The Effectiveness of Tipback Mechanics for Correction of Class II Malocclusion

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The Effectiveness of Tipback Mechanics for Correction of Class II Malocclusion

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Introduction and Review of Literature

The prevalence of Class II malocclusion among Caucasians ranges from 23.8% to 33% in the United States.\(^1\) These patients are routinely treated with either extraction of maxillary bicuspids or non-extraction methods which include distalization of maxillary molars or functional appliances. Various treatment modalities have been suggested to aid in Class II correction. The different appliances target either the maxillary (intra-arch) or both maxillary and mandibular arches (inter-arch) and can be divided into two broad categories based on compliance. Headgear has been one of the most popular intra-arch, compliance-based, extra-oral appliances.\(^2\) More recently, non-compliance appliances have gained popularity since they don’t rely on the patient’s cooperation to obtain the desired effects. Among these, intra-arch options include the Pendulum,\(^3\) Distal Jet,\(^4\) and Jones Jig \(^5\) appliances. Although effective distalization of the maxillary molars can be obtained with these appliances, anchorage loss has been reported during the process, observed as anterior displacement of the teeth mesial to the first maxillary molars.\(^6\) The reason for this anchorage loss is related to the mesial force delivered by these appliances in an attempt to drive the maxillary molars distally.

Tipback mechanics is also a non-compliant intra-arch approach that circumvents the problem of applying a mesial force, by delivering instead, an intrusive force to the anterior teeth while distalizing the maxillary molars.\(^7\) From a theoretical perspective this is a sound concept; however very limited information in the literature on the effectiveness of these mechanics for Class II correction has been reported.
The Segmented Archwire for Predictable Force Systems

In 1962 Burstone\textsuperscript{8} introduced the concept of segmented arch mechanics. The rationale of a segmented arch was to deliver light constant forces while controlling the reactive (anchorage) units. With segmental mechanics, different types and multiple cross sections archwires can be used. Full sized rigid archwires can be used to reinforce anchorage and prevent unwarranted side effects. This allows for great versatility in the appliance in order to achieve desired tooth movements, since the force values can be altered for a differential response on the active and reactive units. Other advantages with segmental mechanics over a continuous arch are that firstly, one can vary the point of application; secondly, the use of long inter-bracket spans can reduce the load deflection rate of the wire; and thirdly, forces on the reactive units are better distributed. Additionally, due to the low load deflection rate, relatively constant forces and moments can be delivered.\textsuperscript{9} On the contrary, in straight wire mechanics, the reactive units are the adjacent teeth, thereby limiting the versatility when compared to segmental mechanics.

**Equivalent force systems and importance of the center of resistance (CR) in segmental mechanics**

A simple distal force at the bracket level of an incisor will result in the crown moving distally, which is appreciable clinically. However, the complete information on the quality of movement is generally lacking when the tooth movement is described at the level of the crown. A better way to describe tooth movement is to transfer the force system to the CR of the individual tooth or group of teeth. So, to describe the effects on a tooth of a simple force at the bracket level, an equivalent force system of that force at the
CR would be equal to the same force (in magnitude and direction), plus a moment, which will cause the tooth to tip. Thus, in order to accurately predict the type of tooth movement anticipated with a particular force system, knowledge of the location of the CR of a tooth, or group of teeth, is absolutely necessary. If the CR is known, an appropriate moment to force ratio can be determined and consequently altered based on the desired tooth movement with the 1 couple system.

Various analytical and experimental studies on locating the CR of the maxillary anterior teeth have been reported in the literature. Yoshida et al. reported that the CR of the maxillary central incisors was approximately two-thirds of the palatal alveolar bone height, when measured from the root apex. Jeong et al. reported the CR at 13.5mm apical and 12mm posterior from central incisor incisal edge for the maxillary 4 incisors. Furthermore, the CR for the maxillary 6 anterior teeth was located 13.5mm apical and 14mm posterior from the central incisor incisal edge. Matsui et al. reported the CR of the maxillary incisors 6mm apical and 4mm posterior to a line perpendicular to the occlusal plane from the interproximal alveolar bone crest of the central incisors. Vanden Bulcke et al. reported the CR of the 4 maxillary incisors between the canine and first premolar at the coronal third of the canine root, and between the middle third of the premolars roots for the 6 maxillary anterior teeth. Pedersen et al. found the CR of the 4 incisors close to the CEJ (cemento-enamel junction) of the maxillary canine and 2-3mm above the CEJ of the maxillary first premolar, for the maxillary six anterior teeth.

Clearly, all the above studies were not consistent in determining the location of the CR for 4 and 6 maxillary anterior teeth. These inconsistencies could be due to the difference in the methodology (laser holography/ photoelastic technique/ finite element study) for
determining the CR. Nonetheless, all these studies locate the CR of the anterior maxillary teeth in a narrow region that can be used as a reference to predict tooth movement clinically, based on the force system delivered.

**One couple force systems or statically determinate system**

One bracket/couple force system is an excellent example of segmental arch mechanics in orthodontics. In this force system, a couple is created when a wire is engaged in the bracket or tube at one end, while at the other end of the system a single force is generated as a point contact. The force magnitudes are equal and opposite in direction, acting separately on the active and reactive units. The moment of the couple produced at the molar tube will rotate this tooth with its center of rotation at the CR, resulting in a type of tooth movement known as uncontrolled tipping. To minimize the side effects on the anchor units, the line of force can be directed through the center of resistance of the anchorage segment. If the force is not through the CR, then a moment due the force is generated, which can rotate the tooth. The rotational tendency can be minimized by varying the point of force application to a point close to the CR. If the distance is significant from the CR to the point of force application, the moment due the force will be large; whereas moving the force closer to the CR will reduce the magnitude of the moment. Any undesirable tooth movements of the anchor units can be negated with the use of transpalatal arches, elastics or headgears. The one couple system is a statically determinate force system that enables the prediction of the quality of tooth movement on the active and anchor units.
Newton’s law of equilibrium can be applied to design statistically determinate 1 couple appliances for bringing about various types of tooth movement. The most common clinical applications of 1 couple appliances in orthodontics are: cantilever springs in three dimensions (first order, second order and third order), 3-piece intrusion arches, Connecticut intrusion arches, extrusion arches, tipback mechanics, and Burstone’s torqueing auxiliary. These appliances are designed for anterior intrusion and extrusion, midline correction, uprighting, correction of aberrant mesiodistal inclination of 1 or more teeth, Class II correction, palatal root torque for anterior teeth, etc. In fact, the movement of 1 tooth or a group of teeth can be accomplished in any plane with this force system. 9

**Tipback mechanics**

Tipback bends in the posterior teeth were incorporated in the multibanded appliance in Tweed’s edgewise technique in order to provide anchorage during space closure after premolar extractions. 15 Although a commonly used approach in continuous arch mechanics, tipback bends can produce undesirable side effects on the adjacent teeth. Hence, the force system is statically indeterminate, which precludes accurate prediction of the direction and force magnitude exerted on the teeth.

A variation of tipback bends in a statically determinate force system known as tipback mechanics was introduced by Romeo et al. 16 for correcting unilateral 17 or bilateral Class II malocclusions due to aberrant mesio-distal inclination of the buccal segments, devoid of patient compliance and undesirable side effects on the anterior teeth. Specifically, the purpose of these mechanics was to correct the second order inclinations of either
individual teeth or a group of posterior teeth by means of a one couple system that generates a moment to tip the posterior teeth distally.

A one-couple force system in tipback mechanics results in distal crown tipping of the posterior teeth or segment and an intrusive force through the center of resistance of the anterior segment. Theoretically, the moment required to tip the molar ranges from 800-1200 gm/mm and from 2400-3600 gm/mm for the whole posterior segment. The distance from the point of force application to the molar can be determined clinically and the amount of vertical force needed to produce the tipback moment can be calculated. The point of force application can be varied in the anterior segment based on the type of movement required anteriorly. Anterior teeth can be flared or uprighted by changing the point of force application and its relationship to the center of resistance of the anterior segment. In a patient with a Class II Division 1, the incisors are flared labially, thus any point of force application labial to the center of resistance will result in further flaring of the incisors. To overcome this side effect, the point of force application can be modified to a location distal to the center of resistance of the anterior segment. Similarly, for patients with a Class II Division 2, a point of force application labial to the center of resistance can upright the incisors.

**Appliance design**

In the original tipback mechanics introduced by Romeo et al., a 0.018 x 0.025-in cantilever spring with a helix was used. The incorporation of a helix was intended to reduce the load deflection rate of the wire. The cantilever spring was activated so that the spring lied gingival in its neutral, unloaded position, and was hooked to an anterior
segment of teeth. Depending on the number of posterior teeth to be tipped back, a rigid wire connected these teeth so that the distal tipback moment acted on the full unit. If the treatment objective was to distalize only the molar, the cantilever spring only engaged that tooth and no rigid archwire was placed in any other of the posterior teeth. Burstone\textsuperscript{16} recommended placing a rope tie from the molar to the other teeth anteriorly to also tip them distally. It has been reported that arch length is increased nearly 2-3 mm/side with tipback mechanics.\textsuperscript{16, 20}

Since its introduction in 1977, tipback mechanics has been modified both in its applications and types of archwire used. Based on the type of tooth movement required, tipback mechanics can be applied bilaterally as a 1 piece intrusion arch or unilaterally as a cantilever spring, either with a continuous or segmented arch.\textsuperscript{18, 19, 21} In deep overbite subjects, simultaneous incisor intrusion and molar distalization can be achieved with tipback mechanics. Light constant forces delivered from an intrusion archwire, which is manufactured either with nickel titanium or beta titanium alloys, allow for intrusion of the anterior teeth. Another major advantage with this mechanics is that the large inter-bracket span between the molar tube and incisor brackets favorably reduces the load deflection rate,\textsuperscript{9} obviating the need for frequent reactivation.

**Differential torque concept: Modified 1 couple system**

Nasiopoulos\textsuperscript{22} et al. proposed an alternative method of Class II correction using a modified one-couple system. In this study, 19 patients who had a Class II Division 1 malocclusion with increased overjet and overbite received a 2x4 appliance with tipback bends or V-bends placed in a 0.020-in stainless steel archwire engaging the molars and
incisor brackets anteriorly. No extra-oral appliance or Class II elastics were used in these patients. Superimposition of cephalograms before and after tipback was evaluated to analyze the treatment effects of the 2 x 4 appliance.

The results yielded an overjet reduction of 4mm, overbite reduction of 3mm, maxillary molar mesialized by 0.5mm, and point A moved forward by 0.12mm. Comparing the results with longitudinal growth studies, they found an average additional 3 mm anterior displacement in molar and point A in the untreated subjects. Based on these outcomes, they consider that the differential torque mechanics could be a treatment alternative for the correction of Class II division 1 malocclusion and consider the study as pilot data for future research. The authors concluded that Class II correction can be attained by either maxillary first molar distal movement or by maintaining the position of the upper first molar and allowing the lower first molar to erupt in a forward and upward direction in the presence of mandibular growth.

**Tipback mechanics for distalization of maxillary molars and molar root uprighting with headgear**

In 1998, Nanda et al. introduced the Connecticut Intrusion Arch for correction of deep bites and Class II malocclusions. The 1-piece intrusion arch is attached to the incisor brackets as a point contact and posteriorly engaged in the molar tube. The uniqueness of this system was the constancy in force delivery, no wire changes and less adjustment of appliances during the appointments. All this was made possible as the intrusion arch was prefabricated with v-bends in nickel titanium wire to deliver an intrusion force in the range of 40 to 60-g anteriorly.
The Connecticut intrusion arch has a v-bend positioned close to the molar and engages the anterior teeth over the brackets resulting in 1-couple force system. The intrusion arch does not engage the maxillary incisor bracket slots. The intrusive force generates a clockwise moment of approximately 1200g-mm if the distance between the point of force application and molar tube is approximately 30mm. This moment was sufficient to tip the molar distally.

With the use of the Connecticut intrusion arch, simultaneous intrusion of maxillary incisors and tipback of the maxillary molars can be obtained. If no intrusion of the maxillary incisors is required, then the anterior segment can include the canines and allow only the molar to tip distally. However, to upright the maxillary molar, the use of headgear has been advocated. The outer bow of the headgear should be above the center of resistance of the maxillary molars to upright the molar while maintaining the Class I molar relation.

**Tipback mechanics for simultaneous distalization of maxillary molars and deep overbite correction**

Faber et al. evaluated the 1 couple force system from the intrusion arch fabricated from nickel titanium and beta titanium archwires. The primary objective was to determine the reaction of the maxillary incisors to the statically determinant 1 couple force system using a single activation of the intrusion arch. Patients were followed for 3 months and the data were analyzed. In the nickel titanium intrusion arch group, they found 1.1mm of maxillary incisor intrusion, 0.55mm of molar tipback and 4.7 degrees of distal molar crown tip. In the beta titanium group, 1.27mm of upper incisor intrusion, 1.67mm of
molar tipback and 9.9 degrees of molar distal tipping was seen. The maxillary incisors flared by 1.56 degrees and 3.26 degrees for beta titanium and nickel titanium archwire groups, respectively.

Van Steenberg et al. reported 8.74 degrees of incisal flaring with the intrusion arch used for incisor intrusion. Based on the above findings, the anterior segment consisting of maxillary incisors intruded but labial crown movement was also observed. Thus, tipback mechanics when used only for maxillary molar distal movement requires possibly more teeth in the anterior region to negate the observed labial flaring.

**New treatment method for molar root uprighting after maxillary molar distalization after tipback mechanics**

In Faber’s study, the molar tipback was obtained with a predictable 1 couple force system using the intrusion arch. However, after distal crown tipping of the maxillary molar, it is necessary to upright the root using extra-oral appliances and retract the anterior teeth. During this phase, the distalization obtained may be lost by mesial migration of the maxillary molar as seen with other distalization appliances.

Instead of using headgear, we propose new a treatment alternative to be evaluated, in which the root uprighting of the maxillary molar can be achieved by sequentially increasing the dimension and stiffness of the archwires to fill the molar tube while the intrusion arch remains in place.

After the tipback completion and when a continuous archwire is placed, the force system changes to a statically indeterminate force system. Placement of a continuous archwire generates a counterclockwise moment due to an intra-bracket couple (moment due to
couple-Mc). The side effect of this moment may tip forward the molar, with an intrusive effect on the molar and extrusion of the premolars. However, this side effect can be negated with the use of an intrusion arch, which counteracts the anticlockwise moment and intrusive force generated due to the placement of a continuous wire after tipback. At the same time, the additional arch length gained after tipback can be utilized by retracting the anterior teeth with the aid of Class II intermaxillary elastics.

Another difference with this proposed treatment approach is the larger size of the anchorage unit that includes all the anterior teeth from second premolar to second premolar. Previously, only the maxillary 4 anterior teeth have been used as anchorage/active units and extensively investigated with either 1 couple or 2 couple system based appliances. With these appliances, maxillary incisor intrusion and simultaneous distalization of the maxillary molar can be achieved predictably. This type of treatment effects may be beneficial in the treatment of Class II Division 2 malocclusion. However, when the deep overbite is corrected and further distalization of the molar is needed, maxillary canines and premolars can be connected to the 4 incisors with a stainless segment to act as a rigid anchorage unit. However, the effect of a large anterior anchorage unit (from second premolar to the contralateral second premolar) in minimizing the anterior intrusive force is largely unknown.

**Tipback mechanics for maxillary molar distalization in subjects with normal overbite**

The versatility of tipback mechanics can bring about various tooth movements by changing the point of force application or by increasing the anchorage units, etc.
Simultaneous deep overbite correction and molar distalization can be achieved with tipback mechanics. However in subjects with normal overbite, the use of an intrusion arch on the anterior anchorage unit may intrude and flare them, and posteriorly, can tip the maxillary molar distally. To prevent intrusion and labial tipping of the incisors in subjects with acceptable overbite, inclusion of maxillary canines for increasing the anchorage of anterior segment has been suggested. However, there are no studies in the literature that have evaluated the effectiveness of 6 anterior teeth in preventing any unwarranted side effects due to this 1 couple force system. Additionally, we recommend the maxillary first and second premolars to be included in the anterior anchorage unit. Theoretically, the inclusion of all premolars should successfully negate the side effects on the maxillary incisor teeth. However, the dental response to this new force system has not been evaluated before.

**Summary**

Appliances based on a one couple system have been used in orthodontics since the past five decades. Among these appliances, tipback mechanics with the use of an intrusion arch are routinely used for maxillary incisor intrusion and also for tipback of maxillary molars. During the distalization of the maxillary molars, the anterior 4 maxillary incisors tip labially and intrude apically. Similar results were reported with the other intra-arch distalization methods. To reinforce the anchorage, the maxillary canines, first premolars and second premolars can be added to the maxillary incisors. Theoretically, a 10 teeth segment should successfully prevent the side effects on the anterior anchor unit if only maxillary molar distalization is intended. However, there aren’t any studies
evaluating the dental response of the maxillary incisors and maxillary molars to the above mentioned biomechanical force system.
Rationale

The effectiveness of tip-back mechanics for distalization of maxillary molars as a non-extraction treatment for Class II correction has been reported. However the clinical outcome for Class II correction with tipback mechanics has not been evaluated or quantified. The purpose of this prospective study was to determine the maxillary incisor and molar changes to a 1 couple force system from a Connecticut intrusion arch.

Specific Aims

The purpose of this study was to evaluate the treatment outcomes achieved with tipback mechanics by measuring the:

1. Changes in maxillary first molar position calculated in the vertical and anteroposterior dimensions after maxillary molar tipback is completed, and later, after the molar root uprighting is completed.

2. Maxillary incisor position changes in the vertical and anteroposterior dimensions after maxillary molar tipback is completed and after maxillary first molar root uprighting.

Null Hypotheses

1. There is no significant difference in the anteroposterior and vertical position of the maxillary incisors when an anchorage unit from second premolar to the same contralateral tooth is used with tipback mechanics.

2. There is no significant difference in the anteroposterior position of the first maxillary molar with tipback mechanics.
Materials and Methods

Ethical approval from the Institutional review board (IRB no: 11-016-1), University of Connecticut Health Center was obtained for this prospective study. A power analysis was performed using the data from Faber’s research. The minimum sample size needed was 17 subjects. To account for an attrition rate of 15%, overall recruitment goal was 20 subjects. Nineteen patients were recruited in the study based on these inclusion criteria. Two patients were excluded from the study as they did not meet study requirements prior to study intervention. Recruitment of subjects was stopped as soon as the 17 subjects were actively enrolled and were undergoing the study intervention as per protocol.

In this observational descriptive study, all the subjects underwent study intervention with tipback mechanics. The subjects recruited in this study were 7 males and 9 females with a mean age of 12.63 ± 1.1 years (Table I). Patients were selected according to the following inclusion criteria:

1) Angle’s’ Class II end on molar relationship bilaterally,
2) Non-extraction treatment plan,
3) Age group between 11-14 years and
4) Patients with good oral hygiene.

The exclusion criteria were:

1) Presence of any primary teeth,
2) Missing or malformed permanent teeth (except third molars),
3) Any medical issues that could have an effect on the tooth movement, and
4) Failure to provide oral and written consent to be included in the research.
**Tipback Guidelines**

Patients were bonded with 0.022-in self-ligating Carriere brackets (ClassOne Orthodontics, Co). After leveling and aligning stages with nickel titanium archwires, the patient was reassessed whether they maintained the end on molar relation or not. When a 0.016 x 0.022-in stainless steel archwire could be placed passively, tooth positioning jigs were placed on the auxiliary tubes of the first maxillary molars and stabilized with an O-ring. Tooth positioning jigs on the left side and right side were oriented in opposite direction and height. A pre tipback lateral cephalogram (T1) was taken with the jigs in place which made it possible to radiographically differentiate the right side from the left side.

Following this, a 0.016 x 0.022-in stainless steel segment was placed from the second premolar to contralateral second premolar. If canines were erupting, step out bends were placed to avoid any interference for the canines. A prefabricated 0.017 x 0.025-in Connecticut intrusion arch was placed in the first molar tubes and tied over the brackets of the 4 maxillary incisors with a 0.016 x 0.022-in stainless steel base archwire. To keep the activation of the intrusion arch consistent, a prefabricated intrusion arch was used for all patients. Tipback was completed when Class I molar relationship was achieved clinically or it was determined clinically that further tipback of the molar was not possible. The intrusion arch with base archwire was removed and tooth positioning jigs were placed and a second lateral cephalometric radiograph (T2) was taken.

**Molar Uprighting Guidelines**

In this phase, 0.017 x 0.025-in nickel titanium arch wire was placed from maxillary first molar to first molar. The Connecticut intrusion arch was maintained in the first molar
auxiliary tubes and tied to the lateral incisors over the base archwire to counteract the side effects due to placement of a continuous archwire. The subjects were instructed to wear Class II elastics for retraction of the anterior teeth after tipping of the maxillary molars. Archwires were sequentially built up in size until reaching a 0.017 x 0.025-in stainless steel archwire. The uprighting phase of the maxillary molar was considered complete 4 weeks later. The tooth positioning jigs were placed again at this point and a third lateral cephalometric radiograph (T3) was taken.

**Lateral Cephalometric Analysis**

Tooth positioning jigs were placed in the maxillary first molar tubes and lateral cephalograms were taken prior to molar tipback after the initial leveling and aligning phases were complete (T1), when the molar tipback was complete (T2), and when the molar root uprighting was complete (T3). Tooth positioning jigs were made from 0.017 x 0.025-in stainless steel archwires and inserted in the auxiliary slot of the maxillary first molar tube. The jigs were bent at a 90 degree angle to the slot, and for identification between right and left side, the left jig was 10mm in height and bent mesially. On the other hand, the right jig was 5mm in height and bent distally. The anteroposterior and vertical measurements of the maxillary molars on the lateral cephalogram were done at the jigs entrance from the auxiliary slot of molar tube as described by Davoody et al. 27 The lateral cephalograms taken at T1, T2, T3 were traced and superimposed on the internal cortications of the maxilla to measure the dento-alveolar response to the tipback mechanics.
**Lateral cephalogram superimposition method:**

The superimposition of lateral cephalograms at 3 time point was done as described by Davoody et al.\textsuperscript{27} To evaluate and quantify dental changes to the tipback mechanics, the maxillary superimpositions were performed. The superimpositions were done on internal cortication of the maxilla (Figure 1) and an X-axis which was drawn by connecting the anterior nasal spine (ANS) and posterior nasal spine (PNS). A Y-axis was derived by drawing a line perpendicular to the X-axis, passing through the sella turcica. After superimposition on the internal cortication of the maxilla, the X-Y coordinate system was transferred to the T2 and T3 cephalograms from the T1 lateral cephalogram. The antero-posterior changes of the maxillary first molars and central incisor were measured using the Y axis as reference plane. Similarly, the vertical molar and incisor changes were measured from the X-axis. Right and left side measurements were measured for molar dental movements in the vertical and antero-posterior dimensions and they were averaged to determine the extrusion and tipback. Angular change of the molars was measured by extending the line along the axis of the tooth positioning jig through the X axis and measuring the interior angle formed (Figure 1, no. 5). Similarly, the change in inclination of the maxillary incisor was measured by extending a line along the long axis of the incisor to the X axis and the interior angle was measured to determine the changes in incisor angulation (Figure 1, no. 10).

Vertical maxillary incisor changes were measured from the X-axis for intrusion and antero-posterior changes, and from the Y-axis for labial tipping. However, the incisor measurements in either plane were done from the root apex, incisal edge, and centroid
point. Centroid point was a constructed point defined as 15mm from the incisal edge along the long axis of the incisor.

Figure 1 depicts the summary of measurements used in the study:

**Maxillary regional superimposition**

1. Distance of U1 Tip to Y at T1, T2, and T3.
2. Distance of UR6 and UL6 to Y at T1, T2, and T3.
3. Distance of UI Centroid to Y at T1, T2, and T3.
4. Distance of UI Apex to Y at T1, T2, and T3.
5. Average Angulations of UR6 and UL6 to X at T1, T2, and T3.
6. Distance of UR6 and UL6 to X at T1, T2, and T3.
7. Distance of UI Tip to X at T1, T2, and T3.
8. Distance of UI Centroid to X at T1, T2, and T3.
9. Distance of UI Apex to X at T1, T2, and T3.
10. Angulation of UI to X at T1, T2, and T3.
Data Analysis

The sign conventions followed in this study were: a negative value indicated a distal, backward or intrusive movement and a positive value indicated a mesial, forward or extrusive movement. The dental changes of maxillary first molars and incisor after tipback was determined by subtracting the T1 values from T2 (T2-T1). Similarly, after root uprighting of the molar, dental changes after molar uprighting were determined by subtracting the T1 values from T3 values (T3-T1).

Statistical Analysis

Statistical analysis was performed using the SPSS software, version 17.0. The Shapiro Wilk test for normality was conducted and data were found to be normally distributed. As the sample size was less than 30, Friedman’s test, which is a non-parametric statistical test, was performed to determine whether there was a significant change from T1 to T2 or T3. Wilcoxon signed rank test was used to evaluate changes between T1, T2, and T3 time points. P value < 0.05 was considered as statistically significant. The results are presented below in Tables III to V.
Results:

Table I shows the demographics of the patients enrolled in this prospective study. Overall, 19 subjects were enrolled and 2 subjects were excluded from the study after the initial alignment phase due to changes in the occlusal relationship. Specifically, the initial end-on Class II molar relationship shifted unilaterally or bilaterally to a full cusp Class II molar relationship. In one of the study subjects, the T2 lateral cephalogram was distorted due to a technical problem in the x-ray machine and measurements were not taken for all the 3 time points; this subject was excluded from the study.

Table II shows the results of intra class-correlation coefficient (ICC), which is a measure for the intra-rater reliability of the measurements of the variables. ICC Cronbach’s alpha ranged from 0.94 to 0.99, indicating an excellent reliability by a single rater (N.J.). All the lateral cephalograms were retraced again 4 weeks later and measurements recorded for intra-rater analysis. The first set of measurements which were recorded initially, was used for the statistical analysis. Bland Altman analysis was used to investigate the agreement between the measurements at the different time points. Figures 2 to 5 are the Bland Altman plots showing the mean differences and limits of agreements between the two measurements. Mean difference for the right side molar tipback at T1 was $0.15\text{mm} \pm 0.47$ with 95% limits of agreement at -0.77 to 1.08, at T2 was $0.03 \pm 0.69$ with 95% limits of agreement at -1.33 to 1.39, and at T3 was $0.34\text{mm} \pm 0.81$ with 95% limits of agreement at -1.24 to 1.93. Mean difference for the left side molar tipback at T1 was $0.18\text{mm} \pm 0.44$ with 95% limits of agreement at -0.67 to 1.05, at T2 was $0.0 \pm 0.6$ with 95% limits of agreement at -1.18 to 1.18, and at T3 was $0.37\text{mm} \pm 0.61$ with 95% limits of agreement at -0.83 to 1.58.
Mean difference for incisor apex at T1 was 0.06mm ± 0.47 with 95% limits of agreement at -0.87 to 1.0, at T2 was -0.031 ± 0.34 with 95% limits of agreement at -0.69 to 0.63, at T3 was 0.09mm ± 0.58 with 95% limits of agreement at -1 to 1.23. Mean difference for right molar angular change at T1 was 0.15mm ± 1.06 with 95% limits of agreement at -1.92 to 2.23, at T2 was 1 ± 2.89 with 95% limits of agreement at -4.66 to 6.6, and at T3 was 0.46mm ± 1.56 with 95% limits of agreement at -2.59 to 3.53. This analysis demonstrates that the average discrepancy between two measurements was not large enough and may not be clinically significant. The differences between the measurements are within the limits of agreement 95% of time (limits of agreement are mean ± 1.96 times its standard deviation).

Tables III - V display the summary statistics of all the variables examined in this clinical study. Significant differences were evident for molar tipback, molar extrusion, angular change in molar, incisor apex, centroid point of the incisor both vertically and antero-posteriorly, incisor incisal edge vertically and angular change of the maxillary incisor.

Maxillary molar distal movement of 1.53mm was seen after tipback (T2). However the crown came forward by 0.09mm after molar uprighting (T3) with a resultant distal crown movement of 1.43mm. However, the molar extruded by 0.86mm after tipback and 0.74mm of molar extrusion was maintained at T3. The angular change of 6.65 degrees of molar was recorded after tipback, however 4.97 degrees of angular change was present at the end of root uprighting phase (T3).

The maxillary incisor position at the incisal edge flared labially by 0.4mm at T2 and moved back to 0.12mm at T3 (Table V). The centroid point moved backwards by 0.4mm after tipback at T2 and moved backward by 0.77mm at the end of T3. Similarly, the
maxillary incisor root apex moved palatally by 1.19mm at T2 and moved further palatally by 1.5mm at T3. Vertically the incisal edge intruded by 0.97mm at T2, but the incisal edge extruded by 0.56mm at T3. Centroid point intruded by 0.78mm at T2, but the 0.63mm of intrusion was lost at the end of the uprighting phase (T3). Incisor apex intruded by 0.46mm after the tipback phase (T2) and 0.31mm of intrusion was lost at T3.

Discussion
The rationale for segmented mechanics introduced by Burstone was to deliver light constant forces on the active units while maintaining the ability to control the reactive or anchor units. Tipback mechanics, a type of segmental mechanics, is a 1 couple system and statically determinate force system. An intrusion arch engaging the maxillary incisors anteriorly and the maxillary molars posteriorly can simultaneously intrude the incisors and tip the molars distally. This biomechanical force system can be the treatment of choice in Angle’s Class II malocclusion. Various methods for the management of Class II malocclusion have been advocated. Class II elastics, distalization of maxillary posterior teeth with intra and inter-arch appliances, functional appliances, extra-oral appliances and camouflage are popular methods of intervention. Although tipback mechanics as a treatment alternative in these patients has been recommended, there is scarce information in the literature regarding its effectiveness measured as amount of molar distalization and quality of molar movement obtained after distalization.

Nasiopoulos et al. quantified a modified tipback approach using a differential torque concept and found that the molar mesialized by 0.64mm during the study intervention. They compared this finding to longitudinal growth studies and found that the maxillary
molars moved forward by 3mm in untreated controls. The authors concluded that the differential torque concept had a restraining effect on the maxillary molar. However, the major drawback of this study was that they quantified the maxillary dental changes after the completion of treatment retrospectively. Furthermore, it was difficult to determine the type of maxillary molar movement attained with their mechanics.

Faber quantified the amount of maxillary incisor intrusion with nickel titanium and beta-titanium archwires. They reported molar tipback of 1.65mm and 0.55mm for beta-titanium and nickel titanium archwire groups, respectively. Vertically, the molar extruded by 1.11mm and 1.10mm for beta-titanium and nickel titanium archwire groups, respectively. Unfortunately, this study lacked important information of clinical relevance after completion of tipback. The author failed to describe whether Class II correction was achieved or not, what type of tooth movement was achieved (controlled or uncontrolled tipping of the molar), and the precise location of center of rotation of the molar.

In the present study, 1.53mm of molar tipback was observed. The amount of molar tipback lost during the uprighting phase was 0.09mm, so the overall molar distalization after the molar uprighting phase was 1.43mm. Vertically, the molar extruded by 0.86mm after tipback and 0.12mm of extrusion was lost at the completion of the molar uprighting phase. The angular change in molar inclination was 6.65 degrees and at the completion of the uprighting phase, the molar maintained 4.97 degrees of distal inclination. Based on these measurements, the center of rotation for the molar and the type of tooth movement obtained with this mechanics can be determined.

Based on a free body diagram, any moment due to a couple acts at the center of resistance of that body. The center of resistance has been described to be located near the
trifurcation of the maxillary molar and thus the center of rotation due to a couple of the intrusion arch should be located at the center of resistance. Using the formula $2\pi r = \text{circumference of the circle}$, where $r$ is the radius, we can calculate the center of rotation based on the data obtained from this study.

$2\pi r = 360 \text{ degrees.} \quad \ldots \ldots \text{equation (1)}$

$1.53 = 6.65 \text{ degrees.}$

Using the above equations, $r$ was determined based on $6.65 \text{ degrees of distal tipping}$ and was equal to $13.1 \text{ mm}$, which is $4-5 \text{ mm above the theoretical center of resistance of the molar}$. The average length of the maxillary first molar is $20.5 \text{ mm}$ and an estimated center of resistance near the trifurcation is $11.5$ to $12 \text{ mm from a buccal view}$. However, the derived center of rotation in this clinical study was at the apical third of maxillary first molar, resulting in an uncontrolled distal crown and root mesial tipping of the molar, hence not consistent with the biomechanical force system. One of the probable reasons for this unexpected clinical response to the expected biomechanical stimulus could be due to the mechanical property of the archwire. We hypothesize that, as the intrusion arch is tied over the incisor brackets, there is deflection of the intrusion arch in the posterior region due to the long inter- bracket span and activation bend mesial to the molar. The intrusion arch has an inherent tendency to return to its original configuration by either flaring the maxillary incisors or by exerting a distal force on the molar. However, the anterior anchorage segment being rigidly connected from second premolar to second premolar with a $0.016 \times 0.022$-in stainless steel archwire, may have successfully negated the mesial force present on the system. The maxillary incisors flared only by $0.4 \text{ mm}$ in this study. On the other hand, the force was expressed primarily on the molar in a distal
direction. Various authors \textsuperscript{10, 32} have shown that, any force at the bracket level will result in the center of rotation being 2-3mm above the center of resistance. Due to the distal force at the molar tube, the center of rotation could be above the center of resistance. However, bench top studies are recommended to validate the findings of this clinical study.

The dentoalveolar changes in this larger anterior anchorage unit have not been evaluated previously during tipback mechanics for maxillary molars. Most of studies have evaluated the incisor changes due to intrusive force from the intrusion arch, but so far none of them have evaluated the effect of intrusion on the second premolar to second premolar segment. Steenbergen et al. found that the incisor axial inclination changed by 8.74 degrees labially while intruding the four maxillary incisors.\textsuperscript{24} Faber et al.\textsuperscript{23} reported flaring of 3.26 degrees for 1.1mm of incisor intrusion. However, none of the studies reported the type of incisor movement, specifically the location of the center of rotation corresponding to the angular change.

In this study, we measured an angular change of 3.31 degrees after the completion of tipback phase. The incisal edge moved labially by 0.4mm, the centroid point moved palatally by 0.40mm and the incisor root apex moved palatally by 1.19mm. Study results clearly show that with these mechanics there was minimal labial flaring and significant root movement (lingual root torque) at the apex. Rigid second premolar to premolar anchorage segment successfully controlled the maxillary incisors from flaring.

Analyzing the quality of movement based on the data, by substituting the incisor angular changes in equation number 1, we found the center of rotation at 6.9mm from the incisal edge at T2, which is slightly above the bracket level. At T3, the center of rotation moved
more incisally to 1.94mm from the incisal edge resulting in further palatal root movement. Various biomechanical studies have shown that for root movement, the center of rotation should be between the bracket level to the incisal edge.\textsuperscript{10} Palatal root torque of maxillary incisors was an unexpected significant clinical finding. Nonetheless, it is difficult to biomechanically explain how an intrusive force of 40-g can produce the palatal root torque. Maxillary incisor palatal root torque is least effectively attained with preadjusted edgewise appliances.\textsuperscript{28} In straight wire mechanics with self-ligating brackets, archwire torsion of 22-35 degrees on a 0.019 x 0.022-in stainless steel wire are recommended to produce an effective torque moment of 5-20Nmm.\textsuperscript{33} It is also reported that 2000 to 3000-gmm of moment is necessary to produce the palatal root torque with Burstone’s anterior root torqueing spring.\textsuperscript{34} The amount of torqueing force required is of high magnitude as the distance between the two forces is very small due to the twist in the archwire. Using the treatment method described in this study, one can obtain palatal root torque with light and constant force.

The palatal root torque obtained in the maxillary incisors is difficult to explain biomechanically in spite of using a statically determined 1-couple system. Jeong et al.\textsuperscript{11} in the finite element model (FEM) showed the center of resistance for the maxillary anterior 6 teeth and maxillary dentition was 13.5mm apical and 14mm posterior, and 11mm apical and 26.5mm posterior to the maxillary incisor edge, respectively. However, we assume the center of resistance of the maxillary second premolar to second premolar to be near the middle of the root of the first premolar. The intrusive force of 40 to 60-g at the incisor bracket level may generate a moment of force of 600 to 900-gmm if the perpendicular distance is 15mm from the point of force application. The segment of the
premolar to premolar was connected with 0.016 x 0.022-in stainless steel archwire and successfully negated the flaring of maxillary incisors at the crown level; however, the reciprocal effect of this force system may be expressed on the incisors roots. Additionally, the intrusion arch is tied over the incisor brackets anteriorly and as the molar tips distally, the row boat effect could have prevented the incisor crown from tipping labially. The combination of these two factors may be responsible for the biological response of the maxillary incisors to the intrusion arch.

An alternative hypothesis is also being proposed for the expression of palatal root torque in the maxillary incisors. The theoretical estimation of play between the archwire and the bracket on a 0.016 x 0.022-in stainless steel archwire in a 0.022 x 0.028-in bracket is 18.85 degrees. The intrusive force on the incisors may have possibly reduced the play. Because of light and constant force on the incisors, once the bracket archwire play is eliminated, 2 point contact of the wire with the bracket can generate a moment due to the couple, which could be responsible for the palatal root torque on the maxillary incisors.

A third hypothesis for this biologic response is being proposed. The deflection of the intrusion arch is seen when it is tied rigidly to the maxillary incisors. As the intrusion arch deactivates, it may exert a mesial force on the maxillary incisors and a distal force on the maxillary molar. Since the maxillary anterior teeth are rigidly connected to the premolars on either side, this anchorage unit effectively could have prevented the incisor crown from moving forward. However, the incisor roots are not constrained and free to move palatally due to this dynamic force system. In addition to this, the molar being a single unit, will readily tip in response to the distal force, if present, and to the posterior moment with tipback mechanics when compared to the larger anterior anchor unit. As the
molar tips distally, it can restrain the maxillary incisors crown from labially flaring due to binding of the archwire in the molar tube. However, the maxillary incisor roots may move palatally due to various unknown variables.

The biologic response to a predictable 1 couple force system fails to explain the treatment effects with the intrusion arch. However, we have proposed a few hypotheses which alone or in combination may be responsible for this maxillary incisor tooth movement. Some of confounding variables like the role of friction in this system is difficult to explain. However, carrying forward this clinical research data to an in-vitro investigation may give some valuable information on the forces, frictional forces and moments acting in 3 dimensions in this biomechanical force system.

After the distal tipping of the molar crown, the next objective was to upright the maxillary first molar root. Traditionally, the molar root can be uprighted predictably using headgear, but patient compliance is a major limiting factor. Alternatively, the molar can be levelled by sequential progression of archwires (up to 0.017 x 0.025-in stainless steel) along with the intrusion arch, thus avoiding the need for headgear. Class II elastics were recommended at this stage. Angelieri et al.,\textsuperscript{25} in a prospective study on distalization of maxillary molars using the pendulum appliance, reported 2.2mm of molar distalization and 9.4 degrees of distal tipping. In a systematic review, \textsuperscript{6} they reported maxillary molar distalization of 2.9mm with 5.4 degrees of distal tipping for various appliances. The amount of distalization with tipback mechanics was slightly less, but the angular change was similar to the other appliances. During the leveling and aligning phases, 1.1 mm of molar distalization was lost, and at the completion of fixed orthodontic treatment, the molar returned to its initial position and inclination after distalization with the pendulum
appliance. On the other hand, with tipback mechanics, the molar crown moved forward by 0.09mm and 1.43mm of molar distalization was maintained at the end of the root uprighting phase. However, the molar did not completely upright at the end of this phase, and 4.97 degrees of distal crown tip was still maintained. A net gain of 1.43mm of additional arch length was seen with tipback mechanics.

In the systematic review, the mean incisor flaring reported for all the distalization appliances was 1.8mm with 3.6 degrees of mesial tipping. Similarly, Angelieri et al. reported maxillary incisor flaring of 2.2mm with an angular change of 4 degrees. On the contrary, in this study the anterior anchorage unit from maxillary second premolar to second premolar successfully prevented the maxillary incisors from flaring. An angular change of 3.31 degrees was seen in our study, which was similar to other studies. However, this change in angulation was due to palatal root torque in the maxillary incisors, whereas in the other studies it was due to incisor flaring. The major advantage with tipback mechanics is that there was no anchor loss anteriorly when compared to other methods of distalization.

Vertically, the maxillary molars extruded by 0.86mm with tipback mechanics. At the end of the uprighting phase, 0.74mm of molar extrusion was maintained. With other distalization appliances, average maxillary molar extrusion was 0.5mm which is comparable to our study. This unwanted treatment effect could worsen the Class II malocclusion and prevent the Class II correction in spite of 1.43mm of distal tipping of the maxillary molar.

Absolute intrusion of the maxillary incisors was not seen due to tipback mechanics used in this study. The incisal edge of maxillary incisor intruded by 0.97mm, the centroid
point by 0.78mm, and the incisor apex by 0.48mm. After the uprighting phase (T3), 0.41mm of intrusion at the incisal edge, 0.15mm at the centroid point and 0.41mm at the incisor apex was maintained. On the other hand, maxillary incisor extrusion of 0.4mm was reported with various distalization appliances. In conclusion, incisor movements vertically from T1 to T3 were not significant and transient changes (intrusion) were seen in incisor position between T1 to T2 time points. Furthermore, the results indicate that the anterior anchorage unit consisting of second premolar to second premolar which was rigidly connected by a 0.016 x 0.022-in stainless steel archwire was able to negate the intrusive force of the intrusion arch. Distal tipping of the maxillary first molar can be readily achieved without any side effects on the anterior dentition, a finding which is not seen with the other intra-arch distalization appliances.

The maxillary dental changes obtained after tipback mechanics was quantified in this study. However, how effective the tipback mechanics were in correction of Class II malocclusion is important information for clinicians to select appropriate treatment for their patients. In 37% (6) of patients, the end on Class II molar was corrected to Class I molar relation on only one side after the tipback phase. Bilateral molar correction was observed in 3 (18%) patients after the tipback phase. In 62% (10) of study subjects, Class II elastics were continued after study intervention to correct the end on Class II malocclusion to Class I occlusion. In the remaining 6 subjects, Class II correction was achieved with fixed functional appliances in 5 study subjects and 1 patient had upper first premolar extractions.

Tipback mechanics with the use of the intrusion arch achieved 1.43mm of maxillary molar distalization. The major advantage was minimal or no loss of anchorage of the
maxillary incisors and premolars. Minor insignificant intrusion and significant palatal root torque was seen on the maxillary incisors. For the correction of an end on Class II molar to Class I, a minimum of 2mm distal movement of maxillary molar is necessary. The amount of distalization obtained in this study may not be sufficient to correct an end on Class II molar relationship. However, tipback mechanics with Class II elastics was effective in correction of end on Class II malocclusion in 62% of the patients. It is important to understand and evaluate why Class II correction with this treatment protocol was not achieved in the remaining one third of study subjects. On average, the maxillary molar extruded by 0.74mm in the study patients, possibly negatively impacting the Class II malocclusion. Extrusive mechanics with unfavorable vertical growth may have prevented successful Class II correction in 37% of the subjects and further research is recommended retrospectively to analyze this hypothesis.

**Clinical significance of the results:**

The predictable force system in this study showed that the molar tipped back by 1.43mm with an angular change of 4.97 degrees. The response of anchorage units to the intrusive force did not flare labially or intrude them. However, palatal root torque was expressed by the maxillary incisors, which is a significant finding of the study. Two important observations can be made, firstly, the anterior anchorage units did not move labially when compared to commonly used distalization appliances. Incisor position was maintained both vertically and antero-posteriorly after the treatment intervention, indicating that the anterior anchorage unit mesial to maxillary first molar was able to successfully negate the intrusive force of the intrusion arch anteriorly. Based on the
results of this study, tipback mechanics can be used to attain molar distal tipping without side effects on the anterior anchorage unit. Secondly, with light and constant forces, palatal root torque can be obtained, instead of using high forces in statically indeterminate straight wire mechanics. Additionally, torque control can be initiated in the early stages treatment instead of in the finishing phase of treatment.

Extrapolating the findings of this research for the clinicians, tipback mechanics failed to correct the end on Class II molar relation in the majority of patients. In 37% of patients, unilateral Class II molar relationship was corrected and in 18% of subjects, bilateral Class II molar correction was seen after 8.21 months of treatment. Distalization appliances corrected the Class II molar to Class I in the similar time range with side effects on the anchor teeth. As the tipback mechanics was not effective in Class II correction, other treatment alternatives can be recommended to the patients. With the introduction of TADS (temporary anchorage devices), tooth movements in three dimensions are possible. Distalization with Tads supported appliances can be obtained predictably. Tipback mechanics may be used for correction of Class II molars with aberrant mesio-distal inclinations as initially introduced by Romeo et al. With the application of 40-g of intrusive force on the incisor brackets, palatal root torque was expressed. Palatal root torque on the maxillary incisors is an incidental finding and can be an important paradigm shift in treatment mechanics for third order correction of anterior teeth. Conventionally, a twist is placed in the anterior part of a stiff archwire to generate a moment of a couple for torque expression. The amount of force required for torque expression is not known with straight wire mechanics. On the contrary, the advantage of tipback mechanics with the Connecticut intrusion arch was that the force values were low
in magnitude and constant (40-g) with a low load deflection rate. However, further research is recommended to evaluate the biomechanics and treatment time for the torque expression.

**Study limitations**

The lateral cephalometric based research studies in orthodontics have several limitations due to inherent errors in magnification, projection, landmark identification and superimposition. To minimize the errors in landmark identification, we used tooth positional locating devices in order to accurately locate the right and left maxillary molars. The lateral cephalograms for the research were taken with the same cephalostat to minimize error due to the magnification factor.

Another major factor affecting the accuracy of cephalometric measurements is the orientation of the head while taking the x-ray at 3 time points. Differences in head orientation can influence both vertical and antero-posterior measurements. However, in this study we could not standardize the head orientation and hence the study results should be interpreted taking this factor into account.

**Conclusions:**

1. The 1 couple biomechanical force system produced tipback of maxillary molars as expected. However, this force system on the anchorage units resulted in palatal root torque on the maxillary incisors.

2. The anchorage unit of second premolar to premolar successfully prevented the intrusion and flaring of maxillary incisors with tipback mechanics, hence we accept our null hypothesis # 1.
3. Tipback mechanics produced significant distalization of maxillary molars; hence we reject our null hypothesis # 2.

4. Tipback mechanics as an alternative distalization method is not an effective treatment method in the correction of end on Class II malocclusion. After the completion of tipback mechanics, use of Class II elastics aided in the correction of the end on Class II malocclusion in 62% of study subjects.
References:


Figure 1: Maxillary molar and incisor measurements—Vertically and AP (antero-posterior)
Table I: Study demographics

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**Table II: Intra-rater reliability: ICC (Intra-class correlation coefficient)**

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<th>Cronbachs Alpha</th>
<th>Variable</th>
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Figure 2a: Bland Altman plot: T1 - Left molar tipback

Figure 2b: Bland Altman plot: T2 - Left molar tipback

Figure 2c: Bland Altman plot: T3 - Left molar tipback
Figure 3a: Bland Altman plot: T1 - Right molar tipback

Figure 3b: Bland Altman plot: T2 - Right molar tipback

Figure 3c: Bland Altman plot: T3 - Right molar tipback
Figure 4a: Bland Altman plot: T1 – Incisor apex

Figure 4b: Bland Altman plot: T2 – Incisor apex

Figure 4c: Bland Altman plot: T3 – Incisor apex
Figure 5a: Bland Altman plot: T1 – Right molar angular change

Figure 5b: Bland Altman plot: T2 – Right molar angular change

Figure 5c: Bland Altman plot: T3 – Right molar angular change
Table III: Friedman analysis

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<td>21.7</td>
<td>20.7 ± 1.63</td>
</tr>
<tr>
<td>Angular change in molar (deg)</td>
<td>77 ± 4.16</td>
<td>74.8</td>
<td>79.2</td>
<td>70.39 ± 6.58</td>
<td>66.8</td>
<td>73.8</td>
<td>72.2 ± 4.25</td>
</tr>
<tr>
<td>Incisor Apex (AP) (mm)</td>
<td>74.5 ± 4.8</td>
<td>71.89</td>
<td>77.1</td>
<td>73.31 ± 4.54</td>
<td>70.8</td>
<td>75.7</td>
<td>73 ± 5.01</td>
</tr>
<tr>
<td>Incisor centroid (AP) (mm)</td>
<td>79.9 ± 5.5</td>
<td>76.95</td>
<td>82.8</td>
<td>79.5 ± 5.34</td>
<td>76.6</td>
<td>82.3</td>
<td>79.1 ± 5.59</td>
</tr>
<tr>
<td>Incisor-incisal point (AP) (mm)</td>
<td>85.7 ± 6</td>
<td>82.4</td>
<td>88.9</td>
<td>86.12 ± 5.84</td>
<td>83</td>
<td>89.2</td>
<td>85.8 ± 5.81</td>
</tr>
<tr>
<td>Incisor apex (V) (mm)</td>
<td>5.96 ± 4.2</td>
<td>3.72</td>
<td>8.21</td>
<td>5.5 ± 4.29</td>
<td>3.2</td>
<td>7.7</td>
<td>5.81 ± 3.79</td>
</tr>
<tr>
<td>Incisor centroid (V) (mm)</td>
<td>18.4 ± 2.2</td>
<td>17.2</td>
<td>19.6</td>
<td>17.68 ± 2</td>
<td>16.61</td>
<td>18.7</td>
<td>18.3 ± 2.15</td>
</tr>
<tr>
<td>Incisor-incisal edge (V) (mm)</td>
<td>32.2 ± 2.6</td>
<td>30.8</td>
<td>33.6</td>
<td>31.28 ± 2.06</td>
<td>30.1</td>
<td>32.3</td>
<td>31.8 ± 2.3</td>
</tr>
<tr>
<td>Incisor angular change (deg)</td>
<td>112.9 ± 6.4</td>
<td>109.4</td>
<td>116.3</td>
<td>116.2 ± 5.3</td>
<td>113.3</td>
<td>119</td>
<td>116.4 ±3.9</td>
</tr>
</tbody>
</table>

*p < 0.05 significant, n=16
### Table IV: Wilcoxon signed ranked test

<table>
<thead>
<tr>
<th>Variable</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T2-T1</th>
<th>P val</th>
<th>T3-T2</th>
<th>P val</th>
<th>T3-T1</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tipback molar (AP) (mm)</td>
<td>51.44 ± 4.27</td>
<td>49.92 ± 4.35</td>
<td>50.01 ± 4.35</td>
<td>-1.53</td>
<td>0.00*</td>
<td>-0.09</td>
<td>0.975</td>
<td>-1.43</td>
<td>0.000*</td>
</tr>
<tr>
<td>Extrusion of molar (mm)</td>
<td>19.96 ± 1.79</td>
<td>20.82 ± 1.75</td>
<td>20.70 ± 1.63</td>
<td>0.86</td>
<td>0.001*</td>
<td>-0.12</td>
<td>0.479</td>
<td>0.74</td>
<td>0.001*</td>
</tr>
<tr>
<td>Angular change in molar (deg)</td>
<td>77.04 ± 4.16</td>
<td>70.39 ± 6.58</td>
<td>72.23 ± 4.25</td>
<td>-6.65</td>
<td>0.001*</td>
<td>1.84</td>
<td>0.352</td>
<td>-4.97</td>
<td>0.001*</td>
</tr>
<tr>
<td>Incisor Apex (AP) (mm)</td>
<td>74.5 ± 4.88</td>
<td>73.31 ± 4.54</td>
<td>73 ± 5.01</td>
<td>-1.19</td>
<td>0.005*</td>
<td>-0.31</td>
<td>0.341</td>
<td>-1.5</td>
<td>0.003*</td>
</tr>
<tr>
<td>Incisor centroid (AP) (mm)</td>
<td>79.9 ± 5.54</td>
<td>79.5 ± 5.34</td>
<td>79.13 ± 5.59</td>
<td>-0.4</td>
<td>0.173</td>
<td>-0.37</td>
<td>0.227</td>
<td>-0.77</td>
<td>0.036*</td>
</tr>
<tr>
<td>Incisor-incisal point (AP) (mm)</td>
<td>85.71 ± 6.07</td>
<td>86.12 ± 5.84</td>
<td>85.84 ± 5.81</td>
<td>0.42</td>
<td>0.104</td>
<td>-0.28</td>
<td>0.666</td>
<td>0.12</td>
<td>0.381</td>
</tr>
<tr>
<td>Incisor apex (V) (mm)</td>
<td>5.96 ± 4.21</td>
<td>5.5 ± 4.29</td>
<td>5.81 ± 3.79</td>
<td>-0.46</td>
<td>0.027*</td>
<td>0.31</td>
<td>0.231</td>
<td>-0.15</td>
<td>0.352</td>
</tr>
<tr>
<td>Incisor centroid (V) (mm)</td>
<td>18.46 ± 2.29</td>
<td>17.68 ± 2.00</td>
<td>18.31 ± 2.15</td>
<td>-0.78</td>
<td>0.008*</td>
<td>0.63</td>
<td>0.014</td>
<td>-0.15</td>
<td>0.711</td>
</tr>
<tr>
<td>Incisor-incisal edge (V) (mm)</td>
<td>32.25 ± 2.62</td>
<td>31.28 ± 2.06</td>
<td>31.84 ± 2.3</td>
<td>-0.97</td>
<td>0.003*</td>
<td>0.56</td>
<td>0.035</td>
<td>-0.41</td>
<td>0.071</td>
</tr>
<tr>
<td>Incisor angular change (deg)</td>
<td>112.9 ± 6.49</td>
<td>116.21 ± 5.36</td>
<td>116.43 ± 3.98</td>
<td>3.31</td>
<td>0.008*</td>
<td>0.22</td>
<td>0.753</td>
<td>3.53</td>
<td>0.014*</td>
</tr>
</tbody>
</table>

*p < 0.05 significant, n=16
Table V: Mean differences with 95% CI at T1, T2, T3 for maxillary dental changes.

<table>
<thead>
<tr>
<th>Variable</th>
<th>T2-T1 Mean diff. + SD</th>
<th>95% CI</th>
<th>T3-T2 Mean diff.+ SD</th>
<th>95% CI</th>
<th>T3-T1 Mean diff. + SD</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tipback molar (AP) (mm)</td>
<td>-1.53 ± 0.65</td>
<td>-1.87</td>
<td>-1.18</td>
<td>-0.09 ± 0.7</td>
<td>-0.27</td>
<td>0.46</td>
</tr>
<tr>
<td>Extrusion of molar (mm)</td>
<td>0.86 ± 0.49</td>
<td>0.59</td>
<td>1.12</td>
<td>-0.12 ± 0.58</td>
<td>-0.43</td>
<td>0.18</td>
</tr>
<tr>
<td>Angular change in molar (deg)</td>
<td>-6.65 ± 5.60</td>
<td>-9.64</td>
<td>-3.66</td>
<td>1.84 ± 5.87</td>
<td>-1.28</td>
<td>4.97</td>
</tr>
<tr>
<td>Incisor Apex (AP) (mm)</td>
<td>-1.18 ± 1.31</td>
<td>-1.88</td>
<td>-0.48</td>
<td>-0.31 ± 1.2</td>
<td>-0.95</td>
<td>0.33</td>
</tr>
<tr>
<td>Incisor centroid (AP) (mm)</td>
<td>-0.40 ± 1.0</td>
<td>-0.94</td>
<td>0.12</td>
<td>0.34 ± 1.1</td>
<td>-0.93</td>
<td>0.24</td>
</tr>
<tr>
<td>Incisor-incisal point (AP) (mm)</td>
<td>0.40 ± 1.08</td>
<td>-0.17</td>
<td>0.98</td>
<td>-0.28 ± 1.31</td>
<td>-0.98</td>
<td>0.42</td>
</tr>
<tr>
<td>Incisor apex (V) (mm)</td>
<td>-0.46 ± 0.76</td>
<td>-0.87</td>
<td>-0.06</td>
<td>0.31 ± 0.89</td>
<td>-0.16</td>
<td>0.78</td>
</tr>
<tr>
<td>Incisor centroid (V) (mm)</td>
<td>-0.78 ± 0.87</td>
<td>-1.24</td>
<td>-0.31</td>
<td>0.63 ± 0.82</td>
<td>0.18</td>
<td>1.06</td>
</tr>
<tr>
<td>Incisor-incisal edge (V) (mm)</td>
<td>-0.97 ± 1</td>
<td>-1.5</td>
<td>-0.43</td>
<td>0.56 ± 0.85</td>
<td>0.1</td>
<td>1.01</td>
</tr>
<tr>
<td>Incisor angular change (deg)</td>
<td>3.31 ± 3.79</td>
<td>1.28</td>
<td>5.33</td>
<td>0.21 ± 3.91</td>
<td>-1.86</td>
<td>2.30</td>
</tr>
</tbody>
</table>