THREE-DIMENSIONAL EVALUATION OF MANDIBULAR CHANGES ASSOCIATED WITH HERBST TREATMENT IN GROWING CLASS II PATIENTS

Thomas R. Covington

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Approved by:

Tung T. Nguyen

Ching Chang Ko

Beatriz Paniagua

ABSTRACT

Thomas R. Covington: Three-dimensional evaluation of mandibular changes associated with Herbst treatment in growing Class II Patients: Pilot Study
(Under the direction of Tung T. Nguyen)

Introduction: Herbst appliance treatment of Class II malocclusions is common in orthodontic offices. Recent advances in 3D superimpositions have allowed semi-quantitative assessment of skeletal and dental changes accompanied with Herbst treatment. The aim of this study was to evaluate 3D skeletal and dental changes following Herbst removal. **Methods:** 7 consecutive Herbst patients had CBCTs taken pre-treatment (T1), post Herbst removal (T2), and one year following Herbst treatment (T3). 3-D models were generated from CBCTs; anterior cranial base registrations were performed to evaluate morphological changes of the maxillary and mandibular skeleton. Mandibular registrations on the inner cortical symphysis were performed to evaluate mandibular growth and displacement as well as mandibular dental changes. Registered models were analyzed using color maps and vector based anatomical point-to-point measurements. **Results:** During initial Herbst treatment, patients demonstrated anterior translation of glenoid fossa and condyles and anterior projection of B point, however; variable skeletal changes were observed one-year post Herbst removal. 4-patients demonstrated a posterior displacement and 3-patients had continued anterior displacement of B-point (0.88mm+/-2.54mm). The later three demonstrated inferior displacement of the glenoid fossa/condyle complex leading to a counter clockwise rotation of the mandible one year post Herbst removal. All patients showed posterior displacement of the glenoid fossa and condyles one year post Herbst. While there was a significant maxillary restraining effect during Herbst application, insignificant anterior/posterior changes were seen following Herbst removal.

Conclusions: Maxillary skeletal changes during Herbst treatment were maintained; however anterior/posterior changes in mandibular position one year post Herbst removal were variable. Condyle fossa complex moved anterior during Herbst treatment but was displaced posterior one year following treatment. Inferior positioning of the glenoid fossa/condyle complex may have a larger change in the AP position of the mandible.

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Three dimensional imaging combined with the ability to perform fully automated voxel based registration on the anterior cranial base of growing patients has allowed accurate observation of skeletal changes in adolescent patients[1-3]. These 3D imaging techniques overcome the inadequacies of 2D cephalometric imaging including magnification, distortion, patient positioning errors and obstruction of critical landmarks[4,5]. There is also inherent bias in superimpositions with 2D images [5]. There are different ways to register 3D segmentations[2]. The first is a point to point registration technique. With a point to point registration technique, the researcher identifies landmarks on each time point and then overlays the two time points registering on these two manually identified landmarks. The second 3D registration technique is surface to surface. With surface to surface registration, two surfaces are identified on each time point and the computer digitally overlays the surfaces. The computer algorithm finds a closest approximation of the two surfaces by minimizing the distance between the two surfaces. The third is a voxel based registration. This new registration technique selects thousands of voxels and uses shape, volume and voxel intensity to demarcate between bone and soft tissue[3]. Maxillary and Mandibular adaptive and positional changes can be accurately examined and measured relative to the anterior cranial base using these 3D superimposition techniques[1-3]. Imprecisions of the 2D registration technique are eliminated by an entirely computerized voxel based registration technique. Additionally, 2D lineal and angular cephalometric measurements do not explain the complex 3-dimentional (3D) process of bone remodeling over time. If voxel registration is completed on the anterior cranial base, the researcher is able to accurately examine and measure maxillary and mandibular adaptive and positional changes. Once images are segmented into appropriate skeletal regions, point measurements and visualization using color maps are helpful to determine the true skeletal changes over time. While these observations in maxillary and mandibular changes are progressive, there are still unknowns regarding regional growth of the mandible that lead to anterior/posterior projection. To fully understand mandibular growth and response to treatment, you need to combine cranial base superimpositions with regional mandibular superimpositions.

Recently 3D voxel based mandibular regional superimpositions have been validated to be accurate and reproducible. 3D mandibular regional superimpositions allow you to visualize and quantitate mandibular growth in areas that are difficult to visualize on 2D images. With 3D mandibular regional superimpositions you can measure growth in the condylar region, mandibular surface remodeling, and dento-alveolar alterations. Cranial base superimpositions in combination with mandibular regional superimpositions can define exact mandibular growth that lead to an overall response.

Review of Mandibular Growth

Growth of the mandible occurs at the mandibular condyle and along the posterior surface of the ramus with resorption of the anterior ramus; furthermore, the ramus is increased in height by endochondral replacement at the condyle followed by surface remodeling[6-10]. The pattern of displacement of the condyles is superior and posterior leading to a forward and downward movement of the chin[10]. The amount of superior versus posterior growth of the mandibular condyle translates to the amount of vertical versus anterior growth each patient demonstrates. Historically, growth of the mandible, in particular, rotation of the mandible dates back to 1955 when the idea that the mandibular corpus rotates during growth was first described[6]. Here Bjork said that shape is kept stable by associated substantial surface remodeling[6]. In 1983 Bjork published a 25 year longitudinal cephalometric implant study describing growth and remodeling of the mandible. He concluded that there we individuals that had a forward rotation of the mandible and others that experienced a backwards rotation of the mandible[7]. The rotation is based on how the inferior border of the mandible compares to the anterior cranial base. If these lines converge forward to the face, it is forward rotation. This is a counter clock-wise rotation. However, if there is a clock-wise rotation of the mandible, showing an increased MPA, then Bjork described this as a backward rotational growth pattern[7]. Two distinct types of facial development create backwards rotation, Class II division I patients and people with pathology or condylar fracture[7]. Bjork was also instrumental in describing surface remodeling of the mandible with growth. The remodeling pattern is apposition below the symphysis and anterior part of the lower boarder of the mandible as well as apposition at the posterior surface. Resorption is experienced along the anterior surface of the ramus and at the lower boarder of the angular region[6-9]. These studies also described the eruption of the mandibular dentition. There is marked growth in the height of alveolar process and the direction of eruption is forward relative to the occlusal plane. Meaning there is a forward migration of the dentition relative to mandibular corpus[6-9]. This leads to an increase in incisor proclination over time[7].

Class II Orthodontic Treatment

The orthodontic profession is challenged with the treatment of malocclusions. Many perceived dental malocclusions have an underlying dentofacial orthopedic component. These skeletal relationships are classified based on the amount of protrusion or retrusion of the maxilla and mandible. Skeletal Class II relationships are commonly encountered in orthodontic practices in the United States[10]. The etiology of a skeletal Class II malocclusion includes a prognatic maxilla, a retrognathic mandible or a combination of both. A study by McNamara in 1981 revealed that up to 85% of class II patients have some component of mandibular deficiency underlying the skeletal class II discrepancy[11]. Treatment of the skeletal Class II patient is based on severity. Treatment ranges from dental compensation including camouflage with extractions to surgical procedures targeted at moving the jaw at fault. In growing patients, growth modification of the skeletal structures offers an intermediate treatment option. Growth modification is appealing over camouflage because ideally, the skeletal discrepancy should be addressed for optimal treatment results.

When evaluating treatment options for Class II patients, the extent of the skeletal discrepancy and the skeletal maturity of the patient need to be considered. In non-growing patients with a less severe skeletal discrepancy, class II camouflage may be appropriate. However, if camouflage treatment is delivered to a patient with a relative severe skeletal class II discrepancy, it can result in a poor esthetic outcomes[12]. Surgical treatment may be indicated for patients with extremely severe skeletal problems, or for patients with no growth potential remaining. Most common surgical treatment involves mandibular bilateral sagittal split osteotomy advancement, because a majority of the patients have some component of mandibular deficiency[13]. However, maxillary set back can also be conducted as an isolated procedure or in conjunction with a mandibular advancement procedure[13]. Surgery is expensive and is associated with comorbidities including paraesthesia, anaesthesia, paralysis and potentially death. Because of these potential complications, patients are often reluctant to go through surgical treatment. In fact, from 1984 to 1996, only 42% of the patients seen at the Dentofacial clinic at the University of North Carolina for surgical correction of a class II skeletal problem accepted and completed surgical treatment[13]. Alternatively, if the patient is intercepted when there is inherent growth remaining, growth modification can be attempted to correct the skeletal discrepancy.

Growth modification for skeletal Class II patients includes restricting forward (anterior) growth of the maxilla and promoting forward growth/projection of the mandible. This takes advantage of differential growth resulting is more anterior projection of the mandible. Timing for growth modification is extremely important. Both human and animal orthopedic investigations have recognized the ideal time for class II growth modification is during the pubertal growth spurt[14-17]. This treatment window is during the peak pubertal growth spurt, which corresponds to CVM stage of CS3-CS4[18]. From McNamara, we know a majority of class II patients have mandibular deficiency, thus, utilizing growth modification treatment modalities that target the jaw at fault (i.e. the mandible) is ideal. Functional appliances are claimed to increase mandibular projection. Orthodontic treatment with appliances like the Herbst, bionator, twin block, or headgear can effectively achieve ideal overjet and class I dental relationships, however a systematic review by Cozza and Baccetti published in 2006 revealed that the Herbst appliance is the most effective at increasing mandibular projection[19].

Class II treatment with the Herbst appliance

The Herbst appliance is a commonly used functional appliance for the correction of a class II malocclusion[20]. The inventor was Emile Herbst, and he first presented the appliance at the 5th International Dental Conference in Berlin in 1909. Due to controversies in damage to the periodontium, the Herbst fell out of favor for a number of years until Hans Pancherz revisited the treatment modality. Herbst appliance design has evolved over the past 100 years; however, the basic mechanism has remained unchanged. The device includes bilateral telescope mechanisms that guide the mandible into an anterior position during rest, and all functional movements[20]. Current designs include crowns on the maxillary first molars and crowns on the mandibular first molars with straight telescoping mechanisms. A cantilever extends mesial to the mandibular molar crown to which the telescoping arms attach. These telescoping arms extend mesial of the mandibular premolars applying a force in an anterior direction. It is often referred to as the cantilever Herbst. The cantilever Herbst was initially designed for the mixed dentition prior to the eruption of the mandibular canines or first pre-molars. This design also allows the orthodontist to bond anterior teeth for increased anchorage and concurrent leveling/ aligning of the mandibular arch.

The cantilever Herbst design requires extra consideration. Because of the long anterior arm extension, the distance of the force to the center of rotation is very large and can lead to significant mesial tipping of the mandibular molars. For this reason, an occlusal rest that extends from the mesial of the mandibular molar to the occlusal of the 1st premolar is recommended. In addition, a rest from the distal of the mandibular first molars to the occlusal of the mandibular second molars helps to prevent eruption of the second molar. Often, a lower lingual holding (LLHA) arch is included in the design of the cantilever Herbst in order to prevent mesial crown tip of the mandibular molars. From the LLHA a support bar that crosses the occlusion distal to the mandibular canine can be added to preserve the transverse dimension. Preservation of the transverse dimension protects the patient from adverse gingival damage of the cantilever arm.

In the maxilla, occlusal rests are extended from the distal of the first molars to the occlusal of the second molars. This helps to control distal tipping of the first molars. Because there is an inherent vertical force created by the telescoping arms, the maxillary occlusal rest also prevents intrusion of the maxillary first molar and extrusion of the second molar.

An adverse effect of the Herbst appliance is proclination of the lower incisors[21]. Proclination of the lower incisors can be prevented in the cantilever Herbst with brackets and rectangular wires that add negative root torque. Adding brackets to the lower incisors can also help to control the cantilever forces exhibited on the molars by increasing anchorage. In addition, adding brackets during Herbst treatment can allow leveling of the curve of spee that is often present in Class II malocclusions.

The Herbst is a tooth supported appliance. As such, some studies suggest the effects of the Herbst are primarily dentoalveolar[22]. Many studies report the Herbst, improves mandibular projection, consequently improving the underlying skeletal discrepancy[22]. A mild restraining effect in response to Herbst treatment has been noted by many studies, and the effect has been shown to be statistically similar to the effect produced by headgear[23-26]. Meanwhile, some studies suggest the skeletal headgear effect displayed by the Herbst is negligible. Ultimately, available data which examines the extent of skeletal verse dentoalveolar adaptation in that lead to the class II correction when using the Herbst is controversial. The skeletal component of class II correction has been reported to extend from 13% to 85%[27-30].

Dentoalveolar effects of the Herbst provide large changes leading to class II correction. In general, mandibular molars will move mesially (often tipping) between 0.5 and 5.5mm. Maxillary molars may have up to 1 mm of intrusion, and distalize between 0.6 and 3.0 mm. Distal tipping of the maxillary molars between 5.6° and 6.4° are also observed. The mandibular and maxillary 2nd molars often extrude because overcorrection of the OJ to an end-to end or negative overjet causes posterior disocclusion. The lower incisors will procline between 5.4° and 10.8° and will move mesially between 0.2mm and 4.0 mm. The occlusal plane rotates in a clockwise direction due to intrusion of maxillary molars between 1.1° -5.5°.

Skeletal effects of the Herbst appliance have variances in the literature. It is partly due to the discord in measurement methods used with 2D images. The method developed by Pancherz utilizes a reference grid constructed from the occlusal line (OL) and the occlusal line perpendicular (OLp)[28,29]. Maxillary measurements using this method are subject to patient positioning errors. Many studies use an angular measurement, SNA, to examine maxillary changes. However, increases in the vertical dimension as seen with growth will mask the anterior-posterior change when using these angular measurements[5]. Skeletal changes observed at A point, indubitably depend on the methodologies used.

Studies supporting a maxillary restraining effect of the Herbst theoretically make sense. During treatment the Herbst appliance exerts an upward and posterior force that is similar to a high-pull headgear. Studies report a restraining effect on the maxilla with decrease SNA ranging from 0.4°-1.2°[24,31]. However, the SNA angle often relapses to preclinical values[24]. Authors using the grid system to evaluate maxillary restraint found 0.4 mm maxillary restraint to 2.8 mm[21,29,32]. It is important to understand that authors often found different effects on the maxilla depending on the method of analysis employed. Mild tipping of the palatal plane have also been reported. Overall, many studies found no difference in the anterior-posterior projection of the maxilla. These studies employed 2D technologies leaving image methodology as a variable in the discrepancy. Other authors suggest that remaining growth potential after Herbst treatment is cause for the relapse. Recent studies using 3D cone beam computed tomography demonstrate that anterior displacement of A-point was more predominant in the controls when compared with the Herbst patients (1.20 +/- 0.53 mm vs -1.22 +/- 0.43 mm; P < 0.001)[26]. After a rigid, voxel based registration on the anterior cranial fossa was performed, this study used closed point measurement between the two different time points.

Alteration of anterior-posterior projection of the mandible can be attributed to changes in mandibular growth, changes in the direction of growth and/ or condylar/ fossa positional changes. Previous studies report conflicting results with some showing increased mandibular length with Herbst treatment[14,19,24,30,33]. While other studies show no significant increase in mandibular length[21,30]. Deviations in patient positioning, as well as differences in magnification ratios between the left and right sides of the mandible can affect 2-D measurements of mandibular corpus length and ramus height.

Currently, most of the literature that evaluates mandibular growth following functional appliance therapy use condylion, an arbitrary condylar point, or a proxy- point such as articulare. Condylion landmark identification is associated with low reliability due to obstruction of the overlying temporal bone. Utilizing an arbitrary condylar point, as in the method described by Creekmoor, and used by Pancherz improves landmark identification. However, this method is still subject to distortion, magnification, and mandibular regional registration errors during the transfer process. Additionally, rotational deviations in patient positioning between T1 and T2 image capture, will have a large effect on the perceived mandibular corpus length regardless of the measurement used. Any discrepancy in "tilt" or pitch positional errors will also affect vertical measurement error. Lastly, using articulare as a proxy condylar point is going to present significant measurement error. The position of articulare is dependent on vertical and anterio-posterior changes of the glenoid fossa and condyle. Because articulare is dependent on growth, it does not suit well as a proxy point for condylion in longitudinal growth studies.

Despite these limitations, Baccetti et. al. found that class II subjects treated with a Herbst achieved chin advancements from 2.5 mm to 5 mm greater than untreated class II patients and had 2 mm to 4 mm greater chin advancements (determined by B point and pogonion) compared to patients treated with head gear and class II elastics[24]. Increasing mandibular growth with Herbst therapy has also been reported by Pancherez et. al[32]. Meanwhile some studies show an increase in the anterior-posterior projection of the mandible without a statistically significant increase in mandibular length. Long-term change in SNB angles are variable, with some studies finding no difference, while other studies report increases of 0.3°-2.6°[23,25,29,32,34]. The ANB angle has been shown to decrease between 1.1° to 3.9°, and remains relatively stable. A counterclockwise rotation secondary to dental effects was noted in a study by Papadopoulos. This movement helps the class II skeletal relationship. The literature is in discord regarding increases in posterior mandibular height. Again, these differences likely arise due to different methodologies in measurement protocols.

In addition to increased length, alterations in growth pattern will also impact anterior-posterior projection of the mandibular base. Opening of the gonial angle and posterior flexure of the condyle are anatomical changes that can lead to more anterior mandibular positioning. Initial placement of the Herbst causes the condyle to be placed anteriorly onto the articular eminence. After 6-12 weeks, the condyles showed a more posterior position in the glenoid fossa, and the posterior superior aspect of the condyle showed increased signal intensity on MRI[35,36]. Condylar osteogenesis during Herbst treatment has also been shown in animal studies. Sagittal condylar growth has been reported to occur. The condyle moves between 1.5-3.1 mm superiorly and 2.1-4.0 mm posteriorly. Interestingly, the direction of condylar osteogenesis occurs in the direction of tension from the stretch of disc fibers on the condyle and glenoid fossa.

In addition to redirection the growth pattern of the mandible, altering the growth process of the glenoid fossa can also allow for increased mandibular projection. It is believed that there are two sites in the temporal mandibular joint (TMJ) that adapt to the forces of the Herbst: 1) condyle; and 2) glenoid fossa[36]. The condylar position changes within the fossa have also been proposed however this is not significantly confirmed in ether animal or human studies. Pancherz et al looked at the size of the joint space pre- and post Herbst treatment. They found that there was no statistical difference in the condylar position. However, there was great variation among patients. It was revealed that post treatment condylar positions were on average slightly more anterior than pretreatment positions.

Translation of the glenoid fossa, has been shown to contribute to mandibular positional changes post Herbst treatment[26]. However, 2D imaging techniques used in human studies are greatly flawed when assessing for remodeling of the glenoid fossa. Human studies often rely on an unchanged condyle-fossa relationship because they utilize the method described by Buschang and Santos[37]. Ruf and Pancherz conducted an MRI study to evaluate effective condylar growth in Herbst patients[36]. They noted increase uptake in the T2-weighted sequences in the glenoid fossa and condyle. This was interpreted to be definitive areas of condyle and fossa remodeling. However, because the incidence of capsulitis rises during Herbst treatment up to 100%, virtually all patients would be expected to have increased T2 signal due to the amplified inflammatory process. Differentiating inflammatory processes from the cellular cascade of skeletal remodeling is difficult. Additionally, techniques to register and superimpose MRI scans to evaluate changes critically from T1 to T2 have not been developed for the cranial base. Therefore, MRI scans cannot be used to adequately examine skeletal adaptations until a proper registration and superimposition technique is developed.

Some studies have suggested remodeling may occur. However, these studies use condylion or articulare as a proxy point to approximate the position of the fossa. Those conclusions were not absolute due to imaging limitations and measurement errors. After examining all of the condylar and fossa changes, they concluded overall the "effective condylar growth" during Herbst treatment resulted in six-times more horizontal growth and four-times more vertical growth when compared to Bolton Standards[36]. Recently a CBCT study registered on the anterior cranial base have demonstrated anterior glenoid fossa remodeling in a 1:1 relationship with the condyle[26].

Herbst Studies using CBCT Imaging

Newer studies are using CBCT images to account for ambiguity in the methodology and to avoid the limitations of 2D imaging. LeCornu et al. used 3D cranial base superimpositions to describe skeletal changes immediately after Herbst removal[26]. They found that there was an anterior displacement of the condyles and glenoid fossa that lead to an increase in projection of B-point in Herbst patients (2.62 +- 1.08mm vs 1.49 +/- 0.79mm; $P < 0.05$)[26]. This anterior translation of the glenoid fossa/condyle was compared to controls that have posterior displacement in concordance with normal growth. They also confirmed the maxillary headgear effect with mild maxillary restraint. Without mandibular regional registration they were unable to account for the amount and direction of mandibular growth each patient demonstrated during treatment. Growth of the mandible occurs at the mandibular condyle and along the posterior surface of the ramus with resorption of the anterior ramus; furthermore, the ramus is increased in height by endochondral replacement at the condyle followed by surface remodeling[6-10]. Mandibular regional superimpositions allow you to visualize if continued mandibular growth was present. These, along with the cranial base superimpositions, demonstrate a more complete picture of treatment response and mandibular growth patterns.

Relapse with Herbst Treatment

Occlusal results have been shown to be relatively stable with Herbst treatment. A recent 32 year follow up demonstrated that 86% of patients had acceptable overjet and overbite[38]. However, the amount of correction that was dentoalveolar versus skeletal in nature is still controversial. The amount of favorable mandibular changes post Herbst treatment are disputed due to 2D imaging methodology and continued growth of the patient. In 1991, Pancherz studied 15 relapse and 14 stable patients post Herbst treatment. It was stated that relapse in overjet and sagittal molar relationship resulted mainly from post treatment maxillary and mandibular dental changes[28]. However, Pancherz et al. in 2002 suggested that all the favorable condylar (mandibular skeletal) changes and remodeling of the glenoid fossa reverted in a post treatment period ranging from 6-12 months post Herbst removal. During this time the glenoid fossa was displaced posteriorly; the amount of condylar growth and effective TMJ changes were reduced. This would suggest any skeletal contribution was due to maxillary restraint or the headgear effect. Wigal et al. suggested that after early treatment with the Herbst appliance there was a continuous restraint of maxillary growth as well as dentoalveolar adaptations that contributed to maintaining a portion of the correction[23].

Demonstrated above, the literature reveals tremendous variation in the amount of skeletal adaptation leading to improvement in the class II profile. This variation stems from the limitations of 2D imaging. If a majority of skeletal Class II patients have a degree of mandibular retrognathism then a likely treatment goal would be to improve mandibular projection.

However, there is not data to suggest that we have any lasting effect on the mandible. Research using novel three dimensional imaging techniques to clarify the skeletal response to the Herbst appliance is suggestive of a maxillary headgear effect, anterior remodeling of the glenoid fossa, and anterior projection of the condyle. This is a net combined anterior projection of B-point without increasing corpus length of the mandible. However, there is 2D research showing that the favorable changes in the TMJ do not last 1 year following Herbst removal. Research using 3D CBCT technology is needed to accurately demonstrate skeletal relapse post Herbst removal.

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THREE-DIMENSIONAL EVALUATION OF MANDIBULAR GROWTH CHANGES ASSOCIATED WITH HERBST TREATMENT IN CLASS II PATIENTS

Introduction

Three dimensional imaging combined with the ability to perform fully automated voxel based registration on the anterior cranial base of growing patients has allowed improved observation of skeletal changes in adolescent patients[1-3]. These 3D imaging techniques overcome the inadequacies of 2D cephalometric imaging including magnification, distortion, patient positioning errors and obstruction of critical landmarks[4,5]. Imprecisions of the 2D registration technique are eliminated by an entirely computerized voxel based registration technique. The voxel registration technique selects thousands of voxels and uses shape, volume and voxel intensity to demarcate between bone and soft tissue[3]. Maxillary and Mandibular adaptive and positional changes can be accurately examined and measured relative to the anterior cranial base using these 3D superimposition techniques[1-3]. While these observations in maxillary and mandibular changes are progressive, there are still unknowns regarding regional growth of the mandible that leads to anterior/posterior projection. To fully understand mandibular growth and response to treatment, it is necessary combine cranial base superimpositions with regional mandibular superimpositions.

3D mandibular regional superimpositions allow one to visualize and quantify mandibular growth in areas that are difficult to visualize on 2D images. AP, vertical, and transverse changes to the condylar region, lateral surfaces of the mandible, and dento-alveolar alterations in 3 planes of space can be visualized. Recently, 3D mandibular regional superimposition was shown to be reproducible and accurate (Nguyen et al). Cranial base superimpositions in combination with mandibular regional superimpositions can provide a better understanding of mandibular growth patterns that lead to an overall anterior projection.

LeCornu et al. used 3D cranial base superimpositions to evaluate treatment response in Class II patients treated with the Herbst appliance[6]. They found that there was an anterior displacement of the condyles and glenoid fossa that lead to an increased in projection of B-point in Herbst patients[6]. However, they were unable to account for the amount and direction of mandibular growth each patient demonstrated during treatment. Growth of the mandible occurs at the mandibular condyle and along the posterior surface of the ramus with resorption of the anterior ramus; furthermore, the ramus is increased in height by endochondral replacement at the condyle followed by surface remodeling[7-11]. The pattern of displacement of the condyles, relative to the cranial base, is superior and posterior leading to a forward and downward movement of the chin[11]. The amount of superior versus posterior growth of the mandibular condyle translates to the amount of vertical versus anterior growth each patient demonstrates. Thus, mandibular regional superimpositions are required to separate growth effect that leads to forward projection of a patients chin.

Furthermore, investigators have explored the nature of Class II relapse following Herbst treatment with two dimensional cephalometric radiographs with varying conclusions[12-14]. In a long term study Pancherz concluded that relapse of overjet and sagittal molar relationship resulted from maxillary and mandibular dental changes and that skeletal contributions remained stable[12,13]. However, it was also reported that all favorable condylar and glenoid fossa changes that were observed during Herbst treatment reverted after Herbst removal[14].

The aim of this study is to evaluate the skeletal and dental changes associated with the Herbst appliance using 3-D registrations and superimpositions, assess for skeletal and dental relapse one year post Herbst removal, and evaluate mandibular growth patterns. Furthermore, consider if posterior relapse in the glenoid fossa results in posterior movement of B-point.

Subjects and Methods

Skeletal Class II patients (ANB ≥ 4°) near the pubertal growth spurt (determined by cervical vertebral maturation stages CS3-CS4) were identified at the University Of North Carolina Department Of Orthodontics[15]. Seven consecutive patients, who met the inclusion criteria, were enrolled in a prospective pilot study to determine the skeletal effects of the Herbst appliance (Table 1). The inclusion criteria included skeletal ANB ≥4°, Class II dental relationship, and at/near the pubertal growth spurt defined by CVM stage CS3 or CS4[15]. Patient were excluded if they were pre or post CVM CS3-4, had a history of prior orthodontic treatment, trauma to the head and neck area, or a systemic medical condition known to effect growth. Approval from the University of North Carolina Institutional review board was obtained.

Maxillary and mandibular models were obtained for fabrication of the Herbst appliance. The Herbst appliance design included the mini-scope with telescoping arms (Allesee Orthodontic Appliances, Sturtevant, WI). Crowns were placed on upper and lower first molars with a cantilever extending mesial from the mandibular first molar (figure 1). Occlusal rests were added on maxillary second molars and mandibular premolars. The appliance was initially advanced to a Class I molar relationship. Fixed appliances were placed on maxillary first premolar to first premolar and mandibular canine to canine. Mandibular incisor brackets had -10° prescription. Patients were initially started in an appropriate round CuNiTi archwire and advanced to upper and lower 19X25 CuNiTi. A crimp hook was added mesial to the Upper molar and the arch wire was tied back during the Herbst treatment. The Herbst appliance was advanced with 2mm shims to an overcorrected position (OJ = 0 to -1). The duration of the advancement was 6-9 months with a 3-4 month retention period.

Cone Beam Computed Tomography (CBCT) scans were taken pre-treatment (T1), post Herbst removal (T2), and post fixed appliance removal (T3). All CBCT scans were in place of traditional orthodontic radiographs. Average treatment periods were 13 +/- 0.58 months from T1 – T2 and 15.4 +/- 1.6 months from T2 – T3. Premolar and molars were bonded on all Herbst patients to complete orthodontic treatment (between T2 and T3). Scans were taken using the New Tom 3G (Aperio Services LLC, Sarasota, FL) with a 12 inch field of view (FOV). All patients were instructed to bite into maximum intercuspation during the scan. All scans were evaluated to make sure the condyles were seated in the center of the fossa and patients were excluded from study if condyles were postured. No subjects were excluded for posturing during CBCT scan.

First, CBCT DICOM files were converted to an ITK compatible format (open-source software http://www.itksnap.org). Then, 3-D virtual models were constructed of the cranial base, maxilla, and mandible by highlighting each structure using ITK-SNAP. Cranial base registration was completed by roughly approximating the segmentations of the anterior cranial base for T1, T2, and T3 longitudinal scans on analogous landmarks in 3D Slicer (open-source software, http://www.slicer.org). Then, a fully-automated voxel-wise rigid registration was performed on the segmented anterior cranial fossa. This process uses voxel intensity and shape of region of interest to find the best transformation to register each longitudinal scan on T1. Boundaries for the anterior cranial base registration were defined anteriorly by the inner cortical layer of the frontal bone, posteriorly by the anterior wall of sella, laterally including the lesser wings of the speniod bone and superiorly including the frontal bone. The region includes the cribiform plate and superior aspect of the ethmoid bone which are structures known to have completed growth by age seven and are considered stable landmarks.

Mandibular registrations of T3 and T2 to T1 were then separately performed for all Herbst patients. For each time point, a mandibular mask of the region of interest (ROI) was generated in ITK SNAP and served as the volume to register and superimpose T3 and T2 to T1 (Figure 1). Note that the anterior surface on the bony chin above Pogonion and the inferior surface at Menton were excluded because these regions exhibit active remodeling and bone deposition during growth. The superior level of the mandibular registration mask was a line intersecting B point and running parallel to the mandibular plane. The distal border was a plane intersecting the mental foramen. T2 and T3 mandibles were roughly registered to T1 by selecting equivalent landmarks; then, a voxel-based registration was performed using the ROI's to obtain a precise registration on the internal cortical bone of the mandibular symphysis using 3D Slicer. The mandibular registration process was recently validated by Nguyen et al. and shown that including a 3^{rd} molar crypt was not necessary because of the precise nature of voxel-wise registration.

Registered 3-D models were analyzed using closest point measurements from the software 3DMeshMetric (http://www.nitrc.org/projects/meshmetric3d) and point-to-point landmark identification using the software Vectra Analysis Model (Canfield Imaging Systems, Fairfield, NJ). Quantitative evaluation of growth and treatment response were calculated for landmarks on the mandible, fossa/condyle, and maxilla. For all measurements positive values indicate and anterior displacement and negative values indicate a posterior displacement relative to pre-treatment scans (T1). For condylion, positive values indicate superior displacement and negative values inferior displacement.

Each patient was evaluated with a focus on skeletal changes from the prospective of both the cranial base and mandibular regional superimposition. Separate areas of interest were assessed depending on the area of registration. The glenoid fossa/condyle, maxilla, and mandible were evaluated on segmentations registered on the anterior cranial base. Specific anatomical regions of interest included (1) anterior, superior, and posterior landmarks on the glenoid fossa and condyle, (2) anterior surface of the maxilla including ANS and A-point, and (3) anterior mandible including B-point and pogonion. When registered on the inner cortical bone of the mandibular symphysis, skeletal changes in the condylar region and dento-alveolar changes were analyzed.

Results

During Herbst treatment (T1-T2) variations in magnitude of skeletal changes occurred. In the mandible, all patients showed an anterior projection of B-point (2.6 +/- 1.1mm) and pogonion (4.4 +/- 2.3mm). In the maxilla, a skeletal headgear effect was also universally observed with a posterior displacement of A-point (-1.2 +/- 0.4mm). Additionally, there was anterior displacement of the condyle with forward remodeling of the glenoid fossa. Resorption of bone on the anterior glenoid fossa and deposition on the posterior glenoid fossa was witnessed. From a mandibular regional registration, all patients demonstrated superior and posterior growth of the condyle and proclination of the mandibular incisors.

One year post Herbst removal, there were insignificant changes in the anterior/posterior position of maxilla at A-point for 5 out of the 7 Herbst patients. In one patient, A-point and ANS were translated anterior 3.1mm and 4.6mm respectively. A second patient demonstrated a posterior displacement of A-point of -1.5mm. Table II shows individual skeletal changes for each patient during Herbst treatment and one year following Herbst treatment.

In the mandible, one year following Herbst treatment, skeletal changes both in magnitude and direction had greater variation as compared to the maxilla (Table III). B-point was moved in a posterior direction in 57% of the Herbst patients however, 43% demonstrated continued anterior projection of both B-point and pogonion (0.9mm +/- 2.5 and 1.3mm +/- 2.6 respectively). Figure II shows an individual mandibular response during Herbst treatment and one year following Herbst treatment for a patient that experienced relapse of B-point and pogonion. Figure 3 shows an individual mandibular response during Herbst treatment and one year following Herbst treatment for a patient that demonstrated further anterior projection of B-point and pogonion.

All patient had posterior displacement of the glenoid fossa and the condyle one year following Herbst removal. Anterior condylion on the right and left was displaced posterior -0.6 +/- 0.6mm and -0.9 +/- 0.7mm respectively and posterior condylion also moved in a posterior direction (-1.0 +/- 0.2mm on right and -0.9 +/- 0.5mm on left). Insignificant vertical changes in the position of condylion were observed in 57% of patients, however, the remaining 43% demonstrated inferior displacement of the glenoid fossa/condyle relationship. One patient demonstrated inferior displacement of -3.2mm on right and -2.9mm on left condyle (figure same as above).

Mandibular regional superimpositions showed that all patient had condylar growth in both the T1-T2 (Right 5.9mm +/- 2.4 and Left 5.6mm +/- 2.2) phase and T2-T3 (Right 3.2mm

+/- 1.0 and Left 2.1mm +/- 1.9) phase of treatment. Individual variations in vertical versus posterior growth were observed.

Discussion

The intent of this study was to evaluate the skeletal and dental changes in patients treated with the Herbst appliance using 3D image analysis. The combination of cranial base and mandibular regional superimpositions allowed visualization of treatment response during Herbst treatment and skeletal changes one year post Herbst treatment. Our focus was on maxillary, mandibular, and glenoid fossa/condylar changes. LeCornu et al showed changes in maxilla and glenoid fossa/ condylar region following Herbst application, but was unable to account for mandibular growth at the condylar region because their study only incorporated cranial base registrations[6]. Furthermore, their study had only pre-Herbst (T1) and immediately post-Herbst (T2) data and did not contain additional follow up data representing the end of comprehensive treatment[6]. Numerous previous studies have explored skeletal and dental changes with Herbst treatment but have endured the limitation of 2D imaging[16-19]. Additionally, there were various methodologies used to measure these changes on 2D images also accounting for discord in the literature. Hence, the present study using 3D images with reasonable follow up data post Herbst removal using both cranial base and mandibular regional superimpositions was developed.

<u>Maxillary Skeletal Changes</u>

Many studies have reported a maxillary restraining effect, often referred to as the headgear effect, produced by Herbst treatment [6,13,16,19-21]. Our study indeed demonstrated this same result from T1 to T2. Of more interest are results one year post Herbst removal. Five of the seven patients showed insignificant anterior/posterior changes one year later. One patient showed a posterior movement of A-point -1.5mm as if additional "headgear" effect was continued; yet, another patient showed an initial restraining effect during Herbst treatment and then rebound of 3.1mm anterior movement of A-point one year later. Normal growth of the maxilla is in a forward and downward pattern[11]. It seems likely that the majority of the patients had completed growth while the outlier had a larger amount of continued normal maxillary growth. While this may be the case in the maxilla, all patients demonstrated mandibular growth in the condylar region from T2 to T3 suggesting that there was still inherent craniofacial growth during this time. A study by Pancherz suggested that most maxillary skeletal changes reverted within 6 months following Herbst treatment[22]. While our results were variable, the majority of patients demonstrated retained maxillary restraint one year following Herbst treatment.

Mandibular Skeletal and Glenoid Fossa Changes

Anterior-posterior projection of the mandible is influenced by growth of the mandible in the condylar region leading to downward and forward projection as well as condylar/fossa positional changes. Translation of the glenoid fossa in an anterior direction has been shown to contribute to favorable anterior positional changes during Herbst treatment [6,20,23-25]. All patients demonstrated this expected downward and forward projection of B-point and pogonion during Herbst treatment. The mandibular regional superimpositions confirmed that this was largely due to mandibular condylar growth, however, there was also anterior translation of the glenoid fossa. 2D studies have suggested that this favorable anterior translation of the glenoid fossa/condyle complex relapses[12]. Our study confirms that each patient had some degree of posterior movement/relapse of the glenoid fossa/condyle complex from T2 to T3. However, it is not clear if this was due to normal growth post Herbst removal. Buschang reported that normal condylar growth in adolescents was between 1.8 and 2.1mm posteriorly when compared with a cranial base superimposition[26]. Kokich suggested that the temporal bone and glenoid fossa are displaced posteriorly during facial development which can have an effect on mandibular position[27]. Thus, the posterior displacement of the glenoid fossa/condyle complex from T2 to T3 could be a result of remaining normal inherent growth. Additionally, when compared to previously published Class II controls, these patient still have more anterior position of the glenoid fossa/ condyle complex then if Herbst treatment was not initiated[6].

To assess if this posterior movement of the glenoid fossa resulted in a posterior movement of B-point, cranial base superimpositions from T2 to T3 were compared. B-point was moved in a posterior direction in 57% of the patients even though there was continued growth in the condyle region of these patients suggesting that posterior position of the condyle had a larger impact on chin position than continued condylar growth one year post Herbst removal. Continued mandibular growth did not overcome this relapse of chin position, due to the fact that the direction of condylar growth was more vertical than horizontal. (Figure 2). Even though there was posterior displacement in the glenoid fossa in all of the cases, 43% of the patients experience anterior projection of B-point and pogonion. This patient exhibited an inferior displacement of the glenoid fossa leading to a counter clockwise rotation of the mandible (Figure 3). Inferior displacement of the glenoid fossa has been documented in 2D studies in normal growing children and adolescents[26]. However, 2D imaging techniques have intrinsic potential for errors when assessing remodeling of the glenoid fossa. Deviations in patient positioning, as well as overlapping of the right and left sides of the glenoid fossa and condyle can effect 2D measurements[5]. Also, these studies often use condylion and articulare as proxy points to estimate the position of the fossa[26]. With CBCT images registered using voxel based registration for growing patients, we were able to analyze the glenoid fossa. This is the first study using 3D imaging that demonstrates the variation patient's of growth in post-Herbst treatment as well as the importance of inferior displacement in the glenoid fossa that leads to an increase in mandibular projection.

Mandibular Dental Changes

Using 3D mandibular registrations and superimpositions, mandibular dentoalveolar treatment responses to Herbst therapy were assessed. Studies have shown labial movement of the lower incisors and/or proclination of the lower incisors during Herbst treatment mostly thought to be due to a loss of anchorange[18,19,28-30]. All patients revealed proclination of mandibular incisors during Herbst treatment. However, from T2 – T3 there was favorable relapse in incisor proclination that has not been described using 3D images before. In addition, mesialization of molars during Herbst treatment showed relapse but Class I molar relationship was still maintained due to a combination of mandibular growth and distalization of the maxillary molars. Each patient finished in ideal over jet and Class I sagittal molar relationship at the third time point.

This study was designed to observe skeletal and mandibular dental changes in patients treated using the Herbst appliance. Limitations in sample size are well noted and a larger study with long term follow up is recommended in light of the high variation in treatment response. There are no normative 3D databases available to date, and changes seen in this pilot study could represent those that the patient's would experience with normal growth alone. Patient's skeletal changes were more uniform during Herbst treatment and the extreme variations in mandibular position one year post Herbst removal demonstrate the complexity of growth in Class II adolescents. It is not clear what caused 43% of the patients to experience inferior translation of the glenoid fossa resulting in a counterclockwise rotation of the mandible, and greater projection of the mandible post Herbst removal. However, this growth pattern was not seen in the Class II treated controls[6]. Relapse potential for patients treated with the Herbst appliance is well documented [14,31-33]. The ability to use CBCT's to acquire norms and long term follow up data would be ideal, however, the increase in ionizing radiation exposure is not warranted. Our T3 data was a CBCT taken as a substitute for final orthodontic records which limited the increase in radiation exposure. During this time, the patients were continuing with comprehensive treatment from T2 to T3 striving to achieve an ideal occlusal relationship. True relapse data should be acquired post comprehensive orthodontic treatment with similar retention protocols.

Conclusions

1. AP position of the mandible following Herbst treatment was variable
2. Condyle fossa complex moved anterior during Herbst treatment, but was displaced posterior one year post Herbst removal
3. Inferior positioning of the fossa complex may have a larger change in the AP position of the mandible
4. Headgear effect in the maxilla was maintained

Tables

Table 1 – Patient Demographics.

Table I: Demographics for Herbst Subjects										
Patient	Sex (M/F)	Age T1	Age T2	Age T3	ANB	A-N Perp	B-N Perp	U1-SN	MPA	IMPA
Patient 1	M	13y 7m	14y 8m	16y 0m	4.9	2.1	-3.3	95,1	25.3	92.6
Patient 2	M	13y 11m	15y 1m	16y 2m	6.1	7.7	2.8	109.9	21.1	93.9
Patient 3	M	13y 7m	14y 9m	15y 11m	4.0	-2.6	-11.0	115.8	19.8	99.5
Patient 4	F	14y 1m	15y 2m	16y 3m	5.5	0.6	-7.8	91.3	26.4	100.5
Patient 5	F	13y 2m	14y 4m	15y 9m	4.0	1.9	-3.3	96.1	29.1	83.9
Patient 6	M	13y 1m	14y 10m	16y 4m	6.5	-1.6	-15.1	99.1	37.5	89.3
Patient 7	F	11y 11m	12y 11m	14y 1m	6.4	-1.4	-12.3	89.7	20.2	104.3

Table 2 – Mandibular Skeletal Changes measured from Cranial Base Superimpositions of B-point and Pogonion (mm).

Table II: Mandibular Skeletal Changes for each Herbst Subject (mm)				
	T1 – T2		T2 –T3	
Patient	B-point	Pogonion	B-point	Pogonion
Patient 1	3.9	4.5	-1.1	-1.8
Patient 2	4.3	5.5	-0.6	0.1
Patient 3	2.7	7.1	4.0	4.6
Patient 4	2.4	2.9	-1.5	-1.3
Patient 5	1.2	1.4	2.9	3.5
Patient 6	1.8	3.2	4.1	5.5
Patient 7	2.2	3.7	-1.8	-2.7

Table 3 – Mandibular Growth measured at condylion for subjects during Herbst treatment (T1-T2) and post Herbst Treatment (T2-T3). Measurements taken from Mandibular Regional Superimposition models.

Table III: Mandibular Growth measured at condylion (mm)				
	T1 – T2		T2 –T3	
Patient	Right	Left	Right	Left
Patient 1	5.5	4.6	2.6	3.1
Patient 2	6.2	5.6	1.9	2.3
Patient 3	11.2	10.3	4.1	4.3
Patient 4	3.3	3.6	2.9	2.1
Patient 5	4	3.6	2.3	1.8
Patient 6	5.2	6.3	4.9	3.3
Patient 7	4.3	4.1	2.1	1.3

Table 4 – Maxillary Skeletal Changes measured from models registered on the Anterior Cranial Base during Herbst treatment and one year post Herbst treatment (mm).

Table IX: Maxillary Skeletal Changes for each Herbst Subject (mm)				
	T1 – T2		T2 –T3	
Patient	A-point	ANS	A-point	ANS
Patient 1	-1.5	0.8	0.8	0.4
Patient 2	-1.7	-1.8	0.1	-0.1
Patient 3	-1.4	1.4	3.1	4.6
Patient 4	-0.4	-0.7	-0.1	-0.3
Patient 5	-1.3	0.6	0.6	1.4
Patient 6	-1.3	0.5	1.4	0.4
Patient 7	-0.9	-0.6	-1.5	-0.2

Table 5 – Positional Changes observed in the condyle and glenoid fossa of subjects during Herbst treatment and one year post Herbst treatment (mm).

Table V: Difference between T1-T2 and T2-T3 condyle/ fossa positional changes for Herbst subjects (mm)				
Measurement	T1-T2	SD	T2-T3	SD
Condyle/ Glenoid Fossa Skeletal:				
Anterior condyle (right)	1.32	0.56	-0.62	0.67
Anterior condyle (left)	1.65	0.93	-0.85	0.77
Co (right)	0.38	0.59	-0.98	1.11
Co (left)	0.56	0.64	-0.97	1.13
Posterior condyle (right)	0.44	1.19	-1.02	0.23
Posterior condyle (left)	0.16	1.32	-0.88	0.57
Anterior fossa (right)	1.69	0.62	-0.22	0.56
Anterior fossa (left)	1.43	0.70	-0.35	0.46
Posterior fossa (right)	0.59	1.49	0.04	0.92
Posterior fossa (left)	0.79	1.34	-0.12	0.55

Figures

Figure 1 - Mandibular Mask Region of Interest (ROI) segmentation. Mandibular regional voxel based registration was performed using a ROI created from each time point.

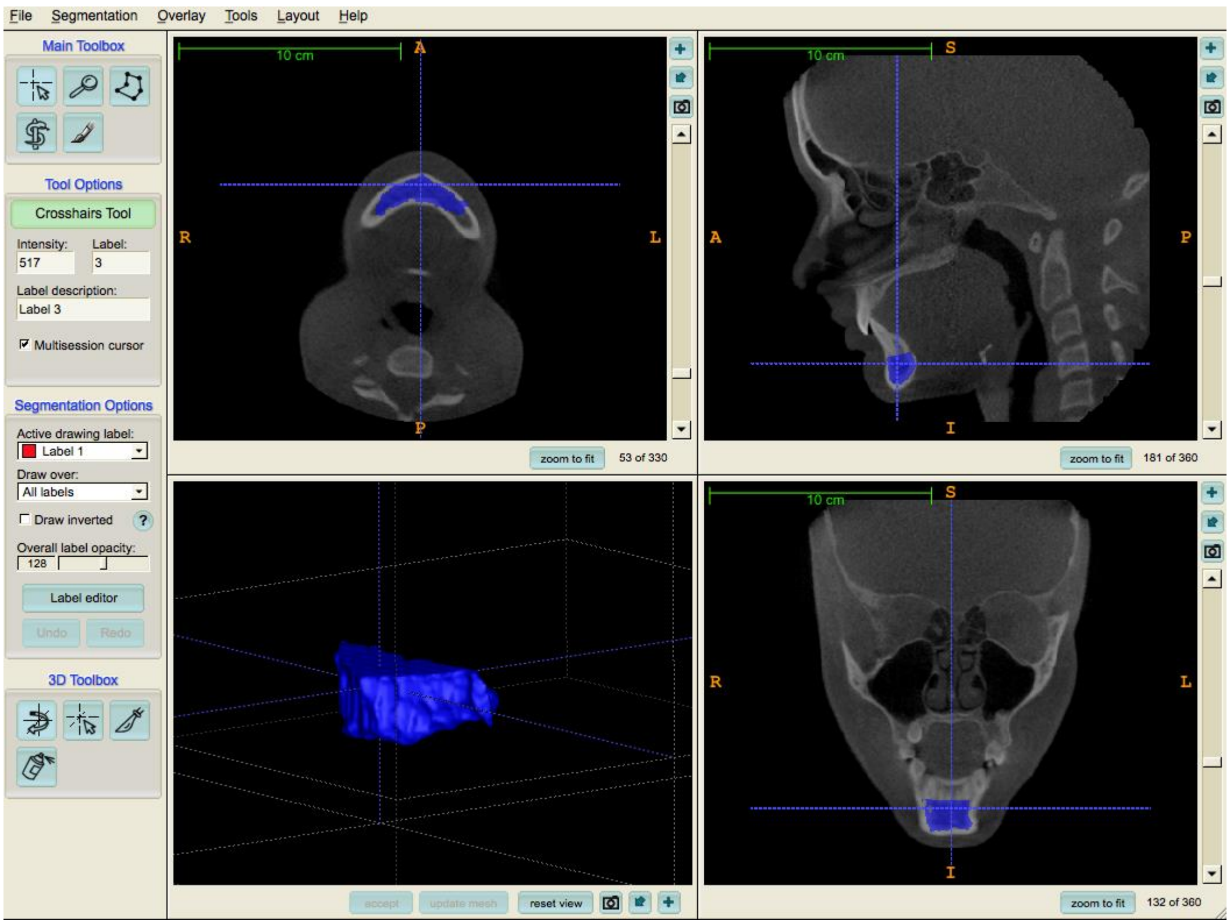


Figure 2 - A. T1 (white) to T2 (red) mandibular superimposition registered on the anterior cranial base showing anterior projection of B-point and pogonion. B. T2 to T3 (blue) mandibular superimposition registered on the anterior cranial base demonstrating relapse at B-point and pogonion one year post Herbst removal. C. Condyles segmented from a cranial base superimposition showing anterior projection from T1-T2 and posterior displacement from T2-T3. D. Mandibular regional superimposition of T1 and T2 demonstrating superior and posterior condylar growth and proclination of the lower incisors. E. Mandibular regional superimposition of T2 and T3 showing continued condylar growth and retroclination of lower anterior teeth. When compared to image B there was continued condylar growth even though posterior displacement of B-point and pogonion.

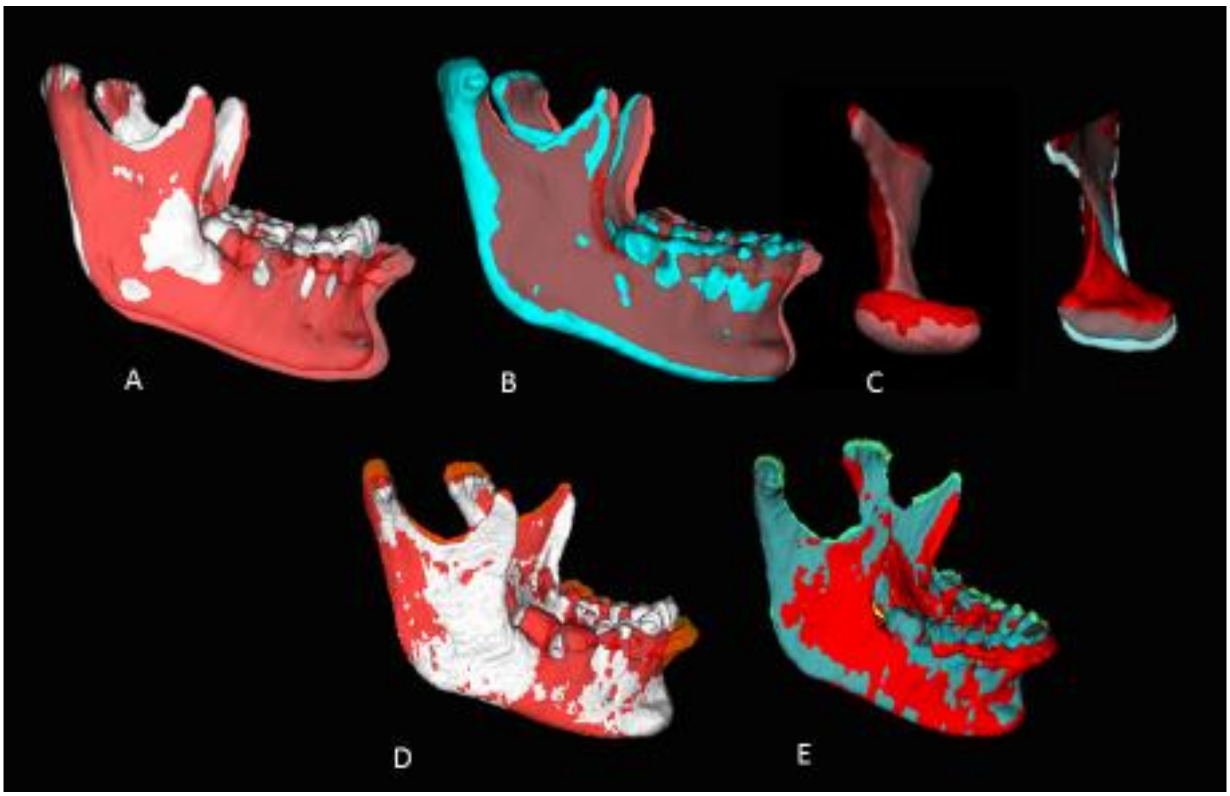
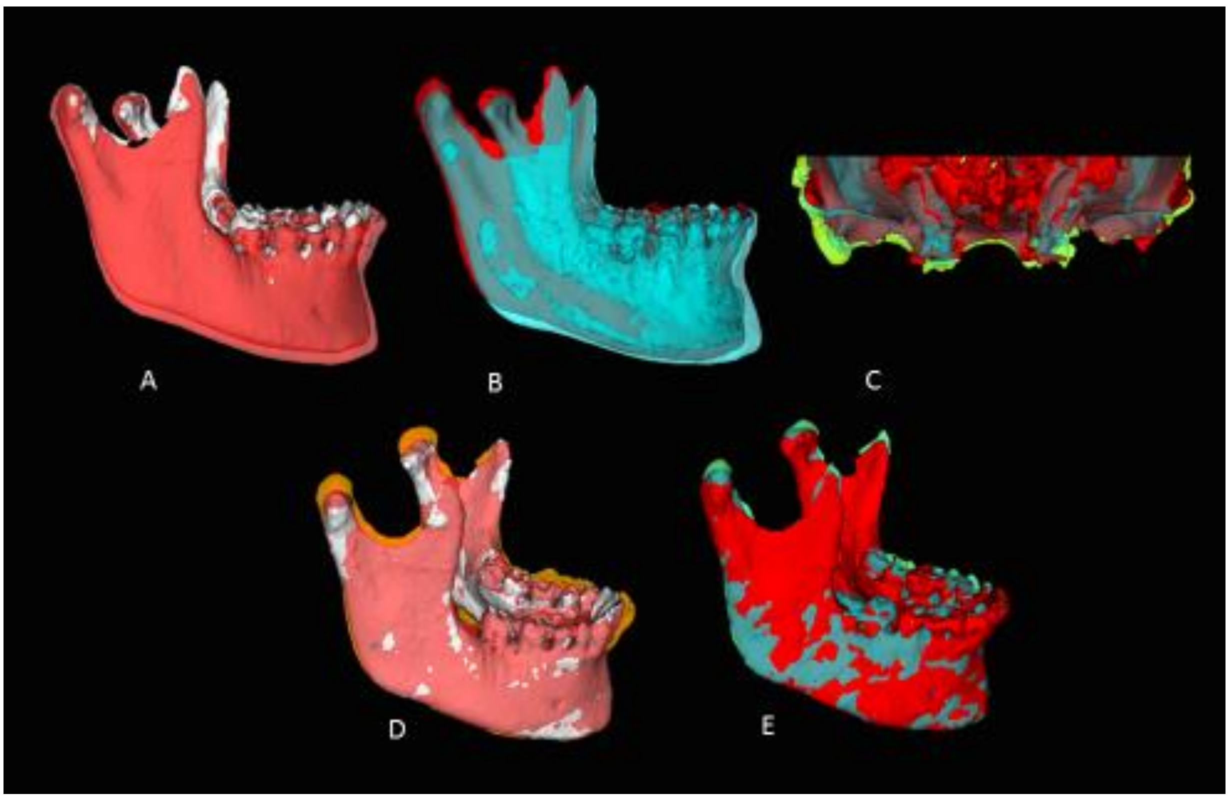


Figure 3 - A. T1 (white) to T2 (red) mandible registered on the anterior cranial base showing anterior projection of B-point during Herbst treatment. B. T2 to T3 (blue) mandibular superimposition registered on the anterior cranial base showing continued forward projection of B-point and pogonion one year post Herbst removal. C. T2 to T3 axial view of glenoid fossa demonstrating inferior displacement of the glenoid fossa leading to inferior displacement of the condyle as seen in image B and a counter clock-wise rotation of the mandible. D. Mandibular regional superimposition of T1 and T2 demonstrating superior and posterior condylar growth and proclination of the lower incisors. E. Mandibular regional superimposition of T2 and T3 showing continued condylar growth and retroclination of lower anterior teeth. There was less condylar growth from T2-T3 compared to T1-T2 even though there was greater projection of B-point and pogonion one year post Herbst removal.



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