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A Cephalometric Study Of The Effects Of Class Ii Malocclusion Correction Utilizing The Carriere® Motion 3D Appliance And Essix Retainer

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A CEPHALOMETRIC STUDY OF THE EFFECTS OF CLASS II MALOCCLUSION CORRECTION UTILIZING THE CARRIERE® MOTION 3D APPLIANCE AND ESSIX RETAINER

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ABSTRACT

Objective: The purpose of this study is to determine the dental and skeletal effects of Class II malocclusion correction with a Carriere® Motion 3D appliance and lower Essix retainer for anchorage, as compared to best-matched controls.

Methods: This is a retrospective case-control cephalometric study uses pre- and post-distalization lateral cephalometric images from 44 (32 female, 12 male, average age 13y 7m) class II patients treated with a Carriere® Motion 3D appliance and lower Essix retainer. These films were analyzed to determine treatment effects and compared with 35 (17 female, 18 male, average age 13y 3m) untreated controls from a historical database best-matched for age and skeletal growth pattern.

Results: Class II molar correction was completed in an average of 4.7 months mainly by dentoalveolar changes, exhibited largely by anterior movement of the mandibular dentition. The maxillary molar was distalized 1.20 mm and tipped 4.85°, while the mandibular molar mesialized 3.16 mm and the mandibular incisors moved forward (1.09 mm) and proclined (2.68°).

Conclusion: The Carriere® Motion 3D appliance with a lower Essix retainer effectively corrects a class II molar relationship in an average of 4.7 months before the onset of

comprehensive orthodontics; treatment effects are similar to the effects seen with class II elastics used with fixed appliances.

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INTRODUCTION

Angle Class II malocclusion is considered the most commonly diagnosed problem in the orthodontic practice. The correction of this particular malocclusion is a captivating topic for orthodontists, as it affects a reported 33% of all US orthodontic patients.[1] As the trend in non-extraction orthodontic treatment endures (driven by popular treatment philosophies such as the Damon® System, as well as the fairly recent popularization of removable aligner therapy[2]), molar distalization has become a commonly utilized method for Class II correction.[3]

A number of treatment modalities are available for maxillary molar distalization. Various methods for molar distalization will be discussed in this paper, highlighting their advantages, disadvantages, and treatment effects. Careful consideration of cooperation, anchorage requirements, and esthetic demands is key in determining the best treatment modality for the individual patient.

Extraoral Force Application—Headgear

The most traditional method of molar distalization, introduced in the 19th century, involves the application of extraoral force with a headgear.[4] Kloehn, who developed the facebow design used today, reported successful treatment of Class II Division 1 malocclusions with a cervical pull headgear;[5] however, he recommended it mainly for anchorage support and growth inhibition of the maxilla in growing patients (not necessarily for maxillary molar distalization).[3] While headgears can certainly be used for molar distalization, a major drawback is its necessity for patient compliance. Poor adherence to a headgear regimen can lead to increased treatment time, increased cost, and possible treatment failure.[6] Even with adequate patient compliance, the amount of molar distalization achieved with extraoral appliances is significantly less than what is achieved (in less time) with intraoral appliances, as reported by Bondemark in a randomized controlled trial.[7]

Headgears have been used for over 100 years with fairly reliable results.[5,8-10] They apply a posteriorly directed force directly to the teeth and consist of two components: the facebow and the neckstrap or headcap. The anchorage unit (the neckstrap or headcap) determines the direction of force applied, either above or below the occlusal plane.[11] Depending on the vertical growth pattern of the patient, the clinician can use a high-pull, cervical-pull, or combi-pull headgear.[4] The high-pull headcap applies a superior and distal force on the teeth and maxilla and is best suited for patients with a vertically excessive growth pattern. A cervical-pull neckstrap will place an inferior and distal force on the teeth and maxilla, and a combi-pull (or straight distal pull) can be created by a combination of high-pull and cervical-pull components.[11] Multiple studies have shown that headgear wear produces both dental and skeletal effects, inhibiting forward and downward maxillary growth by altering sutural apposition in growing patients.[11,13] A force of 12-16 ounces per side for 12-14 hours per day is the current recommendation.[11]

In the early 1900’s, Dr. Calvin Case was the first to utilize a sophisticated headgear to distalize molars[14]; however, he realized the greatest drawback for patients was the "…discomfort and irritation…which frequently causes them to omit wearing it [the headgear apparatus] a sufficient amount of time to be of service."[15] While a heavy reliance on patient cooperation is definitely its most notable weakness, its advantages include a relatively low cost and lack of reciprocal forces directed to the anterior teeth. A 2013 Cochran review comparing headgear to intraoral appliances demonstrated that, although intraoral appliances produced more molar distalization than did headgear, the loss of anterior anchorage in the intraoral appliance group counteracted this effect.[16]

Intraoral Force Application

Fixed intraoral class II correctors were developed in order to place treatment outcomes under the control of the orthodontist. These appliances can be classified based upon how they derive their anchorage: intra-maxillary or inter-maxillary. Intra-maxillary appliances derive their anchorage from the upper anterior teeth, premolars, and palatal vault. Inter-maxillary appliances use the lower arch as anchorage.[17] While the use of these fixed appliances lessens the need for patient compliance, their disadvantages include anchorage loss, high cost, and possible breakage. Several intra-maxillary (pendulum, distal jet, and Jones jig) and inter-maxillary (Herbst, Forsus™, and Carriere® Motion 3D™) class II correctors used today will be discussed.

Intra-maxillary Appliances

Pendulum. The fixed pendulum appliance was introduced by Hilgers in 1992 to distalize and rotate maxillary molars while also expanding the maxilla.[18] The appliance utilizes a large palatal acrylic button for anchorage and 0.032-inch titanium molybdenum alloy

(TMA) springs inserted into lingual sheaths on the maxillary first molar bands. The anterior portion of the appliance is attached to the premolars by either retaining wires soldered to bands or by occlusally bonded rests. The TMA springs are activated to "produce a swinging arc, or pendulum of force, from the palate to the molars."[19] Multiple studies have demonstrated this appliance to reliably distalize maxillary molars and correct Class II malocclusions with a moderate loss of anchorage. Ghosh and Nanda achieved an average molar distalization of 3.4 mm. However, they found that for every milimeter of molar distalization, the first premolars mesialized 0.75 mm.[19] Another study by Bussick and McNamara demonstrated a maxillary molar distalization of 5.7 mm, with the first premolar or primary first molar mesializing 0.32 mm per millimeter of distal molar movement.[20] Multiple studies report varying degrees of distal tipping of the maxillary molars, as well as reciprocal protrusion and tipping of the maxillary anterior teeth.[19-21] Reported advantages of the pendulum appliance include patient acceptance, single activation, adjustment springs for correcting minor vertical and transverse discrepancies, and ease of fabrication.[19] Bussick and McNamara suggest that this appliance is best suited for patients with maxillary second deciduous molars for anchorage and the absence of erupted maxillary second molars.

Distal jet. The distal jet appliance, introduced in 1996 by Carano and Testa, was created to distalize maxillary molars while reducing the tendency for tipping.[22] The appliance consists of an acrylic palatal button supported by attachments on the first or second premolars. The acrylic is embedded with bilateral 0.036-inch tubes that extend distally to the first molars. A bayonet wire, inserted into a lingual sheath on the first molar band, extends into the tube. An open coil spring is placed around the tube and piston arrangement, and a collar is used to compress the spring. The collar is pushed distally to activate the appliance every 4 to 6 weeks.[23] Because the distal force is directed through the center of resistance of the molar, it should, in theory, translate the tooth without tipping.[17] Studies demonstrate that the distal jet appliance does not produce as much molar distalization as the pendulum appliance; however, the movement is in fact associated with less molar tipping.[23-25] A study by Chiu and McNamara comparing the effects of both appliances found that the distal jet produced less molar tipping (5.0° vs. 10.7°), more anchorage loss at the first premolars (2.6 mm vs. 1.4 mm), more upper incisor flaring (13.7° vs. 3.1°), and less molar distalization (2.8 mm vs. 6.1 mm) than did the pendulum appliance during the initial molar distalization phase. This study suggests that, while the distal jet does not lead to as much molar tipping as the pendulum, it causes more anchorage loss at both the premolars and maxillary incisors.[26]

Jones jig. The Jones jig appliance, originally described by Jones and White in 1992, utilizes an open coil nickel-titanium spring which, when activated, exerts 70-75 grams of continuous force to the maxillary first molar[27]. Anchorage is provided by a modified Nance button attached to the bicuspids or the primary molars. A product of American Orthodontics, this appliance can be used for unilateral or bilateral class II molar correction.[17] A clinical retrospective study by Brickman, Sinha, and Nanda compared treatment effects of class II correction with the Jones jig with that of cervical headgear. They found that, after the initial stage of treatment with the Jones jig, the maxillary molar distalized an average of 2.51 mm while tipping distally 7.53°. The premolar was mesialized an average of 2.0 mm and tipped mesially 4.76°. However, despite the loss of anchorage and crown tipping observed, the Jones jig and headgear samples did not show significant differences in the final linear and angular measurements of the maxillary molars, premolars, and incisors.[28] A 2009 study comparing the effects of the Jones jig and the pendulum appliance found that the appliances were similar in the rate and amount of molar distalization; however, treatment with the Jones jig was associated with slightly more anterior anchorage loss (seen by more mesial tipping and extrusion of the second premolars).[29] Molar distalization with the Jones jig, pendulum, and distal jet appliances all produce undesirable side effects (such as varying amounts of maxillary incisor labial tipping, protrusion, and extrusion), but the Jones jig may surpass the other intra-maxillary appliances in its ease of fabrication and buccal force application.[28]

Inter-maxillary Appliances

Herbst. Introduced by Emil Herbst in 1909, the Herbst appliance was one of the first fixed class II correctors invented. This appliance keeps the mandible in an advanced position in order to produce skeletal and muscular function changes and is thusly considered a passive functional appliance.[11,30] It was popularized in the 1980s when Pancherz developed a banded version in an attempt to stimulate condylar growth. The appliance consists of a bilateral telescope apparatus that is attached to the upper and lower molars (via bands or, more recently, cast crowns), forcing protrusion of the mandible in both open and closed positions.[30]

Research suggests that the Herbst can improve class II skeletal discrepancies by restraining maxillary growth while encouraging mandibular growth and remodeling of the glenoid fossa.[31-33] It is recommended for use during the early permanent dentition and is best suited for patients with normal or slightly increased anterior facial height, due to its effect of maxillary posterior dental intrusion.[34] According to Pancherz, class II molar correction with the banded Herbst was due to 43% skeletal and 57% dental changes; overjet correction was due to 56% skeletal and 44% dental changes.[35] Significant dental effects include anterior displacement of the mandibular dentition, as well as maxillary molar distalization and intrusion. One can expect an average of 0.7 mm of maxillary molar intrusion and an average of 2.1 mm of maxillary molar distalization.[36] The mandibular molars come forward an average of 0.8 to 2.2 mm, and mandibular incisors can move forward 1.7 to 2.4 mm.[37] A 2006 systematic review of functional appliances found that Herbst treatment yielded an average amount of 0.28 mm per month supplementary elongation of the mandible (compared to untreated class II controls).[38]

While the Herbst has a significant high-pull headgear effect in the short term, research shows that post treatment relapse does occur. Molar relationships should be overcorrected during treatment, as the maxillary molars typically return to their original position after the Herbst appliance is removed. At the 12-month post treatment period, the contribution of maxillary molar distalization to the sagittal correction was only 11%.[37] Franchi et al reported that at 16 months post-treatment, significant relapse nullified the Herbst's initial effects on the maxillary molar's sagittal position.[62] Similar to other functional appliances, the mandibular skeletal effects of the Herbst are short-term and do not effect the overall growth pattern in the long-term.[38]

Forsus™. The Forsus™ appliance, developed by Vogt in 2001, is currently one of the most widely used fixed appliances for Class II correction. It consists of a spring module that is connected by a pin to the headgear tube of the maxillary molar band. A stainless steel rod (of variable length) is inserted into the module and attached to the lower archwire distal to the canine or first premolar. It is placed after the initial leveling and aligning stage of treatment, once the upper and lower archwires are a minimum 19x25 stainless steel (for 0.022 slot) or 17x25 stainless steel (for 0.018 slot).[39] While it is touted as a fixed functional appliance (like the Herbst or MARA appliances), studies have shown that the treatment effects of the Forsus™ appliance are mainly dentoalveolar with a very limited effect on mandibular growth.[40] A 2018 meta-analysis evaluated skeletal and dental effects of the device. The study reported the Forsus™ appliance had no significant anteroposterior effects on the maxilla and mandible and a significant effect in increasing the occlusal plane angle. The dentoalveolar effects included significant maxillary molar intrusion, highly significant proclination, protrusion, and intrusion of the lower incisors, and significant retroclination of the upper incisors.[41] Even when negative torque was added to the lower archwire in one study, IMPA still increased by 7.8°.[42] While the Forsus™ appliance is effective in correcting Class II maloclussions in non-compliant patients, disadvantages include significant reciprocal tooth movement, poor patient acceptance due to limited mouth opening, and possible emergency visits due to the rod slipping out of the module. However, one study found that a majority of adolescents preferred treatment with a Forsus™ appliance to the previous use of headgear or intermaxillary elastics.[43]

Carriere® Motion 3D™. The Carriere® Motion appliance, introduced in 2004 by Dr. Luis Carrière, is designed to create a class I canine and molar by distalizing the posterior buccal segment as a unit. It consists of a nickel-free stainless steel curved arm with a mesial pad that is bonded to the maxillary canine and a distal component that is bonded to the maxillary first molar. The canine pad, which can be bonded to the first premolar if the canine is unerupted or ectopic, has a hook for attachment of class II elastics. The molar pad is designed to achieve three types of molar movement: 1.) uprighting of the crown (without distal tipping) 2.) distal rotation around the palatal root, and 3.) distalization without crown tipping.[44] The ball-and-socket design of the canine and molar pads were created to mimic the human hip joint and allow for maximum freedom of movement. Mandibular anchorage may be achieved by several mechanisms. The traditional approach is bonding an 0.036-inch lower lingual arch from molar to molar. Other possible anchorage modalities include a lower Essix retainer with bonded attachments on the molars, full mandibular fixed appliances, or miniscrews placed in the attached gingiva between the lower first and second molars.[44] Dr. Carrière recommends heavy class II elastic wear for 24 hours per day for low-angle cases and 14 hours per day for high angle cases. Nighttime wear only would produce a more horizontal force vector, but would increase the amount of time needed for class II correction.[44]

According to the Carriere® company, the main advantage of the appliance is its ability to correct the anteroposterior issues first. Their SAGITTALFIRST™ philosophy allows orthodontists to distalize premolars and molars a reported average of 3 to 6 mm, turning more difficult class II patients into simple class I patients before full fixed appliances are placed.[45] While the Carriere® Motion appliance has gained considerable popularity among orthodontists in the last ten years, minimal literature (besides case studies and case series) describing its treatment effects currently exists.

An extensive search of the current literature yielded a limited number of published retrospective studies investigating treatment effects of class II malocclusion correction with the Carriere® Motion appliance. A 2019 cephalometric study by Kim-Berman and McNamara looked at Carriere® treatment effects on adolescent patients. Utilizing an Essix removable retainer for anchorage, they found the appliance mainly produced dentoalveolar effects: molar relationship improved an average of 5.1 mm with an increase in IMPA of 4.9 degrees during the initial distalization phase. However, the amount of true maxillary molar distalization was not measured, so it is unclear as to how much class II correction occurred by mandibular molar mesialization. The most significant skeletal effects reported were an increase in lower anterior facial height (1.8 mm) and mandibular plane angle (1.2°).[46] This finding supports Dr. Carrière's recommendation that this appliance works best on patients with brachyfacial patterns.[44]

Yin et al compared treatment effects of class II correction using the Carriere® appliance, Forsus™ appliance, and class II elastics. This study did not utilize a consistent anchorage device for the Carriere®—some subjects were treated with a lower lingual holding arch while others were treated with an Essix retainer. Treatment with the Carriere® appliance yielded a class II molar correction of 3.5±1.7 mm, which was similar to the correction seen with class II elastics but less than with the Forsus™ appliance. Carriere® side effects included an average increase in IMPA of 4.7°, an average increase in lower facial height of 6.3 mm, and an average increase in FMA of 1.7°. End-to-end class II molar correction with the Carriere® took 6.3±2.2 months, significantly shorter than with class II elastics (10.3 ± 3.9 months). However, the overall treatment time for the Carriere® group (32.3±8.4 mm) was significantly longer than the class II elastics group (23.9±5.8mm). The treatment times for the Carriere® and Forsus™ appliances were statistically similar.[47] This finding seems to dispute Carrière's claim that an initial sagittal correction increases overall treatment efficiency. However, this finding differs with Kim-Berman and McNamara's research, as they reported an average distalization time of 5.1 months (±2.8 months) and total treatment duration of 18.2 months (±4.8 months) with the Carriere® appliance. This treatment time is considerably shorter than the reported average total treatment time with class II elastics (25.7 months ± 6.8 months);[48] therefore, they concluded that treatment of class II malocclusions with the Carriere® Motion appliance is efficient.[46]

There is a lack of available evidence as to the amount of true maxillary molar distalization achieved with the Carriere® Motion appliance. An unpublished 2012 thesis project by Dr. Careybeth Rivers investigated treatment effects of the Carriere® Motion appliance with a lower lingual holding arch for anchorage. This study found an average maxillary molar distalization of 1.24 mm and an increase in IMPA of 4.8 degrees during the distalization phase of treatment. The class II molar relationship was corrected to a class I; however, two-thirds of the correction was created by mesial movement of the mandibular molars.[49] Sandifer et al. compared treatment effects of the Carriere® Motion appliance using two different anchorage devices on the lower arch—full fixed appliances and lingual arches. This study found an average maxillary molar distalization of 1.6 mm for the fixed appliance group and 2.5 mm for the lingual arch group, with the mandibular plane angle increasing in the lower lingual arch group only. The lack of torque control provided by the lingual arch lead to more mandibular incisor proclination (average IMPA increase of 4.6° vs 1.2° with the fixed appliance); however, the fixed appliance group experienced more mandibular incisor protrusion than did the lingual arch group (2.7 mm vs. 0.09 mm, respectively). Interestingly, this study concluded that the Carriere® appliance with a lingual arch for anchorage corrected a class II molar relationship mainly by maxillary molar distalization (74%), while the Carriere®/lower fixed appliance combination corrected the malocclusion largely by mandibular molar protraction (60%).[50]

It is evident that the type of anchorage used with the Carriere® Motion appliance has some effect on the results achieved during class II malocclusion correction. One may assume that a full-coverage retainer covering the lower dentition would result in less anchorage loss (evidenced by less protraction of the lower dentition) and, therefore, more true distal movement of the maxillary molars. However, minimal studies exist regarding the specific treatment effects of the Carriere® Motion appliance utilizing a lower Essix retainer for anchorage.

SPECIFIC AIM

The goal of this study is to better understand the treatment effects of class II malocclusion correction utilizing the Carriere® Motion appliance. A better understanding of the dental and skeletal changes associated with this popular appliance will aid clinicians in developing individualized treatment plans best suited for each orthodontic patient.

Specific Aim: <u>To radiographically determine specific dentoalveolar and skeletal effects of Class II malocclusion correction utilizing the Carriere® Motion appliance with a lower Essix retainer as anchorage</u>

MATERIALS AND METHODS

This study is approved by the University of Alabama Institutional Review Board for Human Use (IRB: # 300004536).

Subjects

The treatment group for this retrospective study consists of 44 patients (32 female, 12 male, average age 13y 7m) treated for bilateral Class II malocclusions with a Carriere® Motion 3D appliance and lower Essix retainer. Of these 44 subjects, 35 presented with ½ step class II molar relationships, 2 with full step class II relationships, 1 with a ¼ step class II relationship, and 6 with asymmetric class II molar relationships (one molar ½ step, the other molar full step). Inclusion criteria for this study included: 1.) bilateral class II molar relationship at T1, 2.) class I or super class I molar relationship at T2, 3.) non-extraction treatment, 4.) diagnostic quality intraoral photos and cephalometric films at T1 and T2. Exclusion criteria included: 1.) craniofacial anomaly, 2.) dental implant, 3.) crossbite. To limit variability in treatment modalities within the group, all patients were treated by the same practitioner in a private orthodontic office. Orthodontic informed consent was obtained from all patients and/or parents before treatment was rendered.

The control group (17 female, 18 male, average age 13y 3m) was collected from the American Association of Orthodontists Foundation (AAOF) Craniofacial Growth

Legacy Collection database. This database consists of a number of longitudinal collections of radiographic images and other growth records of untreated children from the United States and Canada. These collections include Bolton-Brush, Burlington, Denver, Fels Longitudinal, Forsyth Twin, Iowa, Mathews, Michigan, and Oregon Growth Studies.[51] Every effort was made to best match these subjects for age and growth pattern; however, the time between T1 and T2 was inevitably longer for the control group (as radiographs for the growth studies were taken approximately 1 year apart).

Table 1. Description of Carriere® (treatment) and control groups

Group	Male subjects	Female subjects	Average age at T1	Average time between T1 and T2
Carriere®	12	32	13y7m	4.7 months
Control	18	17	13y3m	14 months

Data Collection

Cephalometric images of all subjects in the treatment group were taken prior to initiating class II correction (T1) with a Carriere® Motion appliance, lower Essix retainer, and class II elastics. A second cephalometric image was taken immediately upon removal of the appliance (T2), after the class II molar relationship was corrected to a class I or super class I relationship. All radiographs were labeled numerically for de-identification. Cephalometric images (T1 and T2) of best-matched controls were obtained from the AAOF Craniofacial Growth Legacy Collection database, and all radiographs were imported digitally into Dolphin Imaging software (Chatsworth, CA). The images were digitally traced by one examiner using Dolphin Imaging software, and 27 cephalometric measurements were obtained for each image in order to determine dental and skeletal changes between T1 and T2. Cephalometric landmarks and measurements used for the analysis are listed and described in Table 2, as adapted from Jacobson.[52]

Statistics

Means and standard deviations of each cephalometric measurement were determined. Independent T-tests were used to determine differences between treatment and control T1 (pre-treatment) groups; paired T tests were used to evaluate changes that occurred between T1 and T2 within each group. All statistical tests were performed using a significance level of 5% (results were considered significant if $P<0.05$). Using the differences between the T1 and T2 measurements within each group, wilcoxen scores (rank sums) were used to analyze overall treatment changes for the treatment group compared to the control group. In order to verify intra-examiner reliability, 5 cephalometric images were selected at random and re-traced. The intraclass correlation coefficient was 0.987.

Table 2. Cephalometric landmarks and descriptions[52]

Landmark/Measurement	Abbreviation	Description
Anterior nasal spine	ANS	The anterior tip of the sharp bony process of the maxilla at the lower margin of the anterior nasal opening
Articulare	Ar	Point at the junction of the posterior border of the ramus and the inferior border of the posterior cranial base
Basion	Ba	The lowest point on the anterior rim of the foramen magnum
Bolton point	Bo	The intersection of the outline of the occipital condyle and the foramen magnum at the highest point on the notch posterior to the occipital condyle
Gonion	Go	Point on the curvature of the angle of the mandible located by bisecting the angle formed by lines tangent to the posterior ramus and the inferior border of the mandible
Gnathion	Gn	Point located by taking the midpoint between the anterior (pogonion) and inferior (menton) points of the bony chin
Incisor to mandibular plane	IMPA	Angle formed by the mandibular plane and a line drawn through the long axis of the mandibular incisor
Mandibular plane	MP	A plane connecting gonion and menton
Maxillary molar position	U6Pos	The distance from the distal of the maxillary first molar to PtV
Menton	Me	The lowest point on the symphyseal shadow of the mandible seen on a lateral cephalogram
Mesial Molar Relationship	MMR	The distance from the mesial surface of the mandibular molar to the mesial surface of the maxillary molar, measured along the occlusal plane
Nasion	N	The most anterior point on the frontonasal suture in the midsagittal plane
Orbitale	Or	The lowest point on the inferior rim of the orbit
Posterior nasal spine	PNS	The posterior spine of the palatine bone constituting the hard palate
Pogonion	Pog	The most anterior midpoint on the bony chin
Porion	Po	The most superiorly positioned point of the external auditory meatus
Point A	A	The most posterior midline point in the concavity between the ANS and prosthion
Point B	B	The most posterior midline point in the concavity of the mandible between the most superior point on the alveolar bone overlying the mandibular incisors and Pog
PT point	PT	The junction of the posterior wall of the pterygomaxillary fissure and the inferior border of the foramen rotundum
Sella	S	The geometric center of the pituitary fossa of the sphenoid bone

RESULTS

A class I or super class I molar relationship was established with the Carriere® Motion appliance and lower Essix retainer in all 44 subjects in an average of 4.7 months. The initial distalization phase of treatment was followed by comprehensive orthodontic treatment with either traditional fixed appliances or clear aligner therapy.

The mean values and standard deviations of each cephalometric value measured are shown in Table 3. Treatment changes (T1 – T2) for each group are shown in Table 4. When comparing T1 values for the treatment and control groups (Table 3), there is no statistical difference in a large majority of measurements. The groups seem to be well-matched in all anteroposterior and vertical skeletal measurements as well as mandibular dental measurements; however, they statistically differ in two maxillary dental measurements: U6-SN° ($P=0.04$) and mesial molar relationship ($P<0.01$).

Table 3. Initial and final measurements and comparison of treatment and control initial forms

	T1				T2				Comparison of T1 forms for treatment vs. control group
	Treatment n=44		Control n=35		Treatment n=44		Control n=35		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	P value
Skeletal Maxillary Components									
Ar-ANS (mm)	86.3	5.0	86.7	10.1	86.3	4.4	85.7	9.6	0.8544
SNA (°)	81.3	3.3	82.9	3.1	81.5	3.6	82.9	2.9	0.1562
Midface Length (Co-A) (mm)	80.6	4.9	82.8	8.7	80.8	4.0	82.9	8.5	0.1949
Skeletal Mandibular Components									
Mandibular Length (Co-Gn) (mm)	104.0	5.8	106.9	11.0	105.5	5.6	107.6	11.9	0.0868
Pog-N Perpendicular (mm)	-5.1	5.1	-3.4	7.0	-4.4	5.9	-2.9	7.4	0.2159
SNB (°)	77.1	3.2	78.6	3.0	77.6	3.5	78.7	2.9	0.1778
Apical Base Relationship									
ANB (°)	4.2	2.2	4.3	2.2	3.9	2.2	4.2	2.0	0.1175
Wits (FOP) (mm)	1.1	3.0	0.1	3.1	-1.5	3.3	0.9	3.4	0.1440
Vertical Skeletal Components									
MP-SN (°)	31.2	5.8	31.6	5.6	31.1	5.7	31.3	5.7	0.7683
Y-axis (SGn-SN - 7) (°)	60.9	3.8	59.6	3.4	60.6	3.8	59.7	3.4	0.1229
Occ Plane to SN (°)	16.5	3.8	15.1	3.5	17.3	4.3	14.4	4.1	0.0905
FMA (MP-FH) (°)	21.5	5.2	23.1	5.9	21.4	5.4	22.8	5.7	0.1847
Occlusal plane angle	77.3	4.0	78.4	3.4	76.6	4.4	79.1	3.7	0.1867
Maxillary Dentition									
U1-NA (mm)	4.2	2.5	3.1	2.4	4.3	2.1	3.2	2.1	0.0571
U1-NA (°)	22.6	7.7	20.0	6.7	23.1	7.4	19.7	6.1	0.1181
U1-PTV (mm)	53.0	4.4	55.2	6.6	53.3	4.8	55.1	6.4	0.0852
U6-PTV (mm)	15.9	3.6	16.3	4.2	14.7	3.8	17.3	4.2	0.6267
U6-SN (°)	68.2	6.3	71.1	5.8	63.3	7.6	72.1	4.7	0.0367*
U6-PP (mm)	16.1	1.9	16.8	2.3	16.4	2.2	17.5	3.1	0.1681
Mesial Molar Relationship | FOP (mm)	1.6	1.0	-0.1	1.5	-2.2	1.4	-0.1	1.4	<.0001*
Maxillary Molar Position (mm)	54.2	4.4	56.4	6.5	53.7	3.8	56.5	7	0.0904
Mandibular Dentition									
IMPA (L1-MP) (°)	99.2	7.4	97.3	6.5	101.9	7.5	97.4	6.4	0.3349
L1 Protrusion (L1-APo) (mm)	1.4	2.2	0.8	2.4	2.7	2.3	1.1	2.3	0.2662
L1-NB (°)	26.5	7.3	25.5	6.2	29.6	7.2	25.4	6.2	0.5080
L1-NB (mm)	4.1	2.3	4.2	2.3	5.2	2.4	4.6	2.1	0.8375
Mandibular Molar Position (mm)	55.5	4.5	57.1	6.5	58.7	3.6	57.3	6.8	0.0955
L6-MP (mm)	27.4	2.4	28.6	3.5	28.1	2.8	29.0	3.9	0.0977

Table 4: Treatment changes

	T1−T2 Treatment Changes					
	Treatment n=44			Control n=35		
	Mean	SD	P value	Mean	SD	P value
Skeletal Maxillary Components						
Ar-ANS (mm)	0.00	2.77	0.9914	0.97	10.03	0.9914
SNA (°)	-0.22	1.40	0.303	-0.09	0.56	0.3716
Midface Length (Co-A) (mm)	-0.19	2.53	0.6146	-0.18	8.85	0.9034
Skeletal Mandibular Components						
Mandibular Length (Co-Gn) (mm)	-1.48	2.67	0.1775	-0.75	11.68	0.7047
Pog-N Perpendicular (mm)	-0.75	3.32	0.1419	-0.52	3.73	0.4121
SNB (°)	-0.50	1.52	0.4121	-0.09	0.81	0.508
Apical Base Relationship						
ANB (°)	0.28	1.00	0.0739	0.03	0.64	0.8137
Wits (FOP) (mm)	2.60	3.05	0.0002*	-0.89	2.59	0.5062
Vertical Skeletal Components						
MP-SN (°)	0.13	1.51	0.5852	0.29	1.12	0.134
Y-axis (SGn-SN - 7) (°)	0.22	1.46	0.3216	-0.1	0.86	0.4956
Occ Plane to SN (°)	-0.82	2.57	0.0398*	0.68	2.01	0.0533
FMA (MP-FH) (°)	0.10	2.34	0.788	0.34	2.08	0.3406
Occlusal plane angle	0.69	2.74	0.1007	-0.68	2.01	0.0527
Maxillary Dentition						
U1-NA (mm)	-0.12	0.98	0.4291	0.05	1.23	0.8276
U1-NA (°)	-0.49	2.97	0.2814	0.22	1.62	0.4265
U1-PTV (mm)	-0.32	3.21	0.5179	0.16	6.41	0.8835
U6-PTV (mm)	1.20	3.24	0.0187*	-0.98	3.63	0.1186
U6-SN (°)	4.85	4.92	<.0001*	-0.94	3.85	0.157
U6-PP (mm)	-0.31	1.01	0.0945	-0.74	2.53	0.0913
Mesial Molar Relationship | FOP (mm)	3.85	1.55	0.2033	0.03	1.5	0.9266
Maxillary Molar Position (mm)	0.49	2.51	<.0001*	-0.1	6.37	0.8932
Mandibular Dentition						
IMPA (L1-MP) (°)	-2.68	2.14	<.0001*	-0.13	1.38	0.5843
L1 Protrusion (L1-APo) (mm)	-1.25	0.71	<.0001*	-0.32	0.98	0.0615
L1-NB (°)	-3.08	2.33	<.0001*	0.07	1.08	0.7084
L1-NB (mm)	-1.09	0.85	<.0001*	-0.43	1.22	0.0448*
Mandibular Molar Position (mm)	-3.16	3.11	<.0001*	-0.24	6.47	0.0514
L6-MP (mm)	-0.65	1.05	<.0001*	-0.36	3.19	0.8296

For the control group, there was no statistical difference between T1 and T2 for any measurement except L1−NB, which increased minimally (0.43 mm) during the observation period. All other vertical and anteroposterior skeletal and dental measurements showed no significant change. The Carriere® group, however, showed significant changes ($P<0.05$) between T1 and T2 for the following cephalometric measurements: Wits, occlusal plane to SN°, U6−PT Vertical, U6−SN°, maxillary molar position, IMPA, L1−APo, L1−NB, L6−MP, and mandibular molar position.

No significant maxillary or mandibular skeletal changes occurred during class II correction with the Carriere® Motion appliance. The apical base relationship was favorably affected, as the Wits appraisal decreased by an average of 2.6 mm. Vertical skeletal changes include an increase in the occlusal plane angle relative to sella-nasion (0.82°); however, there was no evidence of clockwise mandibular rotation, as MP−SN°, Y−axis, and FMA did not significantly change during treatment.

The maxillary incisors were largely unaffected by treatment with the Carriere® Motion appliance. The maxillary molar was distalized 1.2 mm while tipping 4.85° relative to sella-nasion. The mandibular dentition experienced the greatest amount of treatment effects, as all 6 cephalometric measurements were significantly altered during class II correction. The class I molar relationship was achieved by an average of 3.16 mm of lower molar protraction, and the lower incisors experienced statistically significant protrusion and proclination (1.25 mm and 2.68°, respectively).

DISCUSSION

The goal of this study was to determine the specific skeletal and dentoalveolar treatment effects of the Carriere® Motion 3D appliance. Cephalometric measurements were taken immediately after sagittal correction, before initiation of comprehensive treatment with fixed orthodontic appliances or clear aligners. This was done in order to exclude any treatment effects caused by various mechanics that may ensue during the following phases of treatment, allowing us to more accurately isolate Carriere® treatment outcomes. The untreated control group was acquired from a historical database and was used as a reference to determine the treatment changes that occurred. The samples were well-matched in age (13y7m and 13y3m for the treatment and control groups, respectively) as well as pre-treatment skeletal and dental relationships; however, their pre-treatment measurements did statistically differ in two components: U6-SN° and mesial molar relationship.

Using a historical control does pose a problem regarding the time between T1 and T2 timepoints; there was no way to more accurately match the time frame (as the growth study images were collected approximately every 12 months). The average times between T1 and T2 for the treatment and control groups were 4.7 months and 14 months, respectively. The longer “treatment time” for the control group could introduce a growth variable to this sample; however, the T1 and T2 measurements only significantly changed in one component (L1−NB increased by 0.43 mm) (Table 4). Utilizing historical growth records as research controls has also been criticized due to the possibility of secular change. A study by Antoun et al. found that different birth cohorts may exhibit distinctive growth patterns.[53] To minimize this variable, we gathered records from several different growth collections spanning several decades. It is the opinion of the author that historical growth collections remain a vital resource for current and future orthodontic research, as they allow for the establishment of case control studies that otherwise would not be ethically feasible.

According to our results, the sagittal correction was largely caused by dental changes, as only two skeletal measurements were significantly affected (Wits and occlusal plane to SN°). This is to be expected, as the appliance was only in place for an average of 4.7 months. Previous studies largely contributed the class II correction to dentoalveolar changes, as well.[46, 47, 54] Interestingly, Kim-Berman and McNamara reported a statistically significant increase in mandibular length (2.0 mm) during the ~5-month treatment with the Carriere® Motion appliance. They concluded that, due to the mandible being brought forward with full-time elastic use, mandibular length increased over the treatment period no more than what would have occurred with normal growth.[46]

An increase in Wits and an increase in the occlusal plane angle is a common finding among the current literature regarding Carriere® treatment effects.[46, 47, 54] In the current study, Wits appraisal decreased by 2.6 mm during treatment with the Carriere® appliance. Because the Wits appraisal uses the functional occlusal plane as the reference plane to measure the anteroposterior relationship of the jaws, it is heavily influenced by changes in the occlusal plane angle.[55] The significant change in Wits is probably due in part to an increase in the functional occlusal plane angle. We found that treatment with the Carriere® appliance steepened the functional occlusal plane an average of 0.82° in relation to sella-nasion. Kim-Berman and McNamara reported a 3.9° steepening of the functional occlusal plane in relation to Frankfort horizontal; however, this angle flattened by 3.6° during the subsequent comprehensive phase of treatment.[46] A significant increase in the occlusal plane angle is a commonly reported side effect of class II elastic treatment, as the maxillary canine and lower molar are extruded due to the vertical nature of the forces. A systematic review on the effects of class II elastics found that relapse of the steepened occlusal plane is a common post-treatment feature of class II elastic wear;[56] this seems to be in congruence with the post-treatment change seen with the Carriere® appliance, as reported by Kim-Berman and McNamara.[46]

The posterior maxillary dentition was significantly affected by treatment with the Carriere® appliance. The maxillary molar was distalized a mean of 1.20 mm in relation to PT vertical. The control group experienced mesial drift of 0.98 mm, indicating an overall distalization effect of 2.18 mm. This amount of distalization is similar to Areepong's CBCT study, which reported a molar distalization of 1.67 mm in class II skeletal subjects treated with the Carriere® appliance and lower Essix retainer. This amount of distalization is less than what is reported for the Herbst (2.1 mm),[36] and distal jet (2.8 mm)[26] appliances, but more than what is reported for the Forsus™ appliance (0.87 mm).[57] The vertical position of the maxillary molar was not significantly affected by the Carriere® appliance. This contrasts with the Forsus™ and Herbst appliances, which are shown to intrude the maxillary molar approximately 0.4 mm and 1.0 mm, respectively.[38,58] Molar distalization with the Carriere® was associated with 4.85° of distal tipping relative to sella-nasion. The appliance is designed to minimize distal tipping; however, the molar tipping exhibited in this treatment sample is similar to the reported 5.0° tipping seen with the distal jet appliance.[26]

The Carriere® Motion appliance had little effect on the maxillary incisors. This is to be expected, as the anterior arm of the appliance (and thusly the elastic) is attached to the canine or first premolar, with no force directly applied to the maxillary incisors. This contrasts greatly with intra-maxillary class II correction appliances, which tend to flare the upper anterior teeth due to anchorage loss during molar distalization. It has been reported that the distal jet appliance causes an average of 13.7° of upper incisor flaring with an increase in overjet of 1.7±3.8 mm.[23,26]

Anchorage loss with the Carriere® Motion appliance was experienced via significant effects on the mandibular dentition. As the maxillary molar distalized 1.20 mm, the mandibular molar came forward 3.16 mm. This is a greater anchorage loss than what is reported with other fixed class II correctors. The Herbst protracts the lower molar a reported 1.0 mm,[59] while the Forsus™ protracts the lower molar a reported 1.3 mm.[58] The mandibular molar extruded 0.65 mm during treatment with the Carriere®, which is analogous to the vertical effects seen with class II elastic use.[56] Anchorage loss was also exhibited by changes in the lower incisor position. Lower incisor protrusion (L1-APo) increased 1.25 mm, while IMPA increased 2.68°. Interestingly, the amount of lower incisor proclination exhibited in this study is less than what has been reported for other class II fixed appliances. The Forsus™ appliance has been shown to procline the lower incisors a reported 6.4°.[60] Studies regarding the Herbst appliance show an average lower incisor protrusion of 1.7 to 2.4 mm and proclination ranging from an average of 2.0° to 8.4°.[38] Class II elastic use protrudes lower incisors a reported 0.8 mm while proclining

3.8°.[56] Sandifer's study found that the Carriere® appliance with lower fixed appliances tipped the lower incisors only 1.2°; however, the lower incisors came forward 2.7 mm.[50] The negative torque provided by the brackets helps prevent excessive proclination, but the mesially-directed force from the elastic will still be expressed via lower anterior movement.

The Carriere® Motion appliance improved the sagittal molar relationship an average of 3.85 mm. As the majority of treated subjects began with an end-on Class II molar relationship, this is a reasonable amount of correction to be expected. This amount of molar correction is similar to what is reported for the Forsus™ appliance.[58] On the other hand, the Herbst appliance has been reported to produce as much as 6.7 mm of molar correction.[59] It is difficult to compare the amount of class II correction that is possible with each appliance, as the initial malocclusion differs for each study, as well as for each subject treated. In the current study, the majority of molar correction (approximately 70%) was due to mesialization of the mandibular molar. Distalization of the maxillary molar accounted for only ~30% of the sagittal correction. This relationship is similar to the class II correction reported by Heinrichs et al. with the Forsus™ appliance: the maxillary molar distalized 0.5 mm as the mandibular molar came forward 1.3 mm.[58] In contrast, studies on the banded and acrylic Herbst appliances show that mandibular molar protraction only accounts for 20-30% of the overall molar relationship correction.[61]

The results of this study show that the Carriere® Motion appliance in conjunction with a lower Essix retainer can effectively correct a class II molar relationship by dentoalveolar changes, exhibited largely by anterior movement of the mandibular dentition. There was an average molar correction of 3.85 mm; however, this correction was accompanied by occlusal plane steepening (4.85°), mandibular molar protraction (3.16 mm), and mandibular incisor protrusion (1.09 mm) and proclination (2.68°) for a maxillary molar distalization of 1.20 mm. The ideal case selection for this appliance would be a patient whose mandibular dentition would allow for compensation (namely, anterior movement of the lower incisors). Also, the patient's pre-treatment occlusal and mandibular planes should not be excessively steep, as the Carriere® appliance tends to extrude lower molars and can affect these measurements similarly to class II elastics.

Further long-term studies on the treatment effects of the Carriere® Motion appliance are needed, as subsequent comprehensive treatment will undoubtedly effect skeletal and dentoalveolar measurements. Kim-Berman and McNamara found that the lower incisor uprighted 0.7° during the second phase of treatment, and the functional occlusal plane steepness relapsed almost to the pre-treatment measurement.[46] It would be useful to determine how much sagittal molar relapse occurs during this time, as the aforementioned study did not measure the sagittal movement of the molars in relation to a skeletal landmark. A CBCT study would also be useful in order to determine how much maxillary molar rotation, as well as the amount of maxillary canine tipping and extrusion occurs during treatment with the Carriere® appliance. More comparative studies are needed to determine the treatment efficiency of class II correction with the Carriere® appliance versus intermaxillary elastics alone, as the current published literature disagrees on this topic.

CONCLUSIONS

- The Carriere® Motion 3D appliance with a lower Essix retainer effectively corrects a class II molar relationship in an average of 4.7 months before the onset of comprehensive orthodontics.
- The sagittal correction was accomplished primarily by dentoalveolar changes, exhibited largely by anterior movement of the mandibular dentition.
- The maxillary molar was distalized 1.20 mm; anchorage loss in the lower arch was indicated by mandibular molar mesialization of 3.16 mm and mandibular incisor protrusion (1.09 mm) and proclination (2.68°).
- Treatment effects, including an increase in occlusal plane angulation and lower molar extrusion, are similar to the effects seen with class II elastics used with fixed appliances.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL

THE UNIVERSITY OF ALABAMA AT BIRMINGHAM
Office of the Institutional Review Board for Human Use

470 Administration Building
701 20th Street South
Birmingham, AL 35294-0104
205.934.3789 | Fax 205.934.1301 | irb@uab.edu

APPROVAL LETTER

TO: Dean, Julia I

FROM: University of Alabama at Birmingham Institutional Review Board
Federalwide Assurance # FWA00005960
IORG Registration # IRB00000196 (IRB 01)
IORG Registration # IRB00000726 (IRB 02)

DATE: 22-Jun-2020

RE: IRB-300004536

A Cephalometric Study of the Effects of Class II Malocclusion Correction Utilizing the Carriere Distalizer and Essix Retainer

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The IRB reviewed and approved the Initial Application submitted on 16-Jun-2020 for the above referenced project. The review was conducted in accordance with UAB's Assurance of Compliance approved by the Department of Health and Human Services.

Type of Review: Exempt
Exempt Categories: 4
Determination: Exempt
Approval Date: 22-Jun-2020
Approval Period: No Continuing Review

The following apply to this project related to informed consent and/or assent:

- Waiver of HIPAA

Documents Included in Review:

- hsp.clean.200616
- datacollection.200409
- waiverauth.200409
- IRB PERSONNEL FORM

THE UNIVERSITY OF ALABAMA AT BIRMINGHAM
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APPROVAL LETTER

TO: Dean, Julia Irby

FROM: University of Alabama at Birmingham Institutional Review Board
Federalwide Assurance # FWA00005960
IORG Registration # IRB00000196 (IRB 01)
IORG Registration # IRB00000726 (IRB 02)

IORG Registration # IRB00012550 (IRB 03)

DATE: 18-Sep-2020

RE: IRB-300004536
A Cephalometric Study of the Effects of Class II Malocclusion Correction Utilizing the Carriere Motion 3D Appliance and Essix Retainer

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The IRB reviewed and approved the Revision/Amendment submitted on 16-Sep-2020 for the above referenced project. The review was conducted in accordance with UAB's Assurance of Compliance approved by the Department of Health and Human Services.

Type of Review: Exempt
Exempt Categories: 4
Determination: Exempt
Approval Date: 18-Sep-2020

The following apply to this project related to informed consent and/or assent:

- Waiver of HIPAA

Summary of Changes:

Title Change

Documents Included in Review:

- praf.200916