to locate the most superior intersection of the posterior limit of the maxilla and the greater wing of the sphenoid. The most superior point on the scout view was located, and the anterior-superior most point of the fissure was marked in the axial view (Figure 7), and the steps were repeated for the opposite side.

With the second reconstruction oriented so that FH was parallel to the lower border of the screen in both the sagittal and coronal projections, the incisal tip and root tip of the most protruded lower incisor were identified on the lateral image. Menton was located by selecting an axial plane from the scout view that most closely corresponded to the occlusal plane. Scrolling down from this plane on the lateral image, the most inferior point of the lower border of the mandible was identified, and the corresponding axial plane was displayed on the same screen. The middle-inferior most point was marked on the axial plane, and a line drawn tangent to the lower border of the mandible passing through this point was used to determine the mandibular plane. The angle measurement tool was used to identify the angle between the long axis of the lower incisor and the mandibular plane (IMP) (Figure 8).

To measure ANB and overjet (OJ), cross sectional images were made with a width of 250 mm and a thickness of 1mm and passing through the middle of the left and right maxillary first molars. While viewing the axial and sagittal planes on the same screen, the sagittal slice that contained Nasion (Na), and the most concave points of the premaxilla (A) and the symphysis (B) was chosen for angular measurement of ANB. On the same slice, OJ was measured from the facial surface of the lower incisor to the incisal tip of the maxillary incisor (Figure 9).

All measurements were made at T1 and T2 for functional appliance group and T1 and T3 for the control group. Comparisons between time intervals and groups were made. The landmarks and NNT 3D measurement tools were used to determine the effect of functional appliances on mandibular length, position of the glenoid fossa, and the inclination of the lower incisors. The measurements of mandibular lengths (GF-Gn and C-Gn) were made on the axial view (Figure 10). The actual change in the length of the mandible was determined by measuring C-Gn (Figure 10). GF-Gn was used to evaluate the glenoid fossa position with respect to C (Figure 10). Comparing GF-PtM and GF-Po at different time points revealed changes in the position of the glenoid fossa (Figure 11). Finally, changes in proclination of the lower incisors were determined by comparing the IMP at different time points (Figure 8).

Table 1. Landmarks selected for the study

| *Landmark name* | *Anatomic region* | *Lateral view* | *Axial view* | *Anteroposterior view* |
|---|---|---|---|---|
| 1. Gnathion (Gn) | Contour of bony chin | Anterior-inferior-most point | Middle-anterior-inferior-most point | Middle-inferior-most point |
| 2a. Left superior point of glenoid fossa (LGF) | Left temporal bone | Superior-most point | Superior-most point | Middle-superior-most point |
| 2b. Right superior point of glenoid fossa (RGF) | Right temporal bone | Superior-most point | Superior-most point | Middle-superior-most point |
| 3a. Left superior point of condyle (LC) | Left condyle | Superior-most point | Superior-most point | Middle-superior-most point |
| 3b. Right superior point of condyle (RC) | Right Condyle | Superior-most point | Superior-most point | Middle-superior-most point |
| 4a. Left porion (LPo) | Left external auditory meatus | Superior-most point | Laterosuperior most point | Laterosuperior most point |
| 4b. Right porion (RPo) | Right external auditory meatus | Superior-most point | Laterosuperior most point | Laterosuperior most point |
| 5a. Left pterygomaxillary fissure (LPtM) | Left area between greater wing of sphenoid and posterior limit of maxillary | Posterior limit of the maxillary at anterior-superior-most point | Anterior-superior most point | Laterp-superior-most point |
| 5b. Right pterygomaxillary fissure (RPtM) | Right area between greater wing of sphenoid and posterior limit of maxillary | Posterior limit of the maxillary at anterior-superior-most point | Anterior-superior most point | Laterp-superior-most point |
| 6. Lower incisal edge (IE) | Incisal tip of most protruded lower incisor | Superior-most point | Middle point of the MD and BL width | Middle point of the MD width |
| 7. Lower incisor root tip (IRT) | Root tip of most protruded lower incisor | Inferior-most point | Middle point of the MD and BL width | Middle point of the MD width |
| 8. Menton (Me) | Lower border of the mandible | Inferior-most point | Middle-inferior-most point | Inferior-most point |

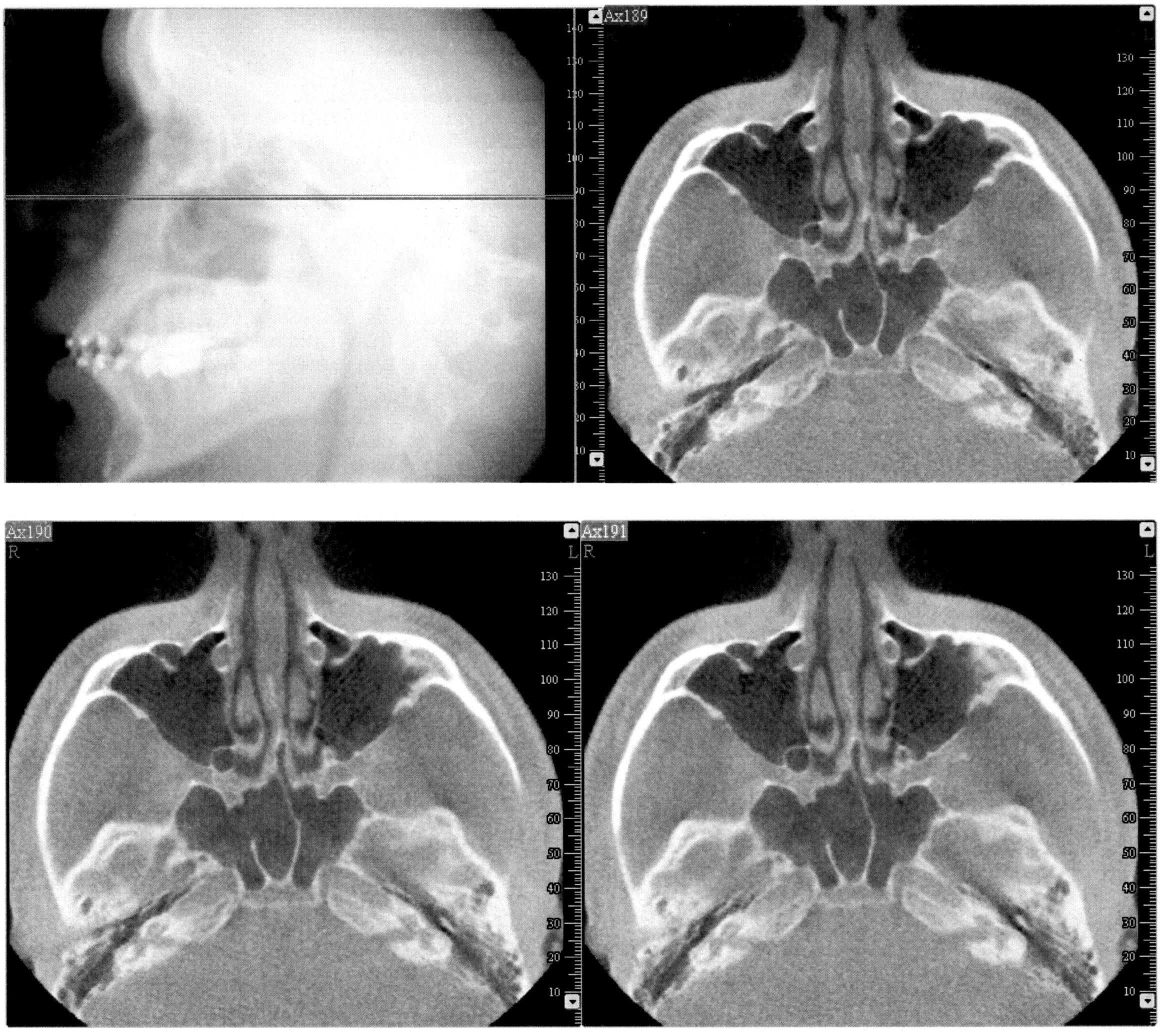

Figure 2. CBCT lateral and axial view of 3D image using Newtom NNT software

Figure 3. CBCT axial and cross sectional images used to locate the superior point of the glenoid fossa (red mark on sagittal cut)

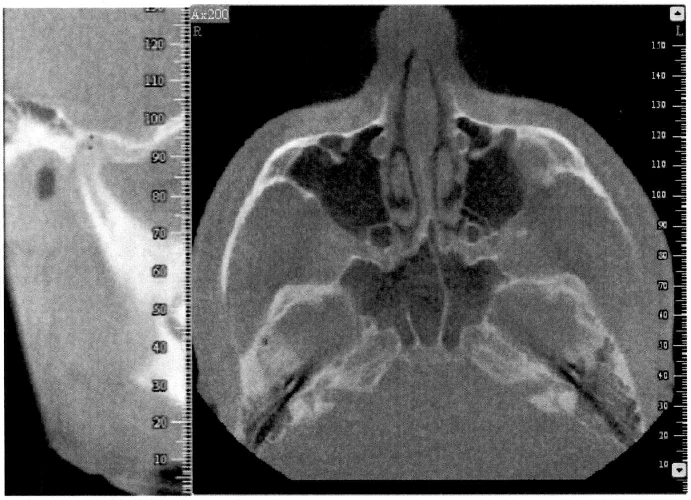

Figure 4. CBCT sagittal and axial image demonstrating the location of the superior point of the glenoid fossa (red mark on axial cut)

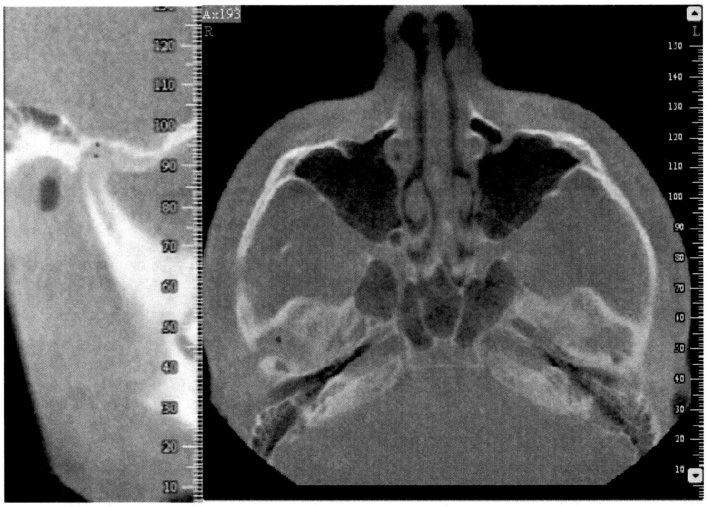

Figure 5. CBCT sagittal and axial images demonstrating the acquisition of the superior point of the condyle (C) (red mark on axial cut)

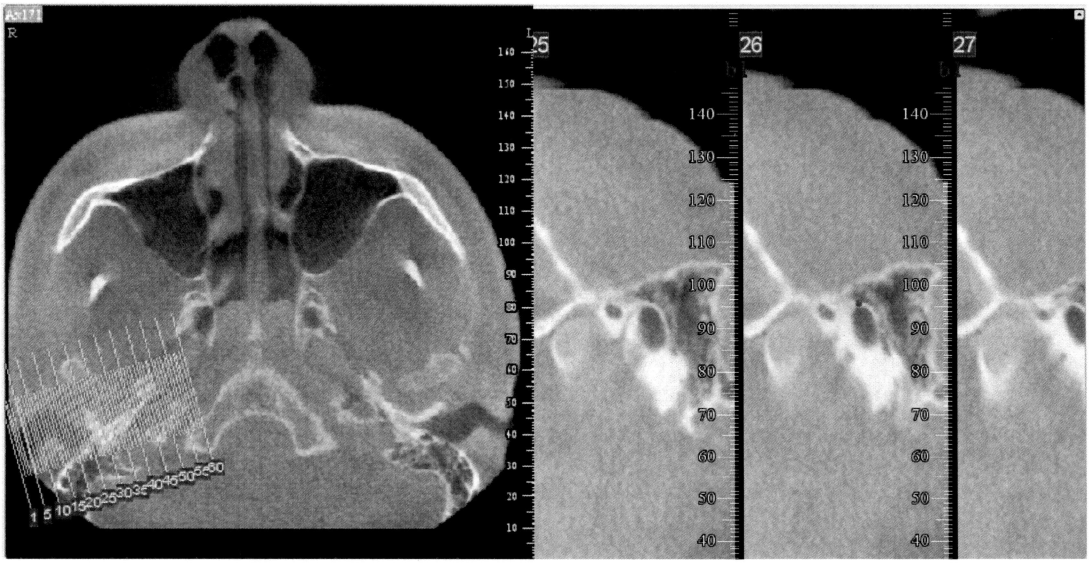

Figure 6. CBCT axial and cross sectional images demonstrating the acquisition of porion (Po) (red mark on sagittal cut)

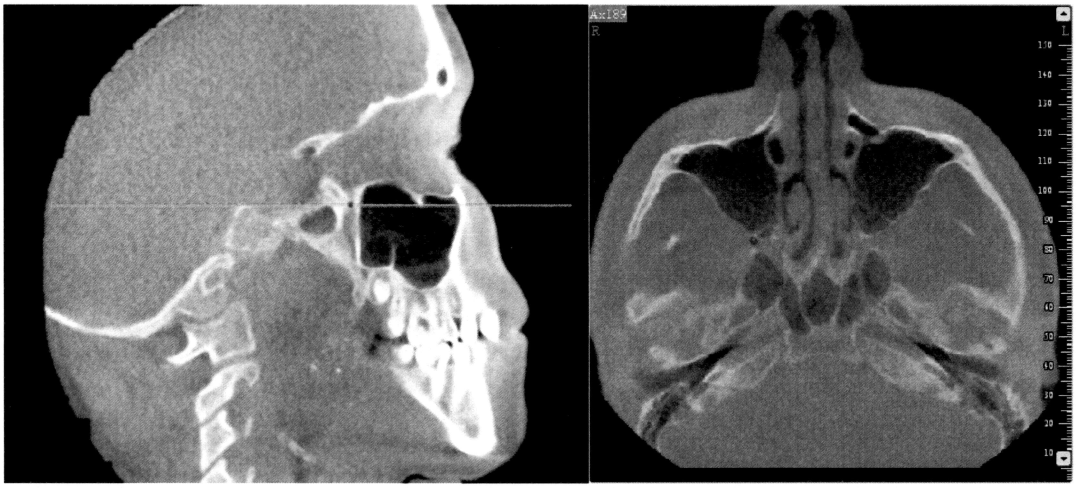

Figure 7. CBCT lateral and axial images demonstrating the acquisition of pterygomaxillary fissure (red mark on axial)

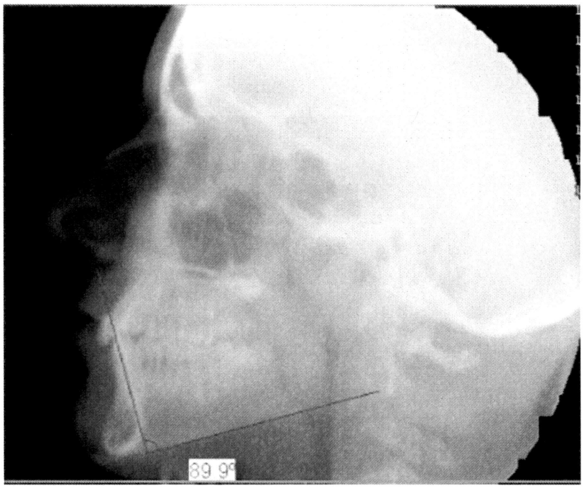

Figure 8. CBCT lateral images demonstrating the acquisition of the incisor mandibular plane (IMP) angle

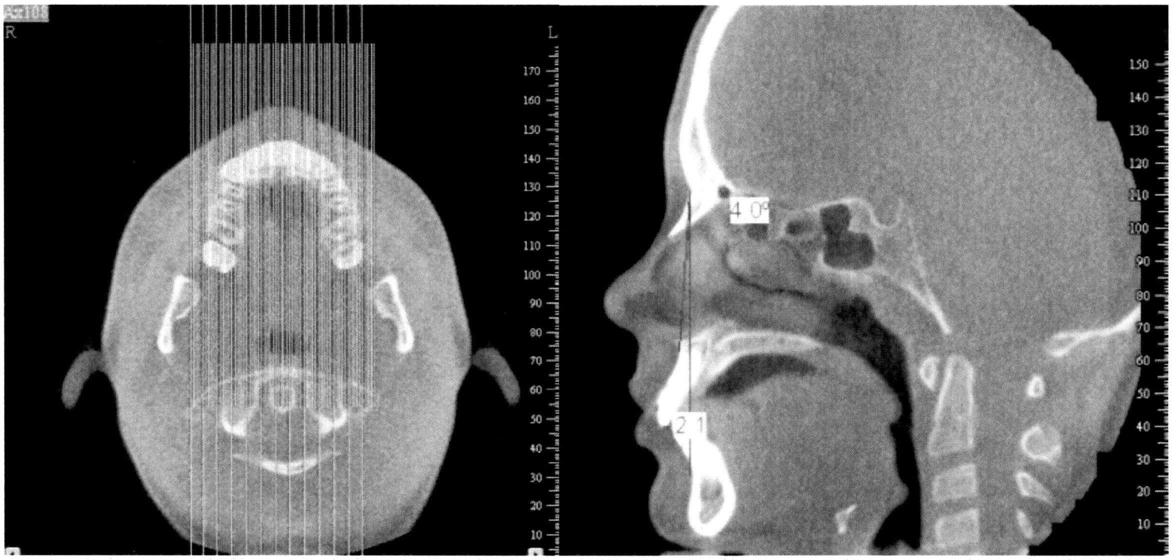

Figure 9. CBCT axial images demonstrating the cross sections aligned with maxillary $1^{st}$ molars and the acquisition of ANB and OJ.

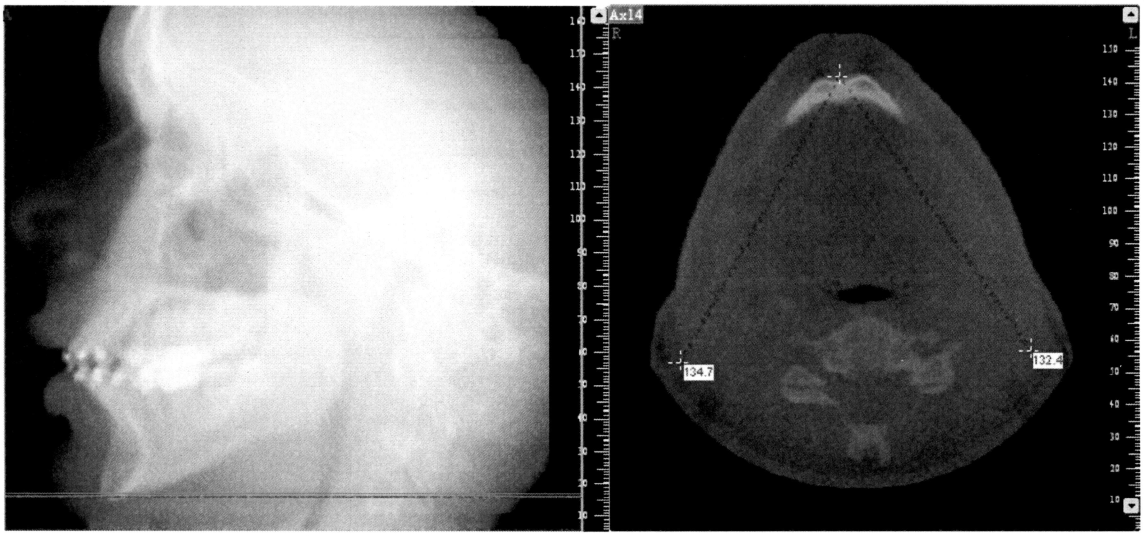

Figure 10. CBCT lateral image demonstrating the location of axial slice used to locate Gnathion (red mark on axial image). 3D Measurement is made from GF-Gn (right) and C-Gn (left)

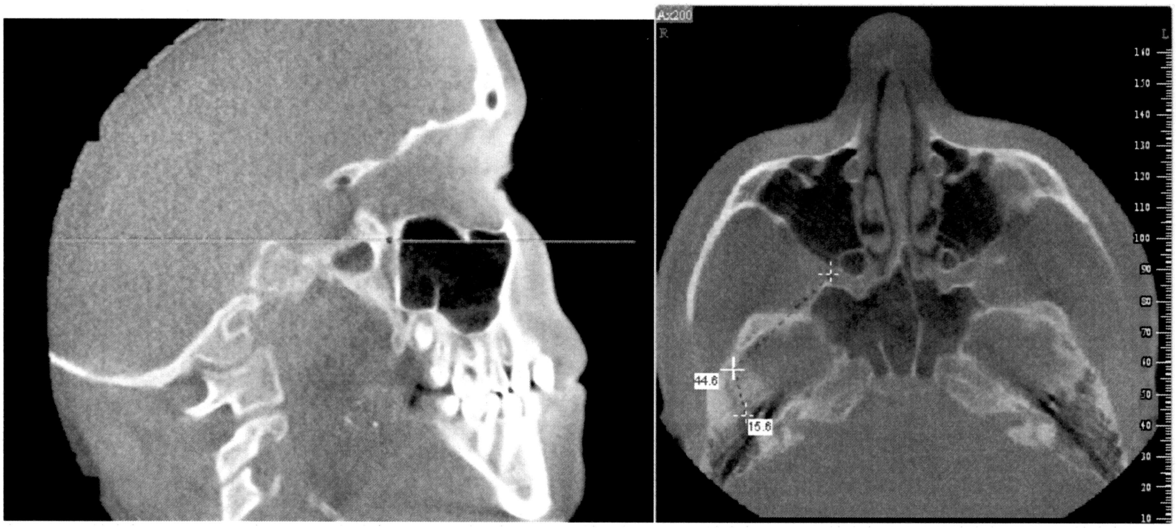

Figure 11. CBCT lateral and axial images demonstrating the acquisition of GF-PtM and GF-Po

## Statistical Analysis

A standard statistical software package, SPSS 16 (Chicago IL), was used to analyze the data. The significance level was set at α=0.05. Intraclass correlation coefficient (ICC) was determined to test intraobserver reliability. Means, standard deviations, and 95% confidence intervals of linear and angular measurements were calculated for both groups. A paired sample t-test was performed to evaluate if there was a significant difference between left and right linear measurements and between T1 and T2/T3 measurements. An independent t-test was done to determine if a significant difference was found between patients treated with functional appliances and those that underwent orthodontics without orthopedic mechanics.

## Results

Twelve patients (10 male, 2 female; mean age, 15.1 years), who were treated with the fixed functional appliance therapy until Class I molar occlusion was achieved (mean treatment time = 11.1 ± 2.6 months), constituted functional appliance group. The control group included twelve gender-and age-matched patients (10 male, 2 female; mean age 15.3 years) who completed treatment for Class I malocclusion with orthodontic mechanics without orthopedic effects (mean treatment time = 33.6 ± 13.2 months). The intraclass correlation coefficient (ICC) for the measurement was 0.88 indicating that the measurement method was reliable and reproducible. No significant differences were found when comparing the left and right measurements at T1 or T2/T3 (Tables 2-5; $p > .05$), so the decision was made to combine the bilateral data sets into the same data group.

### Functional Appliance Treatment Results

The mean ANB measurements of 6.2 ± 3.1 mm and 4.5 ± 2.1 mm were observed at T1 and T2 respectively, corresponding to a mean change of -1.7 ± 1.2 mm. The mean OJ of 5.8 ± 3.4 mm and 2.2 ± 1.1 mm were observed at T1 and T2 respectively, corresponding to a mean change of -3.6 ± 3.0 mm. The changes in GF-Gn (6.5 ± 3.3 mm) and C-Gn (6.4 ± 3.6) were most pronounced and strongly significant (Table 6; $p < 0.001$). There were also significant changes in GF-Po (0.6 ± 0.9 mm; $p=0.039$) and IMP (6.1 ± 6.5°; $p=0.008$) [Table 6]. However, The change in GF-PtM (0.6 ± 1.1 mm) was not statistically significant (Table 6; $p=0.067$).

## Conventional Orthodontic Treatment Results

The mean ANB measurements of 3.0 ± 2.1 mm and 3.1 ± 1.6 mm were observed at T1 and T3 respectively, corresponding to a mean change of 0.1 ± 1.3 mm. The mean OJ of 2.1 ± 1.3 mm and 1.8 ± 0.8 mm were observed at T1 and T3 respectively, corresponding to a mean change of -0.3 ± 1.6 mm. The changes in GF-Gn (6.1 ± 4 mm), C-Gn (6.0 ± 3.7), and GF-Po (1.0 ± 0.5) were most pronounced and strongly significant (Table 7; $p < 0.001$). There were no significant changes in GF-PtM (0.02 ± 1.6 mm; $p=0.957$) and IMP (3.4 ± 6.1°; $p=0.078$) [Table 7].

## Functional Appliance Treatment vs. Conventional Treatment Results

There were no statistically significant differences in the changes of all parameters measured between the 2 groups (Table 8; $p > .05$).

Table 2. Comparison of Left and Right T1 Measurements of Functional Appliance group Using the Paired Sample t-test

| **Measurement** | **Mean ± SD (mm)** | | | **P-Value** |
|---|---|---|---|---|
| | **Left** | **Right** | **Difference** | |
| **GF-Gn** | 115.9 ± 7.2 | 115.1 ± 7.1 | 0.8 ± 1.3 | .062 |
| **C-Gn** | 114.1 ± 7.7 | 113.6 ± 6.9 | 0.4 ± 1.3 | .280 |
| **GF-Po** | 13.7 ± 1.4 | 13.8 ± 1.3 | -0.1 ± 1.3 | .727 |
| **GF-PtM** | 38.1 ± 3.4 | 37.3 ± 3.0 | 0.8 ± 2.7 | .344 |

**N =12**

Table 3. Comparison of Left and Right T2 Measurements of Functional Appliance group Using the Paired Sample t-test

| **Measurement** | **Mean ± SD (mm)** | | | **P-Value** |
|---|---|---|---|---|
| | **Left** | **Right** | **Difference** | |
| **GF-Gn** | 122.3 ± 6.3 | 121.5 ± 6.2 | 0.8 ± 1.4 | .085 |
| **C-Gn** | 120.5 ± 5.6 | 120.0 ± 5.6 | 0.6 ± 1.0 | .076 |
| **GF-Po** | 14.1 ± 1.3 | 14.5 ± 1.1 | -0.5 ± 1.3 | .216 |
| **GF-PtM** | 38.7 ± 3.4 | 38.0 ± 3.7 | 0.7 ± 2.1 | .255 |

**N = 12**

Table 4. Comparison of Left and Right T1 Measurements of Control Group Using the Paired Sample t-test

| **Measurement** | **Mean ±SD (mm)** | | | **P-Value** |
|---|---|---|---|---|
| | **Left** | **Right** | **Difference** | |
| **GF-Gn** | 119.4 ± 5.6 | 119.1 ± 5.1 | 0.3 ± 1.4 | .522 |
| **C-Gn** | 117.6 ± 5.3 | 117.8 ± 5.3 | -0.2 ± 1.1 | .527 |
| **GF-Po** | 13.9 ± 1.7 | 14.2 ± 1.6 | -0.3 ± 1.5 | .517 |
| **GF-PtM** | 38.1 ± 2.8 | 37.3 ± 2.1 | 0.8 ± 1.5 | .079 |

**N = 12**

Table 5. Comparison of Left and Right T3 Measurements of Control Group Using the Paired Sample t-test

| **Measurement** | **Mean ± SD (mm)** | | | **P-Value** |
|---|---|---|---|---|
| | **Left** | **Right** | **Difference** | |
| **GF-Gn** | 125.0 ± 4.7 | 125.6 ± 4.3 | -0.6 ± 0.8 | .069 |
| **C-Gn** | 123.8 ± 4.6 | 123.8 ± 4.5 | -0.1 ± 1.0 | .594 |
| **GF-Po** | 14.8 ± 1.3 | 15.4 ± 1.5 | -0.6 ± 1.2 | .110 |
| **GF-PtM** | 37.8 ± 2.1 | 37.7 ± 2.7 | 0.1 ± 1.3 | .761 |

**N =12**

Table 6. Comparison of T1 and T2 of Functional Appliance group Using the Paired Sample t-test

| **Measurement** | **Mean ± SD (mm)**** | | | **P-Value** |
|---|---|---|---|---|
| | **T1** | **T2** | **T2 – T1** | |
| **ΔGF-Gn*** | 115.5±7.2 | 121.9 ± 6.2 | 6.5 ± 3.3 | .000 |
| **ΔC-Gn*** | 113.8 ± 7.3 | 120.2 ± 5.6 | 6.4 ± 3.6 | .000 |
| **ΔGF-Po*** | 13.7 ± 1.2 | 14.3 ± 1.0 | 0.6 ± 0.9 | .039 |
| **ΔGF-PtM*** | 37.7 ± 2.9 | 38.4 ± 3.4 | 0.6 ± 1.1 | .067 |
| **ΔIMP⬧** | 98.7±6.4 | 104.8 ± 8.1 | 6.1 ± 6.5 | .008 |
| **ΔANB⬧** | 6.2 ± 3.1 | 4.5 ± 2.1 | -1.7 ± 1.2 | .000 |
| **ΔOJ⬧** | 5.8 ± 3.4 | 2.2 ± 1.1 | -3.6 ± 3.0 | .001 |

*** N =24; ⬧ N = 12**
**** Except IMP (°)**

Table 7. Comparison of T1 and T3 of Control Group Using the Paired Sample t-test

| **Measurement** | **Mean ± SD (mm)**** | | | **P-Value** |
|---|---|---|---|---|
| | **T1** | **T3** | **T3 – T1** | |
| **ΔGF-Gn*** | 119.2 ± 5.3 | 125.3 ± 4.5 | 6.1 ± 4 | .000 |
| **ΔC-Gn*** | 117.7 ± 5.3 | 123.7 ± 4.5 | 6.0 ± 3.7 | .000 |
| **ΔGF-Po*** | 14.1 ± 1.4 | 15.1 ± 1.3 | 1.0 ± 0.5 | .000 |
| **ΔGF-PtM*** | 37.7 ± 2.4 | 37.8 ± 2.3 | 0.02 ± 1.6 | .957 |
| **ΔIMP♦** | 90.6 ± 7.8 | 94.1 ± 6.8 | 3.4 ± 6.1 | .078 |
| **ΔANB♦** | 3.0 ± 2.1 | 3.1 ± 1.5 | .11 ± 1.4 | .789 |
| **ΔOJ♦** | 2.0 ± 1.2 | 1.8 ± 0.8 | -.26 ± 1.6 | .580 |

*** N =24; ♦ N = 12**

**** Except IMP (°)**

Table 8. Comparison of Experimental and Control Linear and Angular Measurements Using Independent t-test

| **Measurement** | **Mean ± SD (mm)**** | | | **P-Value** |
|---|---|---|---|---|
| | **Experimental** | **Control** | **Difference** | |
| **ΔGF-Gn*** | 6.5 ± 3.3 | 6.1 ± 4 | 0.4 ± 1.5 | .801 |
| **ΔC-Gn*** | 6.4 ± 3.6 | 6.0 ± 3.7 | 0.4 ± 1.5 | .807 |
| **ΔGF-Po*** | 0.6 ± 0.9 | 1.0 ± 0.5 | -0.4 ± 0.3 | .142 |
| **ΔGF-PtM*** | 0.6 ± 1.1 | -0.02 ± 1.6 | 0.7 ± 0.6 | .240 |
| **ΔIMP♦** | 6.1 ± 6.5 | 3.4 ± 6.1 | 2.6 ± 2.5 | .320 |
| **ΔANB♦** | -1.7 ± 1.2 | .11 ± 1.4 | -1.6 ± | .002 |
| **ΔOJ♦** | -3.6 ± 3.0 | -.26 ± 1.6 | -3.3 ± | .002 |

*** N =24; ♦ N = 12**

**** Except IMP (°)**

## Discussion

This study is the first to use cone-beam computed tomography to compare the osseous changes in the TMJ and the length of the mandible when utilizing functional appliance therapy. Although this subject has been researched extensively in orthodontic literature, technological advancements has enabled more accurate determination of anatomical landmarks by eliminating the ambiguity of superimposed skeletal structures encountered in 2D radiography.[39] [40] [41] Regardless of the current controversy concerning the mode of action of functional appliances, this study aims to determine the actual change that resulted in successful Class II malocclusion correction.

A study investigating the long term effects of temporomandibular joint growth changes in Herbst treatment concluded that the condylar growth was directed posteriorly about twice as much in the functional appliance group, and the fossa was displaced in an anterior inferior direction.[9] Numerous earlier studies focused only on the adaptive quality and enhancement of the mandibular condyle leaving other important factors largely overlooked. [42] [43] [44] Later studies placed more emphasis on the role of the glenoid fossa, and its possible role in skeletal correction. A recent study reported that a possible diagnostic feature of Class II malocclusion associated with a retruded mandible is a significantly more distal position of the glenoid fossa compared to a patient with Class I skeletal relationship.[40] This led to the concept that a proposed mode of action of functional appliances involves restriction of the glenoid fossa from continuing in a natural downward and backward growth direction.[27]

## Length of the Mandible

The concept of enhancing the length of the mandible beyond its genetic potential has been long debated.[9 45 46] Inconsistencies in previous studies including the choice of anatomic landmarks have been attributed to the ongoing debate on appliance efficacy. In this study, the length of the mandible was measured from two readily repeatable landmarks. To eliminate the possibility of increased mandibular length measurements due to the downward and forward positioning of the condyle in the glenoid fossa after treatment, the distance between the superior point of the glenoid fossa to gnathion and the superior point of the condyle to gnathion were both recorded.[47] While GF-Gn did not record the length of the mandible directly, it enabled us to evaluate GF position in relation to C. By evaluating the difference between the two measurements, we could determine that correction to Class I molar relationship did not occur solely by posturing of the mandible forward. In both functional appliance and control groups, ΔGF-Gn and ΔC-Gn were significant and almost identical (Tables 6-8), indicating that while there was a significant increase in mandibular length, a cohesive relationship between condyle and glenoid fossa has been maintained. This was confirmed by comparing the sagittal views of temporomandibular joints at different time intervals (Figure 12-13). Furthermore, ΔGF-Gn and ΔC-Gn between both groups were not significantly different (Table 8; $p > .05$). This can be attributed to the considerably shorter treatment time of 11.1 months (T1-T2) of the functional appliance group compared to the 33.6 months (T1-T3) of the control group.

The results of this study indicate that the length of the mandible increased significantly with functional appliance treatment during the observation period (Table 6).

Though not statistically significant, the mean increase in both mandibular length measurements of the functional appliance group exceeds that of the control (Table 8), which represents a group experiencing an average 24 extra months of growth.

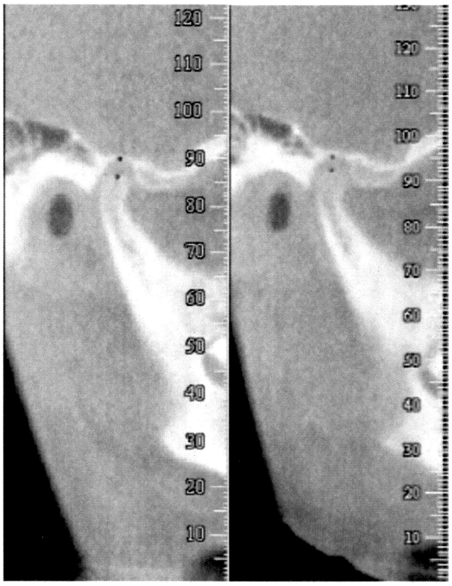

Figure 12. CBCT sagittal image showing condyle position of functional appliance group at T1 (left) and T2 (right)

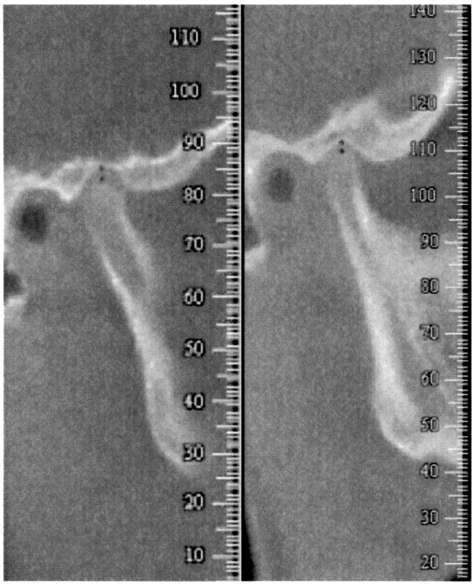

Figure 13. CBCT sagittal image showing condyle position of control group at T1 (left) and T3 (right)

### Location of the Glenoid Fossa

Recent studies have looked at morphological changes of the glenoid fossa as a mode of action of functional appliances.[1 27 29] This study measured the highest point of the glenoid fossa to the pterygomaxillary fissure and porion to determine if skeletal correction was obtained by anterior displacement of the fossa.[27] Our laboratory results found that there was a statistically significant difference in the linear measurement from porion to the superior point of the glenoid fossa but not from pterygomaxillary fissure to superior point of the glenoid fossa in both groups. This indicates that both groups experienced anterior displacement of the glenoid fossa rather than the normal downward and backward growth.[48]

However, the GF-Po measurement in the functional appliance group did not seem to be clinically significant with a change of only 0.6 mm. When compared to the control group, which displayed a change of 1 mm, it appears to be attributed to normal remodeling of the fossa and a part of the overall growth process. Thus, if the GF was not displaced anteriorly, and the relationship between GF and C remained relatively constant, this shows that the mandibular condyle was growing backward and upward toward the GF. In addition to this, it must be noted that the 3D measurements taken at different time points are not in the same sagittal plane of space, which means that lateral displacement of the fossa is not taken into consideration. Therefore, mandibular posturing and especially asymmetrical correction may lead to different results depending on the amount of lateral condylar displacement.[16]

## Mandibular Incisor Position

Proclination of the mandibular incisors is a dental effect of functional appliances as a result of anchorage loss. Although considerable steps are taken to ensure anchorage control, some of the Class II correction of functional appliances is attributed to dental proclination.[49] The results of this study demonstrate a statistically significant increase in IMP only in the functional appliance group, which support the conclusion of numerous studies indicating functional appliance correction occurs through skeletal and dental changes.[40] [50] In addition to these results, the mean correction of OJ in the functional appliance group was 3.6 mm with a mean change in ANB of 1.7 mm. This shows that the correction to Class I molar position is about 50% skeletal and 50% dental.

For this study, it would have been desirable to have a control group of CBCT images of untreated Class II malocclusion patients that were, but this was prohibited by ethical reasons. However, the age and gender of patients undergoing functional appliance treatment were closely matched with Class I malocclusion patient receiving conventional orthodontic therapy. Comparing these two groups enabled us to determine if there were significant skeletal adaptations associated with responses to alterations in the functional position of the condyle. It is important to note that the mean duration between CBCT images of functional appliance treatment patients was 11.1 months and 33.6 months for conventionally treated patients. Further research is required to quantify possible skeletal and dental relapse after the completion of functional appliance treatment and radiographic images at T2 of this group would provide a more reliable comparison with the control.

## Conclusions

1. Functional appliances correct Class II malocclusion by both skeletal (~50%) and dental (~50%) changes.
2. Skeletal change was achieved primarily through increase in mandibular length with negligible change in the glenoid fossa position.
3. Dental correction was achieved through an increase in IMP (incisor inclination).

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