A Comparison of Outcomes Between Tandem Mechanics and Guided Eruption Therapy

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THESIS

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This thesis is dedicated to my loving and extraordinary wife, Lauren, who pushes me every day to be the best version of myself, my amazing parents, Robert and Clare, who have supported me unquestioningly my entire life, my favorite (only) brother, David, who is my closest and most loyal friend and the lifelong friends I am lucky enough to claim of who there are far too many to name. Without the love and support of these people, I would not be the person I am today.

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MJS

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LIST OF ABBREVIATIONS

ANB	Angle made by connect A Point-Nasion-B Point
AP	Anteroposterior
EP	E-Plane
FMA	Frankfort-Mandibular Plane Angle
GE	Guided Eruption
ICC	Intra class correlation coefficients
LL	Lower Lip
L6	Lower first molar
MP	Mandibular Plane
SN	Sella-Nasion Line
TJ	Tanaka-Johnston Analysis
TM	Tandem Mechanics
UL	Upper Lip
U6	Upper first molar

SUMMARY

This retrospective cohort study was carried out to compare the clinical outcomes of patients treated with either Tandem Mechanics (TM) or Guided Eruption (GE) as a phase I orthodontic therapy to treat dental crowding. Records were donated from two different orthodontic offices. Dr. Andrew Haas provided records for patients treated with Tandem Mechanics, a technique he invented. Dr. Robert Stoner donated the records for patients treated with Guided Eruption. Records were collected from two distinct time points: T1, at initial prior to any orthodontic intervention and at T2, the cessation of phase I therapy. Records included cephalometric radiographs and cast dental study models.

Records were collected from 42 subjects who underwent TM treatment and 30 who underwent GE therapy. All records were digitized, de-identified and uploaded into a cephalometric radiograph tracing or dental study model analyzing software program. Customized analyses were developed for the radiograph tracings to evaluate angular and millimetric changes in the horizontal and vertical planes. The custom analysis for the study models included variables in the anteroposterior, vertical and transverse planes. Study models were available at T1 for both samples and at T2 only for the GE sample.

The average mean value of all cephalometric and cast model variables at T1 were calculated for both treatment modalities and compared to one another using Independent Samples t-Test to determine the comparability of samples. Statistical analysis deemed the samples comparable. The samples were divided into subgroups for additional analyses. The first subgroup was based upon the anteroposterior skeletal growth pattern of the subject as dictated by the cephalometric ANB angle norms. We divided the sample into Class I and Class II skeletal relationships. Subjects with a Class III growth pattern were excluded. A second set of subgroups was created that divided the sample according to their vertical skeletal growth pattern. The samples were divided into normal vertical growers and high angle growers according to the cephalometric SN-MP angle norms. Low angle growers were excluded due to a lack of adequate sample size for the subgroup.

All records were traced by the primary investigator for whom intra-observer reliability was statistically confirmed. Inter-observer reliability testing was statistically confirmed by a second operator who received the same training in the orthodontic software. The second operator's measurements were compared to those of the primary investigator and reliability was confirmed.

Statistical analysis of treatment effects was completed using a Single Sample's t-Test for the overall sample and subgroups for each treatment modality. The mean differences between T1 and T2 for each variable were evaluated for statistically significant changes. The comparison of the two modalities was completed using an Independent Samples t-Test to compare the mean differences from T1-T2 for each modality to one another to determine any statistically significant mean differences in treatment effects between the two. Again, this was completed for the overall sample and for all subgroups.

Our analysis of the treatment effects of the two modalities revealed a number of significant cephalometric changes from T1-T2. TM had the following skeletal effects: restriction of maxillary anteroposterior growth, clockwise tip of the palatal plane and clockwise rotation of the mandibular plane. Dental effects included distalization and distal tipping of upper and lower molars, retroclination of lower incisors, bodily retraction of upper incisors and counterclockwise rotation/flattening of the occlusal plane. The upper and lower lips were retracted by TM. GE caused a counterclockwise/closing rotation of the mandibular plane with no other appreciable skeletal changes. The occlusal plane tipped counterclockwise, upper and lower incisors retroclined, both molars mesialized, the upper molar tipped mesially by a subclinical degree and the lower molar tipped distally as a direct result of the counterclockwise rotation of the mandibular plane. Facial convexity increased for GE but to a subclinical amount while there was a significant increase in the Z-Angle, indicating a retraction of the most protrusive lip. This was confirmed by the upper and lower lip to E-plane measurements which showed significant retractions of both lips.

The most striking differences between the two modalities are the skeletal changes. The skeletal morphology of the patients and the desire for orthopedic correction are the most significant factors that we suggest practitioners consider when deciding between the two treatments. Patients who have a vertical growth vector at risk of developing anterior open bite will be more efficiently treated with GE given its ability to cause counterclockwise mandibular plane rotation. Patients with a class II skeletal relationship or low angle skeletal vertical morphology will be more efficiently treated by TM as it restricts maxillary growth and causes the mandibular plane to rotate clockwise.

I. INTRODUCTION

A. Background

Anterior crowding is a common finding in the mixed dentition. This problem may be managed prior to the eruption of the full permanent dentition. Orthodontic treatment in the mixed dentition is referred to as a Phase I therapy The underlying cause of crowding is due to a tooth size-arch length and/or arch circumference discrepancy. As the name suggests, crowding is a result of a discrepancy between the amount of tooth structure present and the amount of space available within the dental arches to house the teeth. There exist two ways to approach this discrepancy: removal of tooth structure or increasing the amount of space available to house the teeth. Our study will compare two Phase I therapies that use these differing strategies to treat mixed dentition crowding. Phase I therapies are considered problem focused, early intervention methods that are used to treat specific orthodontic problems. The therapies are discontinued as soon as the problem they seek to treat are corrected.

Guided Eruption (GE) is a prescribed sequence of extractions of primary and permanent teeth that removes teeth in order to address a tooth size-arch length discrepancy.[1] In contrast, Tandem Mechanics (TM) is an orthodontic therapy that attempts to increase or maintain arch length through the use maxillary expansion, cervical headgear and class III elastics.[2]

Our study seeks to determine if one method is superior to the other, or if there are certain clinical situations in which one technique may treat more effectively. Mixed dentition crowding can have many different appearances clinically, and it is very possible that one of the techniques may more effectively treat certain variations of this diagnosis.

B. **<u>Purpose of the Study</u>**

The purpose of the study is to determine the cephalometric effects of Guided Eruption and Tandem Mechanics as Phase I treatments. We will compare how the effects of these two treatments differ from one another and if either therapy is superior to the other in treating certain types of mixed dentition malocclusions.

C. **<u>Significance of the Study</u>**

- There exist very few studies of tandem mechanics in the literature.
- The majority of previous studies of tandem mechanics have only considered long term stability. We will consider the immediate post phase I treatment effects.
- Tandem Mechanics is not currently a widely used treatment modality. The findings of this study may suggest that this therapy, or others with similar biomechanical effects should be considered in the orthodontist's armamentarium of Phase I treatments.
- Tandem Mechanics and Guided Eruption have never been directly compared in the literature.
- Our study contains a more comprehensive cephalometric analysis than most previous studies on either treatment modality.

D. **<u>Null Hypotheses</u>**

1. There will be no mean difference in treatment time between the two treatment modalities.

2. There will be no mean changes from T1 to T2 for all cephalometric variables in subjects treated with either Tandem Mechanics or Guided Eruption for the overall samples or subgroups.

3. When the mean changes of all cephalometric variables from T1 to T2 of each modality are compared to one another, they will exhibit no differences in the overall sample or subgroups.

4. There will be no mean changes from T1 to T2 for all model measurements in Guided Eruption subjects for the overall samples or subgroups.

II. REVIEW OF THE LITERATURE

A. An Overview of Tandem Mechanics

The tandem mechanic technique was pioneered by Dr. Andrew Haas of Cuyahoga Falls, OH. He used the technique extensively throughout his practice and modified it to treat a variety of different malocclusions. Although the technique can be modified as needed by the orthodontist, the theory and rationale behind all iterations remain the same: posterior teeth are held in space on maxillary and mandibular arches while the jaws are allowed to naturally grow forward bringing the incisors along with them and thereby creating an increase in arch length.[2] Growth potential is therefore a necessity for Tandem treatment. As an aside, this treatment can be modified and used in the non-growing patient, but because the current study does not focus on a non-growing patient population, this overview will focus exclusively on the use of the technique to treat growing aged patients who comprise our study population.

In 2003, Dr. Andrew Haas published an article that outlined the theory, rationale and step by step instructions on how to use his technique and how to modify it for different malocclusions.[2] It was meant to serve as a reference for the practicing clinical orthodontist on how to correctly use Tandem Mechanics. That article will serve as this study's reference on the Tandem Mechanic technique.

This technique was developed as a multifaceted Phase I therapy that could treat both dental and skeletal discrepancies in the mixed dentition patient. Due to its reliance on growth, Haas suggests that the ideal time to begin Tandem treatment would be around the time of eruption of the lower canines, or around ages 10-11.[2] Orthopedic expansion of the maxillary arch is tantamount to the success of the treatment and can be accomplished one of two ways, either with a Haas style rapid palatal expander appliance or with the headgear itself.[3] The headgear is necessary because it produces a distalizing force on the maxillary molars and in cases of class II skeletal discrepancies, on the maxillary skeletal architecture as well. Expansion is attained by expanding the inner bow of the headgear 8-10 mm beyond the current arch width at each adjustment appointment. If a rapid palatal expander is to be used, all expansion must be completed and the appliance removed prior to the use of the headgear. This delays the timing for initiation of tandem mechanics and results in a longer duration of Phase I therapy.[3] Overall treatment time to be expected, assuming adequate patient compliance, is a range of 9-13 months.[2]

The maxillary arch is fitted with a cervical headgear and the mandibular arch is fitted with a prefabricated .022 inch archwire engaged solely into the molar bands. In order to stabilize the mandibular wire that would otherwise only have two points of contact, the four mandibular incisors are individually fitted with a stainless steel ligature wire that is wound around the mandibular archwire. Dr. Haas refers to this tying technique as “sling tying”.[2] Also fitted to the mandibular arch is an open coil spring spanning from the mesial of the molar tubes to the position of the mandibular canines, where a sliding hook is then placed mesial to the coil spring. Depending on the malocclusion of the patient, the cervical headgear will be fitted to produce anywhere form 6-48 ounces of force per side.[2] The headgear is prescribed to be worn at least 12 hours a day. While the headgear is in place, the patient is directed to wear an intermaxillary elastic, ranging in strength from 6-10 ounces, from the elastic hook of the maxillary molar to the sliding hook on the mandibular archwire. The elastic is therefore in a class III direction and applies a distalizing force on the mandibular molar. The name Tandem Mechanics is derived from the fact that the molars on both arches are distalized simultaneously, or in tandem.

The sling ties are removed and the lower incisors are bonded when adequate mandibular arch length is obtained.[2] In Dr. Haas' practice, adequate mandibular arch length could be attained anywhere between 6-15 months after initiation of tandem therapy depending on the amount the patient grew, the compliance of the patient in appliance wear and the amount of initial crowding. At the recommended interval of 10 weeks in between appointments this provides for a possible range of 2-6 appointments of Tandem Mechanics without the use of any other orthodontic appliances. In addition to claiming a reduction in the number of patient visits and overall chair time, Dr. Haas claimed that only 25-30% of cases required the premolars to be bonded following the conclusion of the tandem stage of treatment.[2] In addition to these advantages, Haas also proposed several other advantages including; all components of the technique were prefabricated thereby reducing overhead costs, the treatment utilized the natural growth tendency of the patient, fewer issues with hygiene arose due to reduced time in full bonded appliances, younger demographic of patients tended to be more compliant and finally that the treatment was shown to be stable.[2,3]

B. <u>**Long Term Stability of Tandem Mechanics**</u>

In a previous study of Tandem Mechanics, the method was studied in Angle Class I dental patients who were treated either with the Haas expander prior to initiating tandem treatment, or with concurrent maxillary expansion through use of the facebow of the headgear as outlined in the previous section.[3] Subjects were retrospectively evaluated over a long-term period. Records were evaluated at pretreatment, at the end of active orthodontic treatment and at the end of the post-retention observation period. The records used to evaluate the different time points were dental models from which multiple measurements were taken and compared. The post-retention records took place at least four years following debonding of all orthodontic appliances. The study found that between the debonding stage and the retention stage the following measures showed statistically significant stability: overbite, overjet, Little's irregularity index[4], and intermolar width. However, they showed that the intercanine width in both arches, which was expanded during treatment on all subjects, relapsed to almost pre-treatment levels from the end of active treatment to the post-retention time point.[3] The instability of intercanine width expansion was reported in a previous study by Little and Reidel[5] who found that intercanine width decreased posttreatment for orthodontic patients treated with mandibular arch length increases. This collapse in intercanine width was found in the untreated control group as well. In addition, Little and Reidel showed a significant amount of relapse potential in many of the same treatment categories as were shown to be stable in the aforementioned study on tandem mechanics.[3,5] The authors of this article studying the long term stability of tandem treatment suggested that their study disproved the conclusions made by Little and Reidel regarding the instability of arch length increases in the mixed dentition.

A second, similarly designed, long term follow up study of tandem mechanics was completed with a study population limited to strictly Class II Division I subjects.[6] In addition to the model measurements, this study also considered cephalometric changes. The follow up period for this study was similar to the previous; they considered pretreatment records and evaluated records through the end of the retention phase with the final set of records taken at least two years following the cessation of any retainer use. All subjects had the same retention protocol of a maxillary Hawley retainer and a fixed lower lingual retainer spanning between the first premolars. The length of the time in the retention stage ranged from 5-7 years.[6]

The results of this study showed similar long term changes as were noted in the previous study of class I occlusions. There were no significant changes between posttreatment and the end of retention for intermolar distance or overjet as was seen in the previous study. There was a statistically significant amount of overbite relapse, albeit of an amount of 0.8 mm which they deemed not to be clinically significant. Little's irregularity index was again used to measure anterior crowding.[4] The irregularity index remained constant in this study between the retention and post-retention time points indicating stable final occlusions after the cessation of retention. This study demonstrated a statistically significant lack of incisor relapse in the post retention period verified both with Little's irregularity index and through a cephalometric analysis of the change in angle of the lower incisor to the mandibular plane angle.[3,6] However, there were a number of subjects that did have an increase in incisor relapse in the post-retention period so they elected to perform additional analyses to compare individuals who experienced relapse and those who did not. The investigators sought to determine any variables that may have been associated with either group. The only variable that demonstrated statistical significance was the average amount of time between the retention phase and post-retention phase. The group that developed incisor relapse had an average of 7 years between retention and post retention, while the group that did not experience relapse had an average of 4 years of follow up time. The investigation also found that there was a significant amount of collapse of the intercanine width following the removal of retention in the overall sample and in the divided sample outlined above.[6]

C. **An Overview of Guided Eruption**

The practice of Guided Eruption was popularized in the 1940's following the publications of two European orthodontists, Kjellgren and Hotz.[7,8] Each prescribed a sequence of extractions of primary and permanent teeth but used different names for the technique. For the purposes of this study, the terms are interchangeable, but for consistency we will use the term Guided Eruption.

Graber[9] reviews that, first and foremost, this technique was meant to be implemented in patients displaying normal class I growth patterns but are suffering from arch length and tooth size relationship discrepancies. However, he does state that there are instances where the technique can be beneficial for individuals with abnormal growth patterns, most notably those patients with a class II anteroposterior skeletal relationship. In these situations, the technique must be treated as an adjunct to the corrections of the skeletal discrepancies, and not as the principal corrector. His opinion is that extractions should not be completed solely to obtain a Class I molar relationship as the underlying skeletal discrepancy is not resolved. The number one priority of this technique is to allow permanent teeth to either erupt into normal positions or to allow crowded anterior teeth to drift into the spaces created by the prescribed extractions. The postulate of the founders of this technique was that teeth will align on their own through the utilization of the space created by extraction of primary and permanent teeth resulting in enhanced long term stability and reduced incidence of relapse after cessation of orthodontic treatment.[7,8]

Depending on the age of the patient and the stage of dental development, Guided Eruption typically involves the extraction of the primary canines, primary first molars and the permanent first premolars.[9] The age at which the guided eruption pattern should begin is between 8 and 9 for patients with average dental development patterns.[9] However, there are certain clinical situations in which a practitioner may elect to extract the second premolars in either one or both arches. The factors Graber lists that should influence the decision about which teeth to extract are: the age of the patient, the presence of caries, the amount of crowding present and the growth pattern of the patient in both vertical and horizontal directions.[9] Indications that GE should be considered according to Graber are: loss of leeway space due to premature loss of primary teeth resulting in mesial drift of posterior segments, ectopically erupting permanent incisors or canines, resorption of permanent roots secondary to ectopic eruption and flared permanent anterior teeth with or without loss of attached gingiva and ankylosis. This is not an exhaustive list but it includes the most common clinical conditions that may drive a practitioner to elect to carry out a guided eruption extraction sequence.[9]

Graber suggests a three phase process for sequencing the extractions.[9] The first stage of guided eruption is to remove the primary canine from the maxillary and mandibular arches. The purpose of this stage is to allow the permanent incisors to uncrowd and to prevent ectopic eruption of lateral incisors if they are unerupted. Graber suggests that this will help prevent mesial drift of unerupted permanent canines into positions that could cause ectopic eruption, thereby preventing adverse side effects that are concomitant with ectopically erupted canines, such as damage to permanent incisor roots.[9]

The second stage of the guided eruption protocol is removal of the deciduous first molars in order to expedite the eruption of first premolars. Graber states that while, in theory, this may expedite eruption, it may potentially have the opposite effect depending on the age and dental age of the patient. This is especially true in the mandible where it is common for the permanent canine to erupt before the first premolar. The extraction of first deciduous molars may delay the eruption of the first premolar if the canine erupts distally into the deciduous molar space. Historically, the primary first molars are extracted 12 months after primary canine extraction around the ages of 9-10.[7,8] Graber found that timing for extraction of the primary molar was not as crucial and suggested that for patient psychological benefit, and to reduce the number of surgical procedures, the primary molars and canines can be removed simultaneously.[9]

The third stage takes place when the permanent first (or second) premolar is extracted. This should be completed while the tooth is still actively erupting and before the eruption of the permanent canine. Theoretically, this will allow the canine tooth buds to drift distally and cause them to erupt into the space the premolar previously occupied. This is more easily accomplished in the maxillary arch where the eruption of the first premolar almost always precedes the canine. Factors to consider when electing to extract second premolars over first premolars in the third stage are canine position, space required to correct anterior crowding, tooth shape, overbite and overjet among a number of others. Unfortunately, Graber does not go into explicit detail on how the clinical presentation of each of these categories may influence the decision on which premolars to extract.[9] However, there have been studies on GE that suggest second premolars be extracted in patients who have anterior crowding without proclination.[10]

An alternative to staging the extraction sequence is to extract all primary and permanent teeth simultaneously while the patient is under anesthesia.[1]

D. **Treatment Effects of Guided Eruption**

GE was designed as a treatment option to easily allow crowding to resolve independently without any active orthodontic intervention. A study from Japan examined serial extraction subjects at three time points: before the extraction of any primary or permanent teeth, after the extraction of the permanent first premolars and at the end of the observation period when they elected to begin active orthodontic treatment.[11] The goal of this particular study was to provide quantitative measures of changes in the dentition following GE therapy as it previously had not been published in the literature. Yoshihara and colleagues[11] used a number of model and cephalometric measurements to evaluate the changes in the dentition during these three time points. The measure of crowding used was the Little's irregularity index[4]. The index showed that throughout the three time points, anterior crowding was reduced the most significantly following the two stages of extractions and slightly increased during the observation period.

Cephalometric analysis showed that the first molar tipped about 0.3° mesially per year following extractions but then tipped distally the same amount annually during the observation period. When the subjects were divided by Angle molar relationships, they found that only class I molars had this autocorrection in molar tip while Class II and Class III molars all remained mesially tipped. The molar crowns and apices moved mesially, during all time periods. The greatest amount of annual mesial drift occurred between the extraction of premolars and the end of the observation period (0.9mm for crown and 1.09mm for apex). Subjects with Class III molar relationships at the initial timepoint had the most mesial drift while those with Class II had the least annual mesial drift. The incisors tipped distally during the observation period; the greatest amount of annual distal tipping (1.6°) took place in the period between premolar extractions and the end of the observation period.[11] The principle findings of mesial molar migration and tipping along with distal incisor tipping has been demonstrated across many studies, however this was the first to show that different malocclusions may respond differently to GE.[1,11–13]

E. Comparisons of Guided Eruption and Late Premolar Extraction

As previously described, certain side effects are to be anticipated to result from the implementation of a Guided Eruption extraction sequence. It is therefore pertinent to know whether the side effects of Guided Eruption are different compared to individuals who had premolar extractions completed in the permanent dentition. A previous study sought to determine whether there were any differences between Guided Eruption and late premolar extraction subjects in cephalometric incisor inclinations or occlusal curves as measured on dental models.[13] Only mandibular dentition changes were considered in this study. A previous study that served as the basis for this follow up study showed that subjects who underwent Guided Eruption had significantly less active treatment time, and similar final outcomes to subjects that had premolar extractions in the permanent dentition.[14] Notable changes to the mandibular dentition as a result of GE included distal tipping of the incisors and canines, a side effect that has been extensively documented previously.[1,7–9,11,13,14] Molars tipped mesially more than untreated controls or subejcts with premolar extractions. These movements occurred during the observation period during which no active orthodontic pressure was applied and teeth were allowed to drift physiologically. Also subsequent to the period of physiologic drift was a steepening of multiple occlusal planes of the mandibular dentition; the Curves of Wilson and Monson steepened as a result of Guided Eruption indicating that there was a tendency for the mandibular posterior teeth to collapse lingually during this period of physiologic drift. The tendency for posterior lingual inclination was not observed in untreated controls or subjects treated with late premolar extractions.[13]

The study on which the previous study was based, found that satisfactory final results can be obtained with either Guided Eruption or late premolar extraction and that the only major differences noted between the two techniques were treatment length and the total number of doctor visits.[14] The Guided Eruption subjects had a significantly longer treatment time due to the initiation of the extraction sequence at a young age and the necessary observation period. GE subjects also had a statistically significant higher number of total doctor visits. Notably, the study found that the Guided Eruption subejcts had overall less active treatment time and fewer appointments while in active treatment compared to individuals that underwent late premolar extraction.[14]

F. **Long Term Stability of Guided Eruption**

The belief among the orthodontists who pioneered Guided Eruption was that long term stability would be an innate benefit because it allows the permanent dentition to uncrowd without any orthodontic intervention.[7–10] A study out of the University of Washington was the first to investigate this proposed benefit.[12] The study was collected dental models from subjects at four distinct time points: before treatment, after physiologic drift following extractions, the beginning of retention and at least ten years post retention during which subjects had not used any orthodontic retention. The variables they considered included the Little's irregularity index to measure anterior crowding, mandibular arch length, mandibular intercanine width, overbite and overjet. Every case finished treatment with an acceptable irregularity index but at post retention subejcts demonstrated comparable or even more severe anterior irregularity than at pretreatment. Notable changes following the end of active retention included arch length decreases and intercanine width collapse in all subjects except one. Most subjects demonstrated an increase in overbite and overjet following the cessation of retainer wear. The investigators compared the Guided Eruption subjects to a matched premolar extraction cohort and did not find any statistically significant differences to indicate that one modality was more stable in the post-retention stage than the other. The authors make the statement that based upon their findings, orthodontists can no longer claim increased stability as their rationale for prescribing a Guided Eruption extraction sequence. A long term follow up study conducted by the same author with a similar study design found Guided Eruption to be no less stable than non-extraction treatment.[15]

The same post-retention relapses noted in the studies by Little for non-extraction treatment, GE and late premolar extraction[5,12,15,16] showed the same relapse patterns found in the long term follow up study of TM.[6] Therefore, from our literature review we can determine that there is no advantage in regards to stability of treatment when comparing these two modalities. Our study will seek to determine if any advantages exist between the two modalities.

III. MATERIALS AND METHODS

A. **Approval**

The University of Illinois at Chicago Institutional Review Board approved the application for Expedited Review (Protocol #2019-0001) on January 17, 2019. Approval can be found in Appendix A.

B. **The Sample**

The subject records used in our study were collected from two private orthodontic offices. The subjects that comprise the Tandem Mechanics sample originated from the office of Dr. Andrew Haas of Cuyahoga Falls, OH. The Guided Eruption subject group was compiled from the office of Dr. Robert Stoner of Indianapolis, IN. Subject records included cephalometric radiographs taken at pretreatment (T1) and end the of the Phase I therapy prior to the initiation of comprehensive orthodontic treatment (T2). In addition, all available cast study models from those time points were collected. For the Tandem Mechanic subjects, the T2 time point records were taken the day that Tandem Mechanic was discontinued. T2 records for Guided Eruption subjects was the start records for comprehensive treatment taken following the observation period after primary canine, molar and permanent premolar extraction. The subjects were selected serially to reduce bias in sample collection. Dr. Haas provide records from 42 subjects and Dr. Stoner provided records from 30. T2 models were not available for the TM sample due to standard office procedures not including models at that time point. All records from both offices were taken as part of normal orthodontic practice and were not taken for research purposes. Both practitioners approved the usage of their private records in our study. Copies of their approvals can be found in

Appendices B and C. After digitizing and de-identifying all records, they were returned to their respective offices.

Cephalometric radiographs were uploaded into the Dolphin Imaging™ Software (Dolphin Imaging Systems, Chatsworth, California, Version 11.9 Premium) to be traced and analyzed. Radiographs were either submitted to us in a digital file format or on radiographic film. All film radiographs were digitized using the same Epson Perfection V7750 PRO™ (Epson, Suwa, Nagano Prefecture, Japan) scanner. All cephalometric radiographs were calibrated with rulers and landmarks captured on the radiographs. A custom cephalometric analysis was created for the purposes of our study. The points comprising our analysis included:[17]

- SNA: The angular measurement comprised of the Sella, Nasion and A point. Used to evaluate maxillary anteroposterior (AP) position relative to the cranial base.
- SNB: The angular measurement comprised of the Sella, Nasion and B point. Used to evaluate mandibular AP position relative to the cranial base.
- ANB: The angular measurement comprised of Nasion, A point and B point. Used to evaluate the AP relationship of maxilla relative to the mandible.
- FMA: The angular measurement comprised of the angle formed between the Mandibular plane (Constructed Gonion-Gnathion) and the Frankfort Horizontal Plane (Porion-Orbitale) (FH). Used to evaluate the vertical relationship of the mandible relative to the cranial base and the growth pattern of the subject.
- Palatal plane-SN: The angular measurement comprised of the angle formed between the Palatal Plane (ANS-PNS) and the SN line (Sella-Nasion). Used to evaluate the vertical relationship of the maxilla to relative the cranial base.

- SN-MP: The angular measurement comprised of the angle formed between the SN Line and the Mandibular Plane. Used to evaluate the vertical relationship of the mandible relative to the cranial base and the growth pattern of the subject.
- Occlusal plane-SN: The angular measurement comprised of the angle formed between the SN line and the Downs Occlusal plane (Mid-contact point of 1st molar occlusion and the bisection of the incisal overbite). Used to evaluate the vertical angulation of the occlusal plane relative to the cranial base.
- U1-SN: The angular measurement formed by the angle of the long axis of the upper central incisor (U1) to the SN line. The most procumbent incisor was selected for tracing. Used to evaluate the AP angulation of the upper central incisor relative to the cranial base
- L1-MP: The angular measurement formed by the angle the long axis of the lower central incisor (L1) to the Mandibular Plane. The most procumbent incisor was selected for tracing. Used to evaluate the AP angulation of the lower central incisor relative to the mandibular plane.
- Holdaway Ratio: The ratio determined by the relationship of the distance of the L1 incisal edge to the line connecting Nasion and B point compared to the distance of the Pogonion from the same NB line. Used to evaluate the AP position of the chin.
- U6-PT (mm): A millimetric measurement that provides the distance of the distal surface of the upper first molar (U6) from a line perpendicular to the Frankfort Horizontal Line at the PT point. Used to evaluate the AP position of the maxillary first molar.
- L6-PT (mm): A millimetric measurement that provides the distance of the distal surface of the lower first molar (L6) from a line perpendicular to the Frankfort Horizontal Plane placed at the PT point. Used to evaluate the AP position of the mandibular first molar.

- U6-SN: An angular measurement formed by the angle made by the long axis of the upper first molar to the SN line. Used to evaluate upper first molar angulation.
- L6-SN: An angular measurement formed by the angle made the long axis of the upper first molar to the SN line. Used to evaluate lower first molar angulation.
- LFH/TFH: A ratio comprised of the division of the distance between ANS-Menton by the distance from Nasion-Menton. Used to evaluate the vertical dimension of the lower anterior facial height relative to the entire the face.
- Facial Convexity: An angular measurement consisting of the angle formed by connecting the Frankfort Horizontal Plane to the soft tissue Nasion-Pogonion line. Used to evaluate the convexity of the soft tissue profile.
- Legan Convexity: An angular measurement consisting of the angle formed by connecting the soft tissue points Glabella-Subnasale-Pogonion. Used to evaluate the convexity of the soft tissue profile.
- Z-Angle: An angular measurement consisting of the angle formed by the intersection of the FH plane and a line formed by connecting soft tissue pogonion and the tip of the most protrusive lip. Used to evaluate the convexity of the soft tissue profile.
- Upper Lip-E Plane: A millimetric measure consisting of the distance of the most protrusive point of the upper lip to the line formed by connecting the tip of the nose to the soft tissue pogonion. Used to evaluate the AP position of the upper lip.
- Lower lip-E Plane: A millimetric measure consisting of the distance of the most protrusive point of the lower lip to the line formed by connecting the tip of the nose to the soft tissue pogonion. Used to evaluate the AP position of the lower lip.

All available plaster models were digitized by scanning using the same iTero Element™ 2 (Align Technology, San Jose, CA) digital scanner and converting into a .3dm file compatible with the model analyzing software, OrthoCAD™ (Version 5.9.0.36, Align Technology, San Jose, CA.) We collected the following measurements from all available digitized plaster models:

- Angle Molar Classification: Class I designations were given to molars less than or equal to 50% class II or class III. Anything greater than 25% was considered a full class II or class III.
- Maxillary Arch Length (mm): The millimetric length determining space available in the maxillary arch defined by the length of the arch form perimeter from the mesial of the left first maxillary molar to mesial of the right maxillary first molar.
- Mandibular Arch Length (mm): The millimetric length determining space available in the mandibular arch defined by the length of the arch form perimeter from the mesial of the left first mandibular molar to mesial of the right mandibular first molar.
- Tanaka-Johnston Analysis Maxilla: A mixed dentition analysis that uses the length of the mandibular permanent incisors to predict the size of the unerupted permanent teeth. Used to predict how much space will be required in the permanent dentition.[18]
- Tanaka-Johnston Analysis Mandible: A mixed dentition analysis that uses the length of the mandibular permanent incisors to predict the size of the unerupted permanent teeth. Used to predict how much space will be required in the permanent dentition.[18]
- Upper Crowding: The difference between how much space was determined to be required by Tanaka-Johnston versus the amount of space available as determined by the maxillary arch length measurement.

- Lower Crowding: The difference between how much space was determined to be required by Tanaka-Johnston versus the amount of space available as determined by the mandibular arch length measurement.
- Overbite: The vertical millimetric distance between the tip of the upper incisor to the tip of the lower incisor.
- Overjet: The antero-posterior millimetric space between the tip of the most procumbent upper incisor and the tip of the most procumbent lower incisor.
- Inter-molar width maxilla: The millimetric distance between the functional mesiolingual cusp tips of the maxillary first molars.
- Inter-molar width mandible: The millimetric distance between the functional central fossaes of the mandibular first molars where the maxillary first molar functional cusps should occlude in ideal occlusion.
- Inter-canine width maxilla: The millimetric distance between the mesio-palatal marginal ridges of the maxillary canines where the lower canine cusp would occlude in an ideal occlusion. If permanent canines were not erupted, primary canines were measured instead. If primary canines were exfoliated and permanent had not erupted, the center of the alveolus where the permanent canine would erupt was used.
- Inter-canine width mandible: The millimetric distance between the cusp tips of the mandibular canines. If permanent canines were not erupted, primary canines were measured instead. If primary canines exfoliated and permanent canines had not erupted, the center of the alveolus where the permanent canine would erupt was used.

- Arch Depth Maxilla: The perpendicular distance measured between a line connecting the mesial contact points of the maxillary first molars and a parallel line drawn at the interproximal contact point of the maxillary central incisors.[19]
- Arch Depth Mandible: The perpendicular distance measured between a line connecting the mesial contact points of the mandibular first molars and a parallel line drawn at the interproximal contact point of the mandibular central incisors.[19]

C. <u>**De-Identifying**</u>

Both offices provided records that had not been de-identified. Therefore, part of the responsibilities of the Principal Investigator involved de-identification of the records. After uploading digitized radiographs into the cephalometric tracing software, any patient identifiers were cropped out of the image or blocked out using a privacy feature of the software. Any patient identifiers on the plaster models were not reproduced in the 3D model renderings provided by the model analysis software.

D. <u>**Selection Criteria**</u>

Subjects were selected from the records of 42 patients donated by Dr. Haas that received Tandem Mechanics Therapy and from 30 patients treated by Dr. Stoner with Guided Eruption Therapy according to the following inclusion and exclusion criteria:

Inclusion Criteria:

- Subject must be in the mixed dentition

- Subject must have a class I or class II skeletal relationship according to ANB angle cephalometric norms[20]
    - Class I: $0 \leq ANB \leq 4$
    - Class II $ANB < 4$
- Subjects with a normal or high angle vertical skeletal pattern as designated by SN-MP angle at T1 according to cephalometric norms[20]
    - Normal angle: $27 \leq SN\text{-}MP \leq 37$
    - High angle $SN\text{-}MP < 37$
- Subjects must have been treated with TM or GE
- Subject cephalometric radiographs must be of diagnostic quality
- Subject's initial radiograph must have been taken prior to initiating any treatment
- Subject's final radiograph must have been taken before any comprehensive orthodontic therapy was initiated

Exclusion Criteria:

- Subjects not in the mixed dentition
- Subject with a class III skeletal relationship according to ANB angle cephalometric norms[20]
    - $ANB < 0$
- Subjects with a low angle vertical skeletal pattern as designated by SN-MP angle at T1 according to cephalometric norms[20]
    - $SN\text{-}MP < 27$
- Subjects not treated with either treatment modality

- Subjects with cephalometric radiographs of non-diagnostic quality
- Subjects without pretreatment radiographs
- Subjects without final radiographs taken prior to bonding any orthodontic appliances as component of a Phase II therapy.

E. **Statistical Analysis**

All data was analyzed using SPSS Statistics software (Version 25.0, IBM, Armonk, NY). Statistical significance was set at 0.05 for all tests. The sample consisted of 72 total subjects whose records were analyzed with discrete and continuous variables. Categorical variables were evaluated in tables of frequency and cross tabulations. A Shapiro-Wilks test was computed to estimate the distribution of the raw data and the majority of the variables showed normal distribution. It was determined that the study sample has 80% power to detect statistically significant mean differences assuming a minimum of 25 subjects in each group with an effect size of 0.80 and type error I of 5%.

Single Sample t-Tests, Independent Samples t-Tests and Chi-square tests were used. Comparisons were based on pretreatment (T1) and post-treatment (T2) values. Absolute variations in the treatment time for the two study groups was considered and the samples were further evaluated in subgroups determined by their anteroposterior (AP) and vertical skeletal classifications at T1. Skeletal AP and vertical subgroup classifications were determined by each subjects' ANB and SN-MP measurements respectively and designated according to established cephalometric norms.[20] Subjects with Class I and Class II skeletal AP relationships were included in the study. Class III subjects were excluded. Normal and high angle vertical skeletal patterns were included in the subgroups. Low angle vertical skeletal subjects were excluded due to insufficient numbers of subjects with this growth pattern present within the sample to allow statistically significant comparisons.

1. **<u>Reliability Testing</u>**

Both intra and inter-observer reliability testing was performed. Intra-observer testing was completed by randomly selecting 6 cephalometric radiographs and 6 plaster casts that came from either subject group. The models and radiographs were measured twice by the principal investigator with a waiting period of at least 2 weeks between sessions. To evaluate inter-observer reliability, these same 6 radiographs and models were traced by a second operator who received the same training in cephalometric and model measuring as the principal investigator. The measurements produced by the second operator were compared to the original measurements produced by the principal investigator. Intra class correlation coefficients (ICC) values were generated and used to evaluate the intra and inter-observer reliability.

2. **<u>Descriptive Statistics</u>**

Gender and race information was collected for each sample in the study. SPSS™ descriptive statistic features were used to provide the gender a racial distribution for the whole samples and subgroups. Chi square testing was used to determine if there were any significantly different gender disributions between the two samples.

3. **Matched Samples**

The TM and GE overall, AP and vertical subgroups were compared using an Independent Samples t-test at T1 for all cephalometric and cast model measurements to evaluate the equality of all means.

4. **Determining Treatment Effects of Each Modality**

The effects of the individual treatments were analyzed for the overall samples and for the previously described AP and vertical skeletal subgroups. One sample t-Tests were used to compare the statistical significance of the mean difference of all cephalometric measures from T1-T2. In order to compare the treatment effects of the subgroups of each individual modality to one another, Independent Samples t-Tests were used. These Independent Samples t-Tests were carried out to determine if either modality had statistically significantly different treatment effects between subgroups.

5. **Comparing the Modalities**

The results of treatment were determined by comparing the two treatment modalities to one another. The average treatment effects of the overall samples and the individual subgroups as determined by statistical analysis from the previous section, were compared to each other using Independent Samples t-Tests. Statistically significant differences in mean changes from T1-T2 between the two treatment types were determined for the overall sample and each subgroup.

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IV. RESULTS

A. **Reliability Testing**

The intra class correlation coefficient (ICC) values for both intra and inter reliability testing were higher than 0.80 for all cephalometric and model measurements, indicating good reliability for the measurements used in this study.

B. **Matched Samples**

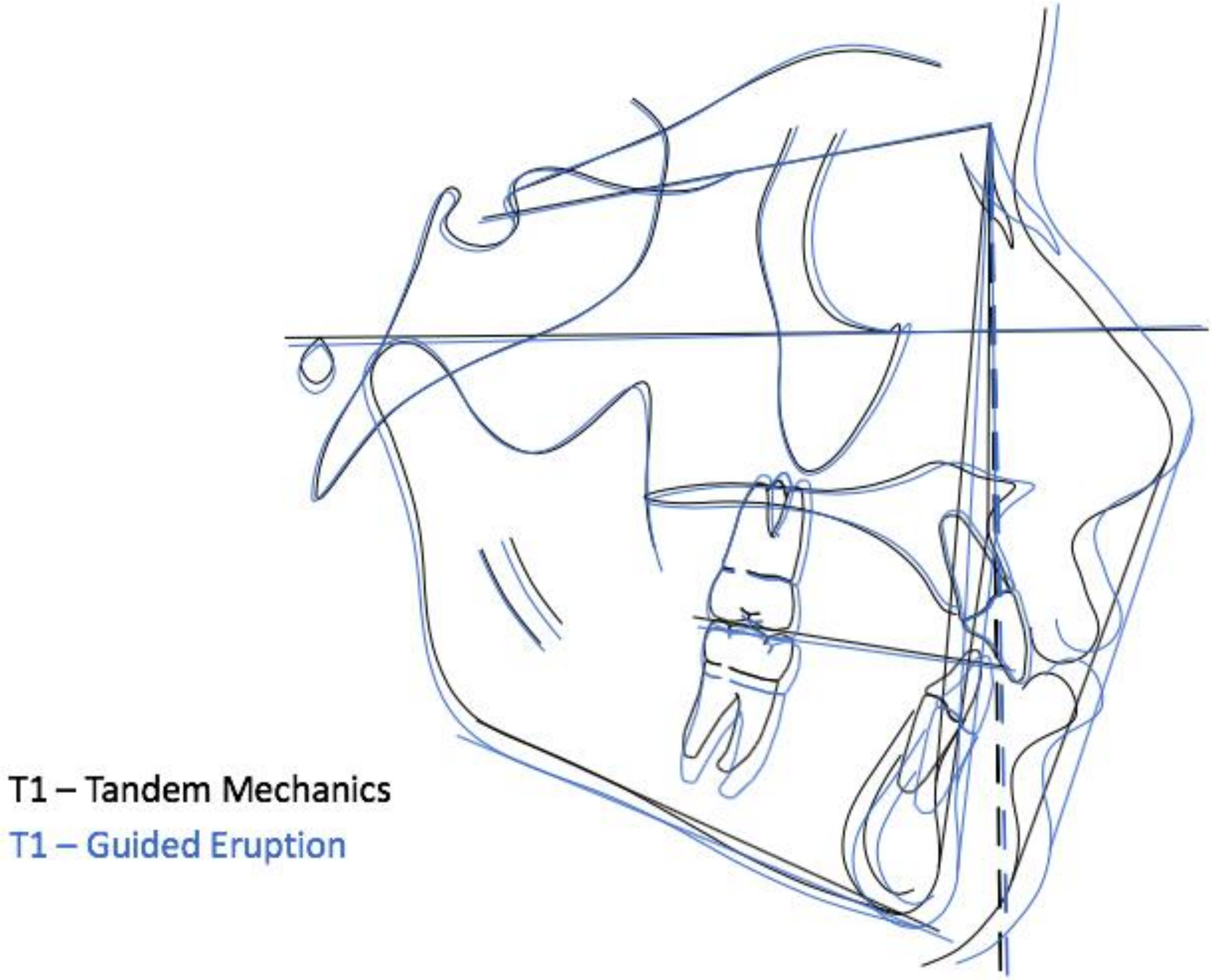
Independent Samples t-Test evaluation of the overall TM and GE cephalometric samples revealed 3 statistically significant different variables between the two samples at the initial time point (Table I). They include age at T1, U6-PT distance, and L6-SN angle. The TM subjects were on average 1.5 years older at initial, had an upper first molar 1.8 mm more mesial than GE subjects, and had lower molars 4.9 degrees more distally inclined to SN than GE subjects. Apart from these three, all other cephalometric variable means were not deemed to be statistically different and determined our samples to be adequately comparable. Figure 1 provides a superimposition of the averaged tracings of the overall samples for both modalities at T1 for a visual representation of sample matching.

TABLE I

MATCHED SAMPLES AT T1: OVERALL SAMPLE AND AP SUBGROUPS

		Overall				Class I				Class II			
	Group	N	Mean	SD	Sig	N	Mean	SD	Sig.	N	Mean	SD	Sig
AGE – T1 (years)	TM	42	10.8	1.7	.000	19	10.5	1.5	.230	23	11.1	1.9	.000
	GE	30	9.3	1.3	.000	16	9.9	1.4	.226	12	8.6	0.8	.000
AGE – T2 (years)	TM	30	12.5	1.7	.131	13	12.3	1.6	.763	17	12.6	1.8	.025
	GE	30	11.9	1.2	.132	16	12.4	1.1	.772	12	11.2	1.1	.016
Treatment Time (years)	TM	30	1.7	1.1	.002	13	1.4	0.9	.011	17	1.9	1.2	.096
	GE	30	2.6	1.1	.002	16	2.5	1.2	.009	12	2.6	1.1	.091
SNA	TM	42	79.0	3.4	.376	19	78.4	3.0	.967	23	79.6	3.6	.107
	GE	28	79.8	4.3	.400	16	78.4	4.2	.968	12	81.7	3.8	.116
SNB	TM	42	74.7	3.4	.097	19	75.7	2.5	.667	23	73.9	3.8	.101
	GE	28	76.1	3.7	.104	16	76.2	3.9	.679	12	76.1	3.4	.093
ANB	TM	42	4.3	1.9	.213	19	2.7	1.1	.312	23	5.6	1.2	.951
	GE	28	3.7	2.1	.224	16	2.3	1.3	.321	12	5.6	1.2	.950
FMA	TM	42	27.1	4.8	.323	19	26.0	3.4	.337	23	28.1	5.7	.919
	GE	28	25.9	5.2	.330	16	24.5	5.9	.361	12	27.9	3.3	.906
Palatal plane-SN	TM	42	8.6	2.7	.944	19	8.8	2.9	.881	23	8.5	2.7	.668
	GE	28	8.6	3.0	.945	16	8.9	3.3	.883	12	8.1	2.6	.663
SN-MP	TM	42	35.9	5.5	.184	19	34.1	3.5	.802	23	37.4	6.4	.194
	GE	28	34.1	5.8	.191	16	33.7	6.6	.812	12	34.6	4.9	.159
Occlusal plane-SN	TM	42	20.1	4.4	.328	19	19.2	3.3	.791	23	20.8	5.2	.363
	GE	28	19.1	4.3	.324	16	18.9	5.1	.799	12	19.4	3.0	.288
U1-SN	TM	42	101.1	7.1	.985	19	102.0	5.1	.311	23	100.3	8.5	.371
	GE	28	101.1	9.1	.986	16	99.6	8.7	.334	12	103.2	9.7	.395
L1-MP	TM	42	91.3	5.6	.201	19	91.2	5.4	.020	23	91.3	6.0	.338
	GE	28	89.1	8.2	.236	16	85.8	7.5	.025	12	93.5	7.1	.369
Holdaway Ratio	TM	42	-0.4	5.4	.412	19	-1.3	8.1	.334	23	0.3	0.4	.124
	GE	28	0.5	2.1	.340	16	0.8	2.7	.304	12	0.1	0.4	.129
U6-PT (mm)	TM	42	12.9	3.9	.045	19	12.5	3.4	.357	23	13.2	4.3	.073
	GE	28	11.1	2.7	.032	16	11.5	2.9	.349	12	10.7	2.6	.039
L6-PT (mm)	TM	42	12.4	3.8	.059	19	12.5	3.5	.449	23	12.4	4.2	.048
	GE	28	10.7	3.3	.052	16	11.6	3.3	.446	12	9.6	3.0	.030
U6-SN	TM	42	68.6	6.1	.819	19	70.2	5.9	.438	23	67.3	6.1	.769
	GE	28	68.3	5.1	.813	16	68.6	6.0	.439	12	67.9	3.7	.733
L6-SN	TM	42	-57.1	4.6	.000	19	-56.8	4.5	.018	23	-57.4	4.7	.000
	GE	28	-52.2	4.4	.000	16	-53.0	4.5	.018	12	-51.0	4.3	.000
LFH/TFH	TM	42	54.4	1.9	.574	19	54.3	1.8	.411	23	54.5	2.0	.945
	GE	28	54.7	1.9	.575	16	54.8	2.0	.416	12	54.5	1.8	.944
Facial Convexity	TM	42	85.7	3.0	.468	19	86.3	2.8	.180	23	85.2	3.2	.417
	GE	28	86.3	3.5	.482	16	87.8	3.4	.189	12	84.3	2.6	.389
Legan Convexity	TM	42	164.5	5.5	.480	19	168.1	3.6	.975	23	161.6	5.0	.810
	GE	28	165.5	5.3	.478	16	168.1	4.1	.975	12	162.0	4.9	.810
Z-Angle	TM	42	67.4	9.5	.567	19	71.1	10.0	.281	23	64.4	8.1	.287
	GE	28	68.8	9.6	.568	16	74.3	6.9	.267	12	61.4	7.5	.277
UL-EP (mm)	TM	42	-0.1	2.2	.486	19	-0.7	2.4	.160	23	0.3	1.9	.274
	GE	28	-0.5	2.7	.503	16	-1.8	2.1	.154	12	1.2	2.4	.317
LL-EP (mm)	TM	42	0.9	2.7	.622	19	0.2	2.9	.382	23	1.4	2.4	.428
	GE	28	0.5	2.4	.615	16	-0.6	2.1	.369	12	2.1	2.0	.401

Figure 1. Superimposition of TM and GE at T1 for matched samples



The class I AP skeletal subgroup had statistically different means between TM and GE for the following variables: L1-MP and L6-SN (Table I). Lower incisors were on average 5.33 degrees more proclined in TM subjects and lower molars were 3.82 degrees more distally angulated to SN for TM subjects. The GE and TM class II skeletal subgroup means differed significantly for the L6-PT and L6-SN variables. The TM subjects on average had L6’s 2.80 mm more mesial and had L6’s 6.35 degrees more distally angulated to SN. The samples were determined similar enough to be comparable for the class I and II skeletal subgroups.

The normal skeletal vertical skeletal subgroup only had one variable at T1 with a statistically different mean, L6-SN. L6-SN was on average 5.69 degrees more distally angulated to SN for TM subjects. The high vertical skeletal subgroup had no statistically different variable means at T1. The vertical skeletal subgroups were therefore also comparable between modalities (Table II).

TABLE II
MATCHED SAMPLES AT T1: SKELETAL VERTICAL SUBGROUPS

		Normal Skeletal Vertical				High Skeletal Vertical			
	Group	N	Mean	SD	Sig.	N	Mean	SD	Sig.
AGE – T1 (years)	TM	24	11.0	1.8	.002	16	10.7	1.7	.069
	GE	19	9.4	1.2	.001	7	9.1	1.8	.084
AGE – T2 (years)	TM	15	12.9	2.0	.106	13	12.1	1.5	.525
	GE	19	12.0	1.3	.127	7	11.7	1.3	.515
Treatment Time	TM	15	1.7	1.1	.043	13	1.6	1.1	.135
	GE	19	2.6	1.1	.043	7	2.5	1.4	.173
SNA	TM	24	79.4	3.1	.399	16	77.6	2.7	.735
	GE	19	80.3	3.9	.412	7	78.1	4.8	.791
SNB	TM	24	75.9	2.5	.319	16	72.1	2.6	.242
	GE	19	76.8	3.0	.330	7	74.0	5.0	.371
ANB	TM	24	3.5	1.7	.883	16	5.5	1.7	.086
	GE	19	3.6	2.2	.887	7	4.1	1.6	.093
FMA	TM	24	25.5	3.5	.526	16	30.9	3.4	.841
	GE	19	24.8	4.0	.533	7	31.2	2.7	.827
Palatal plane-SN	TM	24	8.4	2.5	.900	16	9.3	3.0	.445
	GE	19	8.3	3.0	.902	7	10.3	2.2	.390
SN-MP	TM	24	33.6	2.9	.452	16	41.1	3.0	.973
	GE	19	32.9	2.9	.452	7	41.0	2.8	.972
Occlusal plane-SN	TM	24	18.5	3.0	.365	16	23.5	3.7	.187
	GE	19	19.3	2.9	.362	7	21.5	1.9	.098
U1-SN	TM	24	101.4	5.9	.889	16	99.7	8.8	.668
	GE	19	101.1	9.0	.894	7	101.3	6.0	.619
L1-MP	TM	24	91.1	4.7	.520	16	90.8	6.9	.182
	GE	19	89.8	7.7	.545	7	86.1	8.8	.241
Holdaway Ratio	TM	24	-0.9	7.2	.348	16	0.3	0.4	.617
	GE	19	0.7	2.5	.306	7	0.2	0.3	.567
U6-PT (mm)	TM	24	13.0	4.3	.196	16	12.7	3.5	.229
	GE	19	11.5	3.0	.178	7	10.9	2.1	.149
L6-PT (mm)	TM	24	12.7	4.2	.224	16	12.3	3.5	.187
	GE	19	11.2	3.3	.212	7	10.2	3.0	.168
U6-SN	TM	24	71.5	4.7	.105	16	63.7	5.1	.906
	GE	19	69.3	3.5	.094	7	63.4	5.6	.910
L6-SN	TM	24	-57.2	5.2	.001	16	-57.1	4.0	.123
	GE	19	-51.5	4.6	.001	7	-54.2	4.0	.134
LFH/TFH	TM	24	54.0	1.9	.184	16	54.9	1.8	.444
	GE	19	54.8	1.9	.184	7	54.2	2.1	.483
Facial Convexity	TM	24	86.4	2.9	.547	16	84.1	2.5	.440
	GE	19	87.0	3.1	.551	7	85.2	4.5	.545
Legan Convexity	TM	24	165.5	5.4	.914	16	163.1	5.0	.385
	GE	19	165.7	5.3	.914	7	165.1	5.4	.408
Z-Angle	TM	24	70.7	9.1	.749	16	62.7	8.9	.242
	GE	19	69.8	9.4	.750	7	67.8	10.7	.291
UL-EP (mm)	TM	24	-0.8	2.1	.705	16	0.8	2.1	.114
	GE	19	-0.5	2.6	.713	7	-1.0	2.9	.177
LL-EP (mm)	TM	24	-0.1	2.4	.482	16	2.1	2.7	.172
	GE	19	0.5	2.5	.484	7	0.4	2.4	.160

An Independent t-Test was also used to compare the model measurements at T1. Only one variable had a statistically significantly different mean between the two samples, inter-canine width in the mandible. The TM subjects on average had a mandibular inter-canine width 1.29mm wider than the GE subjects (Table III).

TABLE III
MATCHED SAMPLES AT T1: OVERALL SAMPLE MODELS

	Groups	N	Mean	Std. Deviation	Sig. (2-tailed)
Maxillary Arch Length (mm)	TM	42	76.5	4.1	.065
	GE	21	73.1	10.2	.158
Mandibular Arch Length (mm)	TM	42	65.7	3.5	.976
	GE	19	65.6	4.5	.978
Tanaka-Johnson Analysis of Space Required Maxilla (mm)	TM	42	78.0	3.2	.922
	GE	19	78.1	3.7	.927
Tanaka-Johnson Analysis of Space Required Mandible (mm)	TM	42	68.6	2.7	.778
	GE	19	68.8	3.0	.786
Upper Crowding (mm)	TM	42	1.6	4.2	.215
	GE	20	2.9	3.3	.179
Lower Crowding (mm)	TM	42	2.9	3.3	.917
	GE	20	3.0	3.3	.918
Overbite (mm)	TM	42	3.3	1.8	.606
	GE	19	3.0	2.3	.636
Overjet (mm)	TM	42	6.0	2.5	.180
	GE	19	5.1	1.9	.141
Inter-molar width maxilla(mm)	TM	42	38.8	2.7	.370
	GE	21	39.5	2.6	.362
Inter-molar width mandible(mm)	TM	42	40.0	2.5	.481
	GE	19	40.5	2.6	.485
Inter-canine width maxilla (mm)	TM	42	28.2	2.5	.832
	GE	21	28.0	1.7	.808
Inter-canine width mandible (mm)	TM	42	25.3	2.1	.016
	GE	19	24.0	1.4	.006
Arch Depth Maxilla (mm)	TM	42	28.6	2.0	.198
	GE	21	27.9	2.2	.214
Arch Depth Mandible (mm)	TM	42	23.7	1.6	.983
	GE	19	23.7	2.1	.985

C. **<u>Descriptive Statistics</u>**

The gender distribution in the study sample for TM and GE groups was 45.2% male, 54.8% female and 36.7% male, 63.3% female respectively. Chi square testing did not show statistically significant gender distributions between the two samples. The TM group showed the following gender distribution by Skeletal AP and Skeletal Vertical classifications: 19.0% Class I, 26.2% Class II for male subjects; 26.2 % class I, 28.6% class II for female subjects and 30.0% normal, 15.0% high angle for male subjects; 30.0% normal, 25.0% high angle for female subjects respectively. The GE group shows the following gender distribution by Skeletal AP and Skeletal Vertical classifications: 25.0% Class I, 14.3% ANB II for male subjects; 32.1% class I, 28.6% class II for female subjects and 38.5% normal, 3.8% high for male subjects and 34.6% normal, 23.1% high angle for female subjects. Of the total 72 subjects, 69 were Caucasian with 1 Middle Eastern subject in the TM group and 1 Middle Eastern and 1 Indian subject in the GE sample. Based upon T1 model analysis, molar Angle classification distribution for TM was as follows: 26.2% Class I, 32.8% Class II, 9.8% Class II subdivision 14.8%. The molar angle classification distribution for GE was Class I, 13.1% Class II, and 3.3% Class II subdivision.

D. **<u>Cephalometric Findings in the Overall Sample</u>**

1. **<u>Skeletal Changes</u>**

The overall TM sample displayed statistically significant different changes between T1-T2 for the following skeletal variables (Table IV, Figure 2):

- SNA-decreased by 2.5 degrees
- SNB-decreased by 1.0 degrees
- ANB-decreased by 1.5 degrees
- FMA-increased by 1.6 degrees

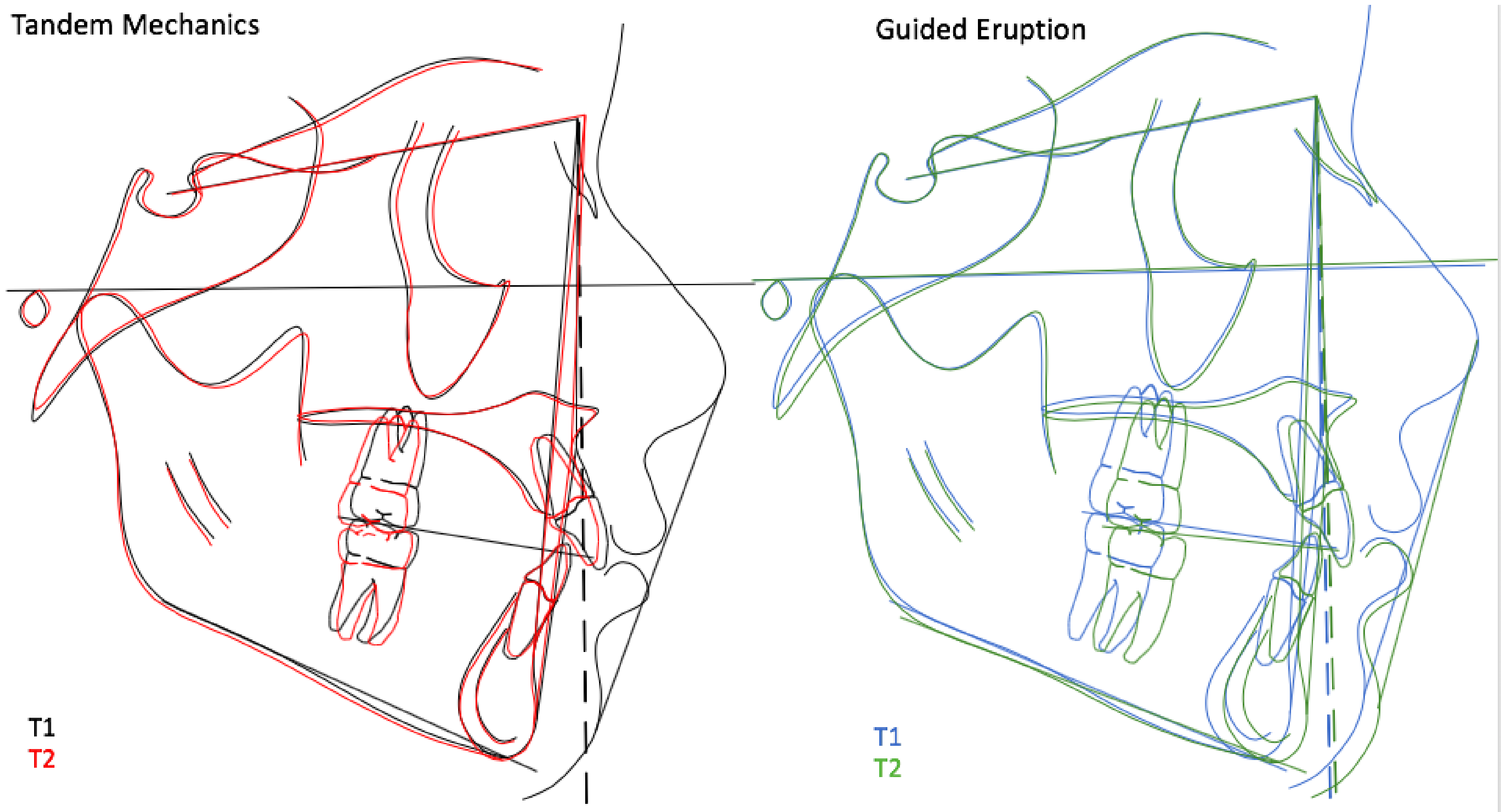
- Palatal Plane-SN-tipped clockwise by 2.3 degrees
- SN-MP-increased by 2 degrees
- Occlusal Plane-SN-tipped counterclockwise by 2.1 degrees
- LFH/TFH-decreased by .6

TABLE IV

MEAN CHANGES BETWEEN T1-T2: OVERALL SAMPLE

		T1		T2			
	GROUP	N	Mean	N	Mean	Δ (T2-T1)	Sig.
Treatment Length (years)	TM	42	10.8	30	12.5	1.7	.000
	GE	30	9.3	30	11.9	2.6	.000
SNA	TM	42	79.0	29	76.2	-2.5	.000
	GE	28	79.8	30	80.4	0.6	.133
SNB	TM	42	74.7	29	73.2	-1.0	.002
	GE	28	76.1	30	76.7	0.5	.056
ANB	TM	42	4.3	29	3.0	-1.5	.000
	GE	28	3.7	30	3.7	0.1	.844
FMA	TM	42	27.1	29	28.6	1.6	.001
	GE	28	25.9	30	24.4	-1.5	.001
Palatal plane-SN	TM	42	8.6	29	11.2	2.3	.000
	GE	28	8.6	30	8.5	0.0	.991
SN-MP	TM	42	35.9	29	38.4	2.0	.000
	GE	28	34.1	30	32.7	-1.4	.001
Occlusal plane-SN	TM	42	20.1	29	18.6	-2.1	.003
	GE	28	19.1	30	17.4	-1.8	.009
U1-SN	TM	42	101.1	29	100.5	0.3	.876
	GE	28	101.1	30	96.7	-4.2	.000
L1-MP	TM	42	91.3	29	86.6	-5.0	.017
	GE	28	89.1	30	86.0	-3.1	.002
Holdaway Ratio	TM	42	-0.4	29	-0.5	-0.8	.374
	GE	28	0.5	30	0.4	-0.1	.904
U6-PT (mm)	TM	42	12.9	29	11.7	-1.4	.382
	GE	28	11.1	30	13.8	2.6	.000
L6-PT (mm)	TM	42	12.4	29	11.7	-0.9	.571
	GE	28	10.7	30	14.4	3.5	.000
U6-SN	TM	42	68.6	29	65.8	-1.8	.263
	GE	28	68.3	30	69.6	1.4	.151
L6-SN	TM	42	-57.1	29	-65.0	-8.3	.036
	GE	28	-52.2	30	-57.1	-5.0	.000
LFH/TFH	TM	42	54.4	29	53.8	-0.6	.015
	GE	28	54.7	30	54.1	-0.6	.023
Facial Convexity	TM	42	85.7	29	85.3	-0.2	.583
	GE	28	86.3	30	87.7	1.3	.004
Legan Convexity	TM	42	164.5	27	164.6	0.7	.091
	GE	28	165.5	30	165.1	-0.5	.487
Z-Angle	TM	42	67.4	27	70.8	3.5	.004
	GE	28	68.8	30	73.6	4.4	.001
UL-EP (mm)	TM	42	-0.1	27	-2.5	-2.3	.000
	GE	28	-0.5	30	-1.8	-1.2	.001
LL-EP (mm)	TM	42	0.9	27	-1.0	-1.9	.000
	GE	28	0.5	30	-0.9	-1.4	.000

Figure 2. Superimposition of TM and GE at T1 and T2 for the entire sample



The overall GE sample displayed statistically significant different changes between T1-T2 for the following skeletal variables (Table IV, Figure 2):

- FMA-decreased by 1.5 degrees
- SN-MP-decreased by 1.4 degrees
- LFH/TFH-decreased by .6

2. **Dental Changes**

The overall TM sample displayed statistically significant changes between T1-T2 for the following dental cephalometric variables (Table IV, Figure 2):

- Occlusal Plane-SN-tipped counterclockwise by 2.1 degrees
- L1-MP-retroclined by 5 degrees
- L6-SN-decreased (tipped distally) by 8.3 degrees

The overall GE sample displayed statistically significant different changes between T1-T2 for the following dental cephalometric variables (Table IV, Figure 2):

- Occlusal Plane-SN-tipped counterclockwise by 1.8 degrees
- U1-SN retroclined by 4.2 degrees
- L1-MP-retroclined by 3.1 degrees
- U6-PT-increased (mesialized) by 2.6 mm
- L6-PT-increased (mesialized) by 3.5 mm
- L6-SN-decreased (tipped distally) by 5.0 degrees

3. **Soft Tissue Changes**

The overall TM sample displayed statistically significant different changes between T1-T2 for the following soft tissue variables (Table IV, Figure 2):

- Z angle-increased by 3.5 degrees
- Upper lip to E-Plane-decreased by 2.3 mm
- Lower lip to E-Plane-decreased by 1.9 mm

The overall GE sample displayed statistically significant different means between T1-T2 for the following soft tissue variables (Table IV, Figure 2):

- Facial convexity increased by 1.3 degrees
- Z angle increased by 4.4 degrees
- Upper lip to E-plane decreased by 1.2 mm
- Lower lip to E-Plane decreased by 1.4mm

4. **Comparison of the Modalities**

When the mean differences (ΔTM-ΔGE) between T1-T2 for the overall samples of both modalities were compared to one another using an Independent Samples t-Test the following variables were shown to have statistically significant differences (Table V, Figure 2):

- Treatment length: TM was on average 0.9 years shorter
- SNA: Mean difference of -3.1 degrees
- SNB: Mean difference of -1.6 degrees
- ANB: Mean difference of -1.6 degrees
- FMA: Mean difference of 3.0 degrees

- Palatal Plane-SN: Mean difference of 2.3 degrees
- SN-MP: Mean difference 3.4 degrees
- U1-SN: Mean difference of 4.5 degrees
- U6-PT: Mean difference of -4.0 mm
- L6-PT: Mean difference of -4.4 mm
- Facial Convexity: Mean difference of -1.5 degrees
- Upper Lip to E-Plane: Mean difference -1.2 mm

TABLE V

COMPARISON OF THE MEAN CHANGES: OVERALL SAMPLE

	GROUP	N	Δ (T2-T1)	Std. Deviation	ΔTM-ΔGE	Sig. (2-tailed)
Treatment Length (years)	TM	30	1.7	1.1	-0.9	.002
	GE	30	2.6	1.1		.002
SNA	TM	29	-2.5	2.0	-3.1	.000
	GE	28	0.6	2.0		.000
SNB	TM	29	-1.0	1.6	-1.6	.000
	GE	28	0.5	1.4		.000
ANB	TM	29	-1.5	1.6	-1.6	.000
	GE	28	0.1	1.3		.000
FMA	TM	29	1.6	2.3	3.0	.000
	GE	28	-1.5	2.1		.000
Palatal plane-SN	TM	29	2.3	2.3	2.3	.000
	GE	28	0.0	1.6		.000
SN-MP	TM	29	2.0	2.5	3.4	.000
	GE	28	-1.4	2.1		.000
Occlusal plane-SN	TM	29	-2.1	3.4	-0.2	.809
	GE	28	-1.8	3.4		.809
U1-SN	TM	29	0.3	9.5	4.5	.024
	GE	28	-4.2	4.0		.024
L1-MP	TM	29	-5.0	10.6	-1.9	.389
	GE	28	-3.1	4.9		.385
Holdaway Ratio	TM	29	-0.8	4.7	-0.7	.636
	GE	28	-0.1	5.7		.637
U6-PT (mm)	TM	29	-1.4	8.7	-4.0	.024
	GE	28	2.6	3.0		.024
L6-PT (mm)	TM	29	-0.9	8.7	-4.4	.014
	GE	28	3.5	3.4		.015
U6-SN	TM	29	-1.8	8.5	-3.2	.089
	GE	28	1.4	5.1		.087
L6-SN	TM	29	-8.3	20.4	-3.3	.409
	GE	28	-5.0	4.6		.405
LFH/TFH	TM	29	-0.6	1.3	0.0	.966
	GE	28	-0.6	1.4		.966
Facial Convexity	TM	29	-0.2	2.4	-1.5	.015
	GE	28	1.3	2.2		.015
Legan Convexity	TM	27	0.7	2.2	1.2	.140
	GE	28	-0.5	3.7		.138
Z-Angle	TM	27	3.5	5.6	-0.9	.558
	GE	28	4.4	6.0		.558
Upper Lip-E Plane(mm)	TM	27	-2.3	2.3	-1.2	.034
	GE	28	-1.2	1.6		.036
Lower lip-E Plane(mm)	TM	27	-1.9	2.3	-0.5	.327
	GE	28	-1.4	1.6		.330

E. **Anteroposterior Subgroup**

1. **Skeletal Changes**

The class I TM sample displayed statistically significant changes between T1-T2 for the following skeletal cephalometric variables (Table VI):

- SNA: Decreased by 1.9 degrees
- ANB: Decreased by 1.0 degrees
- Palatal Plane-SN: rotated clockwise by 1.8 degrees
- SN-MP: Increased by 1.8 degrees

TABLE VI

MEAN CHANGES BETWEEN T1-T2: AP SUBGROUP

		Class I						Class II					
	Group	T1 N	T1 Mean	T2 N	T2 Mean	Δ (T2-T1)	Sig.	T1 N	T1 Mean	T2 N	T2 Mean	Δ (T2-T1)	Sig.
AGE (years)	TM	19	10.5	13	12.3	1.4	.000	23	11.1	17	12.6	1.9	.000
	GE	16	9.9	16	12.4	2.5	.000	12	8.6	12	11.2	2.6	.000
SNA	TM	19	78.4	12	76.0	-1.9	.001	23	79.6	17	76.4	-3.0	.000
	GE	16	78.4	16	79.6	1.1	.070	12	81.7	12	81.6	-0.2	.632
SNB	TM	19	75.7	12	74.1	-0.9	.060	23	73.9	17	72.5	-1.1	.018
	GE	16	76.2	16	77.0	0.9	.041	12	76.1	12	76.2	0.1	.745
ANB	TM	19	2.7	12	1.8	-1.0	.013	23	5.6	17	3.9	-1.9	.000
	GE	16	2.3	16	2.5	0.3	.439	12	5.6	12	5.4	-0.3	.439
FMA	TM	19	26.0	12	27.5	1.5	.091	23	28.1	17	29.3	1.7	.005
	GE	16	24.5	16	22.7	-1.7	.002	12	27.9	12	26.8	-1.1	.160
Palatal plane-SN	TM	19	8.8	12	11.4	1.8	.027	23	8.5	17	11.1	2.7	.000
	GE	16	8.9	16	9.0	0.0	.964	12	8.1	12	8.0	0.0	.974
SN-MP	TM	19	34.1	12	36.8	1.8	.019	23	37.4	17	39.5	2.1	.005
	GE	16	33.7	16	31.7	-2.0	.003	12	34.6	12	34.0	-0.6	.239
Occlusal plane-SN	TM	19	19.2	12	17.3	-2.0	.067	23	20.8	17	19.5	-2.1	.025
	GE	16	18.9	16	17.7	-1.1	.298	12	19.4	12	16.6	-2.8	.001
U1-SN	TM	19	102.0	12	104.6	1.9	.312	23	100.3	17	97.7	-0.9	.752
	GE	16	99.6	16	95.8	-3.7	.000	12	103.2	12	98.3	-4.9	.006
L1-MP	TM	19	91.2	12	89.4	-2.4	.465	23	91.3	17	84.6	-6.8	.015
	GE	16	85.8	16	82.6	-3.2	.014	12	93.5	12	90.6	-3.0	.084
Holdaway Ratio	TM	19	-1.3	12	-0.1	-0.4	.266	23	0.3	17	-0.8	-1.1	.470
	GE	16	0.8	16	0.0	-0.8	.668	12	0.1	12	0.9	0.8	.141
U6-PT (mm)	TM	19	12.5	12	11.0	-2.2	.013	23	13.2	17	12.2	-0.9	.749
	GE	16	11.5	16	13.8	2.3	.004	12	10.7	12	13.6	2.9	.010
L6-PT (mm)	TM	19	12.5	12	11.1	-1.9	.070	23	12.4	17	12.1	-0.2	.933
	GE	16	11.6	16	14.5	2.9	.004	12	9.6	12	13.9	4.3	.001
U6-SN	TM	19	70.2	12	68.2	-0.7	.000	23	67.3	17	64.1	-2.6	.000
	GE	16	68.6	16	69.4	0.9	.000	12	67.9	12	70.1	2.2	.000
L6-SN	TM	19	-56.8	12	-62.4	-5.9	.000	23	-57.4	17	-66.8	-10.1	.000
	GE	16	-53.0	16	-56.9	-3.9	.000	12	-51.0	12	-57.6	-6.6	.000
LFH/TFH	TM	19	54.3	12	53.7	0.0	.000	23	54.5	17	53.8	-1.1	.000
	GE	16	54.8	16	53.9	-0.9	.000	12	54.5	12	54.2	-0.3	.000
Facial Convexity	TM	19	86.3	12	85.7	-0.5	.000	23	85.2	17	85.1	-0.1	.000
	GE	16	87.8	16	89.0	1.3	.000	12	84.3	12	85.6	1.3	.000
Legan Convexity	TM	19	168.1	12	168.2	0.3	.000	23	161.6	15	161.7	1.1	.000
	GE	16	168.1	16	167.3	-0.8	.000	12	162.0	12	161.9	-0.1	.000
Z-Angle	TM	19	71.1	12	73.3	3.8	.000	23	64.4	15	68.8	3.2	.000
	GE	16	74.3	16	77.9	3.5	.000	12	61.4	12	66.9	5.5	.000
UL-EP (mm)	TM	19	-0.7	12	-2.6	-2.2	.576	23	0.3	15	-2.4	-2.5	.839
	GE	16	-1.8	16	-2.8	-1.0	.003	12	1.2	12	-0.2	-1.4	.122
LL-EP (mm)	TM	19	0.2	12	-1.1	-1.8	.491	23	1.4	15	-1.0	-2.0	.120
	GE	16	-0.6	16	-1.8	-1.2	.253	12	2.1	12	0.4	-1.6	.004

The class II TM sample displayed statistically significant changes between T1-T2 for the following skeletal cephalometric variables (Table VI):

- SNA: Decreased by 3.0 degrees
- SNB: Decreased by 1.1 degrees
- ANB: Decreased by 1.9 degrees
- FMA: Increased by 1.7 degrees
- Palatal Plane-SN: Rotated clockwise by 2.7 degrees
- SN-MP: Increased by 2.1 degrees
- LFH:TFH: Decreased by 1.1

The class I GE sample displayed statistically significant changes between T1-T2 for the following skeletal cephalometric variables (Table VI):

- SNB: Increased by 0.9 degrees
- FMA: Decreased by 1.7 degrees
- SN-MP: Decreased by 2.0 degrees
- LFH:TFH: Decreased by 0.9 degrees

The class II GE sample displayed statistically significant changes between T1-T2 for the following skeletal cephalometric variables (Table VI):

- LFH:TFH: Decreased by 0.3 degrees

2. **Dental Changes**

The class I TM sample displayed statistically significant changes between T1-T2 for the following dental cephalometric variables (Table VI):

- U6-PT: Decreased (distalized) by 2.2 mm
- U6-SN: Decreased (tipped distally) by 0.7 degrees
- L6-SN: Decreased (tipped distally) by 5.9 degrees

The class II TM sample displayed statistically significant changes between T1-T2 for the following dental cephalometric variables (Table VI):

- Occlusal Plane-SN: Tipped counterclockwise by 2.1 degrees
- L1-MP: Decreased by 6.8 degrees
- U6-SN: Decreased (tipped distal) by 2.6 degrees
- L6-SN: Decreased (tipped distal) by 10.1 degrees

The class I GE sample displayed statistically significant changes between T1-T2 for the following dental cephalometric variables (Table VI):

- U1-SN: Decreased (retroclined) by 3.74degrees
- L1-MP: Decreased (retroclined) by 3.2 degrees
- U6-PT: Increased (mesialized) by 2.3 mm
- L6-PT: Increased (mesialized) by 2.9 mm
- U6-SN: Increased (tipped mesial) by 0.9 degrees
- L6-SN: Decreased (tipped distal) 3.9 degrees

The class II GE sample displayed statistically significant changes between T1-T2 for the following dental cephalometric variables (Table VI):

- Occlusal Plane-SN: Decreased (tipped counterclockwise) by 2.8 degrees
- U1-SN: Decreased (retroclined) by 4.9 degrees
- U6-PT: Increased (mesialized) by 2.9 mm
- L6-PT: Increased (mesialized) by 4.3 mm
- U6-SN: Increased (tipped mesially) by 2.2 degrees
- L6-SN: Decreased (tipped distally) by 6.6 degrees

3. **Soft Tissue Changes**

The class I TM sample displayed statistically significant changes between T1-T2 for the following soft tissue cephalometric variables (Table VI):

- Facial Convexity: Decreased 0.5 degrees
- Legan Convexity: Increased by 0.3 degrees
- Z Angle: Increased by 3.8 degrees

The class II TM sample displayed statistically significant changes between T1-T2 for the following soft tissue cephalometric variables (Table VI):

- Facial Convexity: Decreased by 0.1 degrees
- Legan Convexity: Increased by 1.1 degrees
- Z Angle: Increased by 3.2 degrees

The class I GE sample displayed statistically significant changes between T1-T2 for the following soft tissue cephalometric variables (Table VI):

- Facial Convexity: Increased by 1.3 degrees
- Legan Convexity: Decreased by 0.8 degrees
- Z angle: Increased by 3.5 degrees
- Upper Lip-E Plane: Decreased by 1.0 mm

The class II GE sample displayed statistically significant changes between T1-T2 for the following soft tissue cephalometric variables (Table VI):

- Facial Convexity: Increased by 1.3 degrees
- Legan Convexity: Decreased by 0.1 degrees
- Z Angle: Increased by 5.5 degrees
- Lower Lip-E Plane: Decreased by 1.6 mm

5. **<u>Comparison of the Modalities in the AP Subgroup</u>**

When the mean differences (ΔTM-ΔGE) between T1-T2 for the AP subgroups of both modalities were compared to one another using an Independent Samples t-Test the following variables were shown to have statistically significant differences (Table VII):

TABLE VII
COMPARISON OF MEAN CHANGES: AP SUBGROUP

		Class I					Class II				
	Group	N	Δ (T2-T1)	SD	ΔTM- ΔGE	Sig.	N	Δ (T2-T1)	SD	ΔTM- ΔGE	Sig.
Treatment Length (years)	TM	13	1.4	0.9	-1.1	.011	17	1.9	1.2	-0.7	.096
	GE	16	2.5	1.2		.009	12	2.6	1.1		.091
SNA	TM	12	-1.9	1.4	-3.0	.000	17	-3.0	2.2	-2.8	.000
	GE	16	1.1	2.3		.000	12	-0.2	1.1		.000
SNB	TM	12	-0.9	1.5	-1.8	.005	17	-1.1	1.7	-1.2	.046
	GE	16	0.9	1.5		.006	12	0.1	1.2		.035
ANB	TM	12	-1.0	1.2	-1.3	.018	17	-1.9	1.8	-1.6	.010
	GE	16	0.3	1.4		.015	12	-0.3	1.2		.006
FMA	TM	12	1.5	2.7	3.2	.001	17	1.7	2.1	2.7	.004
	GE	16	-1.7	1.8		.002	12	-1.1	2.5		.005
Palatal plane-SN	TM	12	1.8	2.5	1.8	.029	17	2.7	2.1	2.7	.001
	GE	16	0.0	1.6		.042	12	0.0	1.7		.001
SN-MP	TM	12	1.8	2.2	3.8	.000	17	2.1	2.7	2.7	.005
	GE	16	-2.0	2.3		.000	12	-0.6	1.6		.002
Occlusal plane-SN	TM	12	-2.0	3.4	-0.9	.540	17	-2.1	3.5	0.7	.525
	GE	16	-1.1	4.1		.529	12	-2.8	2.1		.490
U1-SN	TM	12	1.9	6.2	5.6	.004	17	-0.9	11.2	4.0	.263
	GE	16	-3.7	3.3		.012	12	-4.9	5.0		.210
L1-MP	TM	12	-2.4	10.9	0.8	.795	17	-6.8	10.3	-3.9	.245
	GE	16	-3.2	4.6		.816	12	-3.0	5.4		.200
Holdaway Ratio	TM	12	-0.4	1.0	0.5	.832	17	-1.1	6.2	-1.9	.314
	GE	16	-0.8	7.5		.808	12	0.8	1.7		.246
U6-PT (mm)	TM	12	-2.2	2.6	-4.5	.000	17	-0.9	11.2	-3.8	.267
	GE	16	2.3	2.8		.000	12	2.9	3.3		.203
L6-PT (mm)	TM	12	-1.9	3.3	-4.8	.001	17	-0.2	11.1	-4.6	.182
	GE	16	2.9	3.4		.001	12	4.3	3.4		.128
U6-SN	TM	12	-0.7	10.0	-1.6	.581	17	-2.6	7.6	-4.8	.076
	GE	16	0.9	4.7		.619	12	2.2	5.7		.064
L6-SN	TM	12	-5.9	3.8	-2.0	.132	17	-10.1	26.7	-3.4	.665
	GE	16	-3.9	3.1		.146	12	-6.6	5.8		.613
LFH/TFH	TM	12	0.0	1.1	0.9	.051	17	-1.1	1.2	-0.8	.124
	GE	16	-0.9	1.3		.045	12	-0.3	1.5		.139
Facial Convexity	TM	12	-0.5	2.3	-1.7	.038	17	-0.1	2.5	-1.4	.163
	GE	16	1.3	1.8		.047	12	1.3	2.6		.168
Legan Convexity	TM	12	0.3	1.8	1.0	.388	15	1.1	2.4	1.3	.309
	GE	16	-0.8	3.7		.347	12	-0.1	3.8		.336
Z-Angle	TM	12	3.8	6.3	0.3	.890	15	3.2	5.2	-2.4	.341
	GE	16	3.5	4.8		.895	12	5.5	7.5		.364
Upper Lip-E Plane(mm)	TM	12	-2.2	0.7	-1.2	.002	15	-2.5	3.1	-1.1	.323
	GE	16	-1.0	1.0		.001	12	-1.4	2.2		.306
Lower lip-E Plane(mm)	TM	12	-1.8	1.4	-0.7	.211	15	-2.0	2.9	-0.3	.752
	GE	16	-1.2	1.3		.216	12	-1.6	2.0		.743

Class I Subgroup

- Treatment Length: TM was on average 1.1 years shorter
- SNA: Mean difference of -3.0 degrees
- SNB: Mean difference of -1.8 degrees
- ANB: Mean difference of -1.3 degrees
- FMA: Mean difference of 3.2 degrees
- Palatal Plane-SN: Mean difference of 1.8 degrees
- SN-MP: Mean difference of 3.8 degrees
- U1-SN: Mean difference of 5.6 degrees
- U6-PT: Mean difference of -4.5 mm
- L6-PT: Mean difference of -4.8 mm
- LFH:TFH: Mean difference of .9 degrees
- Facial Convexity: Mean difference of -1.7 degrees
- Upper lip-E Plane: mean difference of 1.2 mm

Class II Subgroup

- Treatment Length: TM was on average 0.7 years shorter
- SNA: Mean difference of -2.8 degrees
- SNB: Mean difference of -1.2 degrees
- ANB: Mean difference of -1.6 degrees
- FMA: Mean difference of 2.7 degrees
- Palatal Plane-SN: Mean difference of 2.7 degrees
- SN-MP: Mean difference of 2.7 degrees

- U6-SN: Mean difference of -4.8 degrees

F. **Vertical Subgroup**

1. **Skeletal Changes**

The normal vertical angle TM sample displayed statistically significant changes between T1-T2 for the following skeletal cephalometric variables (Table VIII):

- SNA: Decreased by 2.2 degrees
- SNB: Decreased by 1.0 degrees
- ANB: Decreased by 1.2 degrees
- Palatal Plane-SN: Increased (tipped clockwise) by 1.5 degrees
- SN-MP: Increased by 1.6 degrees

TABLE VIII

MEAN CHANGES BETWEEN T1-T2: VERTICAL SUBGROUP

		Normal Vertical						High Vertical					
	Group	T1 N	T1 Mean	T2 N	T2 Mean	Δ (T2-T1)	Sig.	T1 N	T1 Mean	T2 N	T2 Mean	Δ (T2-T1)	Sig.
AGE (years)	TM	24	11.0	15	12.9	1.7	.000	16	10.7	13	12.1	1.6	.000
	GE	19	9.4	19	12.0	2.6	.000	7	9.1	7	11.7	2.5	.003
SNA	TM	24	79.4	14	77.1	-2.2	.000	16	77.6	13	74.2	-2.8	.001
	GE	19	80.3	19	80.7	0.4	.430	7	78.1	7	79.1	1.0	.196
SNB	TM	24	75.9	14	74.7	-1.0	.019	16	72.1	13	70.6	-0.9	.106
	GE	19	76.8	19	77.2	0.5	.146	7	74.0	7	75.1	1.1	.058
ANB	TM	24	3.5	14	2.4	-1.2	.001	16	5.5	13	3.6	-1.9	.005
	GE	19	3.6	19	3.5	-0.1	.707	7	4.1	7	4.0	-0.1	.882
FMA	TM	24	25.5	14	26.2	1.0	.133	16	30.9	13	32.4	1.9	.013
	GE	19	24.8	19	23.3	-1.5	.003	7	31.2	7	30.4	-0.8	.455
Palatal plane-SN	TM	24	8.4	14	10.2	1.5	.013	16	9.3	13	12.9	3.2	.000
	GE	19	8.3	19	8.5	0.2	.596	7	10.3	7	10.0	-0.3	.691
SN-MP	TM	24	33.6	14	35.5	1.6	.005	16	41.1	13	43.4	2.3	.025
	GE	19	32.9	19	31.8	-1.1	.016	7	41.0	7	39.2	-1.8	.147
Occlusal plane-SN	TM	24	18.5	14	16.1	-2.1	.033	16	23.5	13	22.2	-2.3	.046
	GE	19	19.3	19	17.1	-2.2	.066	7	21.5	7	19.6	-1.9	.170
U1-SN	TM	24	101.4	14	103.6	2.0	.223	16	99.7	13	96.0	-1.6	.650
	GE	19	101.1	19	96.3	-4.8	.000	7	101.3	7	98.8	-2.5	.057
L1-MP	TM	24	91.1	14	89.6	-1.6	.567	16	90.8	13	84.0	-7.2	.032
	GE	19	89.8	19	86.1	-3.7	.009	7	86.1	7	84.0	-2.2	.095
Holdaway Ratio	TM	24	-0.9	14	0.3	0.0	.959	16	0.3	13	-1.4	-1.7	.395
	GE	19	0.7	19	0.5	-0.2	.913	7	0.2	7	0.1	-0.1	.724
U6-PT (mm)	TM	24	13.0	14	14.9	0.8	.797	16	12.7	13	8.7	-3.6	.002
	GE	19	11.5	19	14.6	3.2	.000	7	10.9	7	11.8	0.8	.254
L6-PT (mm)	TM	24	12.7	14	15.0	1.6	.630	16	12.3	13	8.6	-3.3	.001
	GE	19	11.2	19	15.4	4.2	.000	7	10.2	7	12.1	1.9	.053
U6-SN	TM	24	71.5	14	68.5	-3.0	.000	16	63.7	13	62.9	0.3	.000
	GE	19	69.3	19	70.9	1.5	.000	7	63.4	7	64.4	1.0	.000
L6-SN	TM	24	-57.2	14	-70.1	-13.3	.000	16	-57.1	13	-59.8	-3.1	.000
	GE	19	-51.5	19	-57.4	-5.8	.000	7	-54.2	7	-57.5	-3.3	.000
LFH/TFH	TM	24	54.0	14	53.8	0.0	.000	16	54.9	13	53.8	-1.2	.000
	GE	19	54.8	19	54.1	-0.7	.000	7	54.2	7	53.9	-0.3	.000
Facial Convexity	TM	24	86.4	14	86.4	-0.1	.000	16	84.1	13	83.8	-0.2	.000
	GE	19	87.0	19	88.5	1.6	.000	7	85.2	7	85.9	0.7	.000
Legan Convexity	TM	24	165.5	14	166.1	0.8	.000	16	163.1	12	163.3	0.6	.000
	GE	19	165.7	19	165.8	0.0	.000	7	165.1	7	163.5	-1.6	.000
Z-Angle	TM	24	70.7	14	74.8	4.8	.000	16	62.7	12	66.4	2.2	.000
	GE	19	69.8	19	75.3	5.5	.000	7	67.8	7	69.2	1.3	.000
UL-EP (mm)	TM	24	-0.8	14	-3.6	-2.9	.206	16	0.8	12	-1.3	-2.0	.333
	GE	19	-0.5	19	-2.0	-1.5	.438	7	-1.0	7	-1.5	-0.5	.413
LL-EP (mm)	TM	24	-0.1	14	-2.1	-2.3	.770	16	2.1	12	0.1	-1.4	.080
	GE	19	0.5	19	-1.1	-1.6	.434	7	0.4	7	-0.1	-0.5	.644

The high vertical angle TM sample displayed statistically significant changes between T1-T2 for the following skeletal cephalometric variables (Table VIII):

- SNA: Decreased by 2.8 degrees
- ANB: Decreased by 1.9 degrees
- FMA: Increased by 1.9 degrees
- Palatal Plane-SN: Increased (rotated clockwise) by 3.2 degrees
- SN-MP: Increased by 2.3 degrees
- LFH/TFH: Decreased by 1.2 degrees

The normal vertical angle GE sample displayed statistically significant changes between T1-T2 for the following skeletal cephalometric variables (Table VIII):

- FMA: Decreased by 1.5 degrees
- SN-MP: Decreased by 1.1 degrees
- LFH/TFH: Decreased by 0.7 degrees

The high vertical angle GE sample displayed statistically significant changes between T1-T2 for the following skeletal cephalometric variables (Table VIII):

- LFH/TFH: Decreased by 0.3 degrees

2. **<u>Dental Changes</u>**

The normal vertical angle TM sample displayed statistically significant changes between T1-T2 for the following dental cephalometric variables (Table VIII):

- Occlusal Plane-SN: Decreased (tipped counterclockwise) by 2.1 degrees

- U6-SN: Decreased (crown tipped distal) by 3.0 degrees
- L6-SN: Decreased (crown tipped distal) by13.3 degrees

The high vertical angle TM sample displayed statistically significant changes between T1-T2 for the following dental cephalometric variables (Table VIII):

- Occlusal Plane-SN: Decreased (tipped counterclockwise) by 2.3 degrees
- L1-MP: Decreased (retroclined) by 7.2 degrees
- U6-PT: Decreased (distalized) by 3.6 mm
- L6-PT: Decreased (distalized) by 3.3 mm
- U6-SN: Increased (tipped mesial) by .3 degrees
- L6-SN: Decreased (tipped distal) by 3.1 degrees

The normal vertical angle GE sample displayed statistically significant changes between T1-T2 for the following dental cephalometric variables (Table VIII):

- U1-SN: Decreased (retroclined) by 4.8 degrees
- L1-MP: Decreased (retroclined) by 3.7 degrees
- U6-PT: Increased (mesialized) by 3.2 mm
- L6-PT: Increased (mesialized) by 4.2 mm
- U6-SN: Increased (tipped mesial) by 1.5 degrees
- L6-SN: Decreased (tipped distal) by 5.8 degrees

The high vertical angle GE sample displayed statistically significant changes between T1-T2 for the following dental cephalometric variables (Table VIII):

- U6-SN: Increased (tipped mesial) by 1.0 degrees
- L6-SN-Decreased (tipped distal) by 3.3 degrees

3. **<u>Soft Tissue Changes</u>**

The normal vertical angle TM sample displayed statistically significant changes between T1-T2 for the following soft tissue cephalometric variables (Table VIII):

- Facial Convexity: Decreased by .1 degrees
- Legan Convexity: Increased by .8 degrees
- Z Angle: Increased by 4.8 degrees

The high vertical angle TM sample displayed statistically significant changes between T1-T2 for the following soft tissue cephalometric variables (Table VIII):

- Facial Convexity: Decreased by .2 degrees
- Legan Convexity: Increased by .6 degrees
- Z angle increased by 2.2 degrees

The normal vertical angle GE sample displayed statistically significant changes between T1-T2 for the following soft tissue cephalometric variables (Table VIII):

- Facial Convexity: Increased by 1.6 degrees
- Z angle: Increased by 5.5 degrees

The high vertical angle GE sample displayed statistically significant changes between T1-T2 for the following soft tissue cephalometric variables:

- Facial Convexity: Increased by .7 degrees
- Legan Convexity: Decreased by 1.6 decreased
- Z angle: Increased by 1.3 degrees

4. **Comparison of the Modalities in the Vertical Subgroup**

When the mean differences (ΔTM-ΔGE) between T1-T2 for the vertical subgroups of both modalities were compared to one another using an Independent Samples t-Test the following variables were shown to have statistically significant differences (Table IX):

Normal Vertical Subgroup

- Treatment Length: TM was on average .8 years shorter
- SNA: Mean difference of -2.6 degrees
- SNB: Mean difference of 1.5 degrees
- ANB: Mean difference of -1.1 degrees
- FMA: Mean difference of 2.5 degrees
- Palatal Plane-SN: Mean difference of 1.3 degrees
- SN-MP: Mean difference of 2.7 degrees
- U1-SN: Mean difference of 6.7 degrees
- U6-SN: Mean difference of -4.5 degrees
- Facial Convexity: Mean difference of -1.7 degrees
- Upper Lip- E Plane: Mean difference of -1.4 mm

High Vertical Subgroup

- SNA: Mean difference of -3.9 degrees
- SNB: Mean difference of -2.1 degrees
- ANB: Mean difference of -1.8 degrees
- FMA: Mean difference of 2.7 degrees
- Palatal Plane-SN: Mean difference of 3.5 degrees
- SN-MP: Mean difference of 4.2 degrees
- U6-PT: Mean difference -4.4 mm
- L6-PT: Mean difference of -5.2 mm

TABLE IX

COMPARISON OF MEAN CHANGES: VERTICAL SUBGROUP

		Normal Vertical					High Vertical				
	Group	N	Δ (T2-T1)	SD	ΔTM- ΔGE	Sig.	N	Δ (T2-T1)	SD	ΔTM- ΔGE	Sig.
Treatment Length (years)	TM	15	1.7	1.1	-0.8	.043	13	1.6	1.1	-0.9	.135
	GE	19	2.6	1.1		.043	7	2.5	1.4		.173
SNA	TM	14	-2.2	1.8	-2.6	.001	13	-2.8	2.3	-3.9	.001
	GE	19	0.4	2.0		.000	7	1.0	1.9		.001
SNB	TM	14	-1.0	1.4	-1.5	.005	13	-0.9	1.9	-2.1	.022
	GE	19	0.5	1.4		.005	7	1.1	1.3		.011
ANB	TM	14	-1.2	1.1	-1.1	.012	13	-1.9	2.0	-1.8	.049
	GE	19	-0.1	1.2		.012	7	-0.1	1.5		.033
FMA	TM	14	1.0	2.4	2.5	.002	13	1.9	2.4	2.7	.030
	GE	19	-1.5	1.9		.004	7	-0.8	2.6		.042
Palatal plane-SN	TM	14	1.5	1.9	1.3	.042	13	3.2	2.4	3.5	.003
	GE	19	0.2	1.6		.051	7	-0.3	2.0		.003
SN-MP	TM	14	1.6	1.7	2.7	.000	13	2.3	3.3	4.2	.011
	GE	19	-1.1	1.8		.000	7	-1.8	2.9		.012
Occlusal plane-SN	TM	14	-2.1	3.4	0.1	.956	13	-2.3	3.7	-0.4	.833
	GE	19	-2.2	3.1		.957	7	-1.9	3.3		.828
U1-SN	TM	14	2.0	5.8	6.7	.001	13	-1.6	12.5	0.9	.855
	GE	19	-4.8	4.4		.001	7	-2.5	2.8		.808
L1-MP	TM	14	-1.6	10.3	2.1	.461	13	-7.2	10.7	-5.0	.244
	GE	19	-3.7	5.6		.502	7	-2.2	2.9		.133
Holdaway Ratio	TM	14	0.0	1.5	0.2	.917	13	-1.7	6.9	-1.6	.553
	GE	19	-0.2	7.0		.905	7	-0.1	0.6		.422
U6-PT (mm)	TM	14	0.8	11.9	-2.3	.423	13	-3.6	3.2	-4.4	.003
	GE	19	3.2	3.2		.490	7	0.8	1.8		.001
L6-PT (mm)	TM	14	1.6	11.9	-2.6	.375	13	-3.3	2.7	-5.2	.000
	GE	19	4.2	3.7		.441	7	1.9	2.1		.000
U6-SN	TM	14	-3.0	5.3	-4.5	.023	13	0.3	10.7	-0.6	.889
	GE	19	1.5	5.4		.024	7	1.0	5.3		.866
L6-SN	TM	14	-13.3	28.7	-7.5	.269	13	-3.1	4.6	0.2	.922
	GE	19	-5.8	4.9		.350	7	-3.3	2.2		.905
LFH/TFH	TM	14	0.0	1.1	0.7	.117	13	-1.2	1.2	-0.9	.178
	GE	19	-0.7	1.4		.104	7	-0.3	1.6		.225
Facial Convexity	TM	14	-0.1	2.2	-1.7	.049	13	-0.2	2.7	-0.9	.456
	GE	19	1.6	2.4		.047	7	0.7	1.8		.401
Legan Convexity	TM	14	0.8	2.1	0.8	.462	12	0.6	2.5	2.1	.201
	GE	19	0.0	3.3		.431	7	-1.6	4.6		.288
Z-Angle	TM	14	4.8	5.6	-0.7	.740	12	2.2	5.7	0.8	.779
	GE	19	5.5	5.8		.738	7	1.3	6.4		.788
UL-EP(mm)	TM	14	-2.9	2.4	-1.4	.048	12	-2.0	2.2	-1.4	.182
	GE	19	-1.5	1.4		.070	7	-0.5	1.9		.168
LL-EP (mm)	TM	14	-2.3	2.7	-0.7	.330	12	-1.4	1.8	-0.9	.302
	GE	19	-1.6	1.6		.370	7	-0.5	1.7		.299

G. **Model Findings in the Overall Guided Eruption Sample**

The overall GE sample displayed statistically significant changes between T1-T2 for the following cast model variables (Table X)

- Mandibular Arch Length: Decreased by 7.1 mm
- Overbite: Increased by 1.4 mm
- Overjet: Increased by 0.7 mm
- Mandibular Inter-molar Width: Decreased by 0.6 mm
- Maxillary Inter-canine Width: increased by 1.9 mm
- Mandibular Inter-canine width: Increased by 3.2 mm
- Maxillary Arch Depth: Decreased by 1.7mm
- Mandibular Arch Depth: Decreased by 3.3 mm

TABLE X

MEAN CHANGES BETWEEN T1-T2 FOR GE: MODELS

	t	df	Sig. (2-tailed)	Mean Difference
Treatment Length	11.309	29	.000	2.5
Molar Classification	-.490	18	.630	-0.1
Maxillary Arch Length	-1.446	20	.164	-2.6
Mandibular Arch Length	-12.322	18	.000	-7.1
Tanaka Johnston Maxillary Space Required	1.508	18	.149	0.5
Tanaka Johnston Mandibular Space Required	.746	18	.465	0.3
Overbite	4.701	18	.000	1.4
Overjet	2.296	18	.034	0.7
Maxillary Inter-molar Width	.057	20	.955	0.0
Mandibular Inter-molar Width	-2.142	18	.046	-0.6
Maxillary Inter-canine Width	5.231	20	.000	1.9
Mandibular Inter-canine Width	6.293	18	.000	3.2
Maxillary Arch Depth	-5.276	20	.000	-1.7
Mandibular Arch Depth	-10.806	18	.000	-3.3

V. DISCUSSION

A. Comparison with the Literature

There is a relative lack of literature regarding Tandem Mechanics in comparison to the vast library of studies on Guided Eruption. One of the few available studies evaluating cephalometric changes during Tandem treatment did find that the technique had a propensity to distally tip lower molars and to flatten the profile. [21] These same treatment effects were noted in our study for the overall sample and for all subgroups. This previous study evaluated cephalometric changes in lower molars but did not evaluate upper molars. They evaluated changes in vertical position of lower molars but we did not include any variables for vertical molar position in our study. We can use the superimposition in Figure 2 to provide a basic comparison to their results regarding changes in molar height. Haas[21] found that in addition to distalization of the lower molar at T2, the molar also intruded. Figure 2 displays the same lower molar distal tip, and a slight decrease in lower molar height. Our study found that there was a tendency for the mandible to rotate clockwise and to increase the vertical dimensions of the face as indicated by SNB and FMA and SN-MP measurements respectively. Figure 2 appears to demonstrate extrusion of upper molars. We can theorize that this extrusion paired with the distalization of both molars caused a wedging effect on the mandible. The wedging effect is a commonly accepted phenomena amongst orthodontists where molar extrusion and/or distalization creates a wedge results in a backwards and opening rotation of the mandible.[22] This mandibular plane rotation was noted in our skeletal measurements and can be viewed in Figure 2.

None of the studies we encountered in our search of the literature identified a change in lower incisor inclination, however, we encountered a significant tendency for the TM technique to retrocline lower incisors in the overall sample and within all subgroups. In the overall sample, TM actually caused more retroclination than GE. Lower incisor retroclination is a well documented side effect of GE.[8,9,11,13] Many of the previous studies on TM utilized dental casts to evaluate changes. We did not have models available at T2 for our subjects so we are unable to make comparisons to these studies. We encountered no other studies of TM that also evaluated the technique cephalometrically at the same time point where TM therapy was discontinued so there are no further studies to which we can compare our results.

Our study revealed a number of changes from T1-T2 that were in agreement with a previous study of GE: incisors retroclined, molars mesialized and lip procumbency was reduced.[11] Interestingly, despite the mesialization of the molars, the long axis of the tooth tipped distally. This was in direct contrast to previous studies of GE.[11,13] Our study used a different reference plane to evaluate the angulation change of the first molars, the SN plane, while these two previous studies used the Palatal Plane. It could be that our conflicting findings were a result of the use of different reference planes. Our analysis of the occlusal plane found that there was a statistically significant flattening of the occlusal plane in the overall sample by almost 2 degrees. The flattening of the occlusal plane supports the finding that there was a distal tip of molars as mesially tipped molars would have a tendency to steepen the occlusal plane.

A historical cephalometric study completed on GE found that there was a tendency for the ANB angle to decrease following the observation period of GE as a result of an increase in the SNB angle.[23] Our study also found that there was a trend to an increase in the SNB angle, however it was not a statistically significant treatment effect and was therefore most likely the result of normal growth.

Our study found that there was a statistically significant decrease in all our skeletal vertical measures of the face in the overall sample and in the Class I and normal vertical subgroups. These two subgroups comprised the majority of our study sample. If we had found the same increased SNB and concurrent decreased ANB angle we would be able to conclude that the GE technique effectively reduces the wedging effect of the posterior teeth through mesial drift of molars into extraction spaces that then allows mandibular autorotation, however we cannot. Perhaps, with a larger sample we would have found this result as the historical study to which we are comparing used a 200 subject sample.[23] Regardless of this discrepancy, we can still conclude that the GE technique does effectively reduce the vertical skeletal dimension. We found a mean decrease in the vertical skeletal measurements in the high angle sample however, the mean changes were not statistically significant. This is the subgroup in which these changes would be most advantageous. This may be a result of the limitation in sample size as there were only 7 subjects in the high angle GE subgroup.

We also found a statistically significant reduction in upper and lower lip procumbency for the overall sample and in the subgroups a reduction of the upper lip in class I sample and a reduction of the lower lip in the class II sample. This trend to reduce lip protrusion is congruent with the findings of previous studies of GE.[23]

We found statistically significant increases in intercanine width from T1-T2 of 1.9 mm in the maxillary arch and 3.2 mm in the mandibular arch. This change was in accordance with a previous historical study that considered arch width changes from adolescence to adulthood.[24] The study found that intercanine width increases in both arches during the transition from mixed to permanent dentition. The majority of our GE subjects had primary canines at T1 and those teeth were used as the landmarks to measure for intercanine width so it follows that the T2 intercanine width should increase given that the permanent canines had erupted. Also in agreement with historical GE studies, we found a statistically significant increase in overbite from T1-T2 of 1.4 mm.[1,7,9,11,13,23] This dental change may result in part due to the decreased vertical skeletal dimensions along with the retroclination of upper and lower incisors. Overjet increased statistically significantly from T1-T2, however by a clinically insignificant amount of 0.7 mm. The mandibular intermolar width decreased by 0.6mm. While this amount is not clinically significant, it does aid in validating the findings of Feldman et al.[13] who observed a tendency of the mandibular molars to tip lingually following GE. This decrease in intermolar width would be expected with lingual tipping of molars. The depth of both arches decreased from T1-T2, although the mandibular arch depth decreased by 3.3 mm in comparison to the maxillary arch depth which only decreased by 1.7 mm. This discrepancy in arch depth changes is most likely due the fact that the mandibular molar tended to mesialize by 1mm more than the maxillary molar in our sample.

Our model analysis revealed that these changes were consistent across all subgroups so only the model data analysis for the overall GE sample was provided in Table X.

B. **<u>Comparison of the Techniques</u>**

The average treatment length for the TM subject was on average approximately one year shorter than the average treatment length for GE. This only takes into account the phase I treatment time and not the total treatment time including comprehensive therapies completed after these techniques were completed. The TM subjects had active orthodontic forces applied for the duration of the treatment, while the GE therapy required simple observation following extractions. The only orthodontic appliances used on these subjects were Nance space maintainers in the maxillary arch for subjects with a class II molar relationship. The orthodontic appliances used for the TM technique were much more extensive. One advantage of GE is that no compliance beyond attendance at extraction and observation appointments is necessary, while compliance with multiple orthodontic appliances is absolutely critical to the success of TM.

Significant growth restriction of the maxilla was present in the TM sample as a result of the headgear used as part of the technique. Headgear has previously been shown to restrict maxillary growth.[25] Maxillary growth was restricted in both the class I and class II samples despite non-orthopedic force levels being utilized in the technique for class I subjects.[2] The average ANB for the class II sample was reduced from 5.6 at T1 to 3.9 at T2. The overall sample for TM subjects also displayed a statistically significant decrease in the SNB angle, likely resulting from an opening rotation of the mandible caused by the distalization of the maxillary and mandibular molars inducing a wedge effect on the mandible. However, the maxillary growth restriction resulted in greater reductions in the SNA than reduction in SNB so the ANB angle was statistically significantly reduced. GE subjects did not show any statistically significant changes in the AP skeletal landmark measures.

The TM subjects had an average clockwise rotation of the palatal plane of 2.3 degrees which can be attributed to the direction of force applied to maxillary bone by the headgear.[26] The palatal plane was static in the GE subjects. Interestingly, both techniques caused a counterclockwise rotation of the occlusal plane. In fact, the mean differences in the occlusal plane changes from T1-T2 for the overall samples of both did not display statistically significant differences. This indicates that they cause quantitatively equivalent occlusal plane flattening. This may be attributed to the force applied to the maxillary molars as a result of the long outer bow of the headgear being tipped up to place a mesial crown tipping force meant to counteract the distal crown tipping action of the distalizing headgear force.[2,26,27] Despite the efforts to reduce distal tipping, there was a trend for the maxillary molars to tip distally, although not by a statistically significant amount in the overall sample. The class II subjects displayed statistically and clinically significant 2.6 degrees of distal molar tipping while the class I subjects experienced a statistically significant, but clinically insignificant 0.7 degrees of distal molar tipping. Perhaps this was a result of the different force levels used in class I and class II TM subjects.[2] With higher forces used in class II subjects, the balancing force generated from the tipped facebow may not have been sufficient to overcome the orthopedic forces used in the class II subjects. Figure 2 helps visualize these molar tipping findings to provide an explanation for why the TM subjects experienced occlusal plane flattening despite the distal molar tip that should have resulted in occlusal plane steepening. There was an extrusion of the upper molar paired with lower molar intrusion. The occlusal plane was established by creating a line of best fit from the molar occlusion to the incisal overbite[17] and because the upper molar extruded while the lower molar intruded, the point of molar occlusion moved inferiorly, flattening the occlusal plane.

The vertical skeletal measures were where some of the most striking differences in the effects of the two modalities are noted. The overall sample of TM subjects had an average increase in FMA of 1.6 degrees and average increase of SN-MP of 2 degrees. Both of these measures were statistically significant. The opposite effect was seen in the vertical skeletal dimension for GE subjects. The FMA and SN-MP were reduced by 1.4 and 1.4 degrees respectively in the overall sample. These measures were statistically significant. These same treatment effects were seen in each subgroup for each modality, however not every subgroup resulted in statistically significant changes. The GE high vertical angle subgroup did not benefit from a statistically significant reduction in vertical skeletal measures. Despite having adequate statistical power in the overall sample, our anteroposterior and vertical subgroups have significantly smaller group sizes and the findings in these groups do not carry as much statistical weight as the findings made in the overall sample. With a larger sample of high angle subjects treated with GE, we likely would find that the vertical measures would statistically significantly decrease from T1-T2. This is a future area of study that could be a follow up to this project.

We postulate that the effects each treatment had on the upper and lower molars was paramount to the vertical treatment effects of both modalities. TM distalized upper molars in the overall sample by 1.4 mm and lower molars by 0.9 mm, thereby wedging the jaws open causing a clockwise rotation of the mandible. GE caused 2.6 mm and 3.5 mm of mesialization for upper and lower molar respectively, causing a counterclockwise rotation of the mandibular plane by a reduction of the molar wedge. The distalization of the upper and lower molars in TM was not of a statistically significant amount in the overall sample. The class I subjects experienced on average a statistically significant 2.2 mm of distal molar movement while the class II subjects experienced a statistically and clinically insignificant 0.9 mm of distal molar movement. This may again be attributable to the force modulation used by Dr. Haas depending on their AP skeletal growth pattern.[2] The class I subjects experienced molar distalization while the class II subjects did not because the forces applied to class I subjects' molars via the headgear was of a dental, not orthopedic, force level. This discrepancy in the subgroups explains why the overall sample did not show a statistically significant amount of upper molar distalization.

As noted previously, the GE technique retroclined upper and lower incisors. Upper incisor angulation was unchanged by TM in the overall sample. Previous studies have shown maxillary incisor retroclination to be a side effect of headgear use.[25] An explanation for the lack of maxillary incisor tipping may have been that the space gained from expansion and posterior dentition distalization created adequate space to uncrowd incisors without changing their angulation. We did not include any measures for AP positioning of incisors in our cephalometric analysis, however, Figure 2 indicates that there was a distalization of the upper incisors with TM. This indicates that a bodily movement of these teeth occurred. Figure 2 shows no distalization of the maxillary incisors in GE, but it confirms the maxillary incisor retroclination found in our statistical analysis.

Unexpectedly, as it was not reported in the previous cephalometric studies of TM, TM statistically significantly retroclined the lower incisors in the overall sample, class II subgroup and high vertical angle subgroup. The overall sample experienced an average of 5.0 degrees of lower incisor retroclination, likely resulting from the forces placed on the lower incisors from the class III elastics.[27] When comparing the effects of the overall samples to each other, the TM technique caused significantly more retroclination of lower incisors than GE, whose overall sample experienced an average of 3.0 degrees of retroclination. To our knowledge, this is the first time this treatment effect has been reported in the literature. This same trend was seen in all TM subgroups, with statistically significant mean changes in the class II and high angle subgroups.

The measures of soft tissue profile convexity in our analysis did not provide overwhelming evidence that either modality had a significant effect, statistically or clinically, on soft tissue profiles in the overall sample. The angle of facial convexity established by the angle formed between the Frankfort Horizontal and soft tissue Nasion-Pogonion planes showed statistically significant different means between T1-T2 for GE subjects. This angle only increased by 1.3 degrees, which, while statistically significant, is not large enough to have a visibly noticeable effect on a soft tissue profile. The variable indicates that soft tissue Pogonion tended to move forward with GE, thereby decreasing the soft tissue convexity. The Z-Angle increased by 3.5 and 4.4 degrees for TM and GE respectively. When comparing these mean treatment effects to each other, our statistical analysis determined the mean changes to be of a statistically equal magnitude. These changes confirm that the most procumbent lip tended to retract in both modalities and that a flattening of the profile due to lip retraction tended to be the predominant soft tissue response. This is confirmed by our variables that quantify the changes in lip position. Both modalities caused statistically significant retraction of the upper and lower lips compared to the E-Plane. Surprisingly, the TM technique caused statistically significantly greater retraction of the upper lip and equivalent retraction of the lower lip. A likely explanation is the retraction of the entire maxillary denture resulting from the distalizing force of the headgear on the maxilla as indicated by the reduction in SNA for all TM subjects.[25]

Given these differences in treatment effects, the two most important dimensions to consider when deciding which of these modalities to select for a patient are the anteroposterior and vertical dimension. Given the orthopedic benefits of the TM technique it has the obvious advantage of restricting maxillary growth and allowing for an improvement of a class II skeletal relationships. GE does not have any appreciable changes on the maxillofacial complex in the AP direction and therefore would not be the best tool if orthopedic correction for a class II skeletal relationship is needed. These two modalities have opposing effects on the vertical dimension of the face. The forces applied by TM increases the vertical dimension of face and therefore may be most efficient at treating patients with low angle malocclusions or those who start with excessive dental overbite. GE has the opposite effect, and may be the most beneficial in treating patients with an increased vertical dimension and/or open bite tendency. GEs ability to cause counterclockwise mandibular plane rotation and increase overbite without any orthodontic intervention aside from space maintainers is a very simple technique to manage a problem which may be difficult to manage in comprehensive orthodontic treatment.

C. **Limitations**

There exist certain limitations with retrospective cohort studies. Despite our efforts to reduce the risk of bias in subject selection by requesting that the two contributing clinicians provide records from consecutive patients, the risk of bias is still inherent within the study design. Also, despite running tests to confirm inter and intra examiner reliability in cephalometric tracing and cast model analysis, there still exists the risk of tracing and measurement error in the study which could alter our results.

The size of the samples was a further limitation for our study. While our sample size provided enough statistical power to compare the overall samples, our subgroups, especially the high vertical subgroups, had rather small number of subjects. A larger number of subjects in each subgroup would provide valuable further insight into these treatment modalities as we could provide more statistically powerful results based on individual growth patterns.

In addition, we only had T2 models available for the GE sample. No evaluation of treatment effects for TM could therefore be made and no comparison of the effects could be made to those of the GE sample.

VI. CONCLUSION

- GE has an average longer treatment time than TM due to the necessity of an observation period during permanent tooth eruption following the prescribed extractions.
- TM produces orthopedic forces that restricts maxillary anteroposterior growth and rotates the palatal plane in a clockwise direction. GE does not result in any skeletal changes in the AP plane.
- TM increases the vertical skeletal dimension of the maxillofacial complex through clockwise mandibular plane rotation while GE reduces the vertical dimension through a counterclockwise rotation of the mandibular plane.
- Both TM and GE rotate the occlusal plane counterclockwise.
- TM bodily distalizes maxillary incisors and retroclines lower incisors. GE retroclines upper and lower incisors.
- TM distalizes and tips upper and lower molars distally. GE mesializes upper and lower molars and lower molars tip distally as a result of the mandibular plane counterclockwise rotation.
- No clinically relevant changes in soft tissue convexity resulted from either modality.
- Both TM and GE reduce upper and lower lip procumbency. TM retracts the upper lip to a greater extent than GE.

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APPENDICES

APPENDIX A

UIC Institutional Review Board Approval
Approval Notice
Initial Review – Expedited Review

January 17, 2019

Michael Seelig, DMD
Orthodontics
Phone: (314) 306-0003 / Fax: (312) 996-0873

RE: Protocol # 2019-0001
"A cephalometric comparison of guidance of eruption therapy and tandem mechanics in the Class I patient"

Dear Dr. Seelig:

Members of Institutional Review Board (IRB) #1 reviewed and approved your research protocol under expedited review procedures [45 CFR 46.110(b)(1) and 21 CFR 56.110(b)(1)] on January 10, 2019. You may now begin your research

Your research meets the requirement(s) for the following category - Expedited Review Approval Category 45 CFR 46.110(b)(1)

(5) Research involving materials (data, documents, records, or specimens) that have been collected, or will be collected solely for nonresearch purposes (such as medical treatment or diagnosis).

Please note the following information about your approved research protocol:

Protocol Approval Period: January 10, 2019 - January 9, 2022
Approved Subject Enrollment #: 400
Additional Determinations for Research Involving Minors: The Board determined that this research satisfies 45CFR46.404 research not involving greater than minimal risk. This is a retrospective chart review.
Performance Sites: UIC
Sponsor: None
Research Protocol(s):

a) A cephalometric comparison of guidance of eruption therapy and tandem mechanics in the Class I patient; v1, 12.12.18

Informed Consent(s):

a) Waiver of Informed Consent granted under [45 CFR 46.116(d)

HIPAA Authorization(s):

APPENDIX A (continued)

a) Waiver of HIPAA Authorization Granted Under 45 CFR 164.512(i)(1)(i)

Please note the Review History of this submission:

Receipt Date	Submission Type	Review Process	Review Date	Review Action
01/02/2019	Initial Review	Expedited	01/10/2019	Approved

Please remember to:

→ **Use only the IRB-approved and stamped consent document(s) enclosed with this letter when enrolling new subjects.**

→ Use your **research protocol number** (2019-0001) on any documents or correspondence with the IRB concerning your research protocol.

→ Review and comply with all requirements on the enclosure,
"**UIC Investigator Responsibilities, Protection of Human Research Subjects**"
(http://tigger.uic.edu/depts/ovcr/research/protocolreview/irb/policies/0924.pdf)

Please note that the UIC IRB has the right to ask further questions, seek additional information, or monitor the conduct of your research and the consent process.

Please be aware that if the scope of work in the grant/project changes, the protocol must be amended and approved by the UIC IRB before the initiation of the change.

We wish you the best as you conduct your research. If you have any questions or need further help, please contact the OPRS office at (312) 996-1711 or me at (312) 996-0865. Please send any correspondence about this protocol to OPRS at 203 AOB, M/C 672.

Sincerely,

Camonie J. Johnson
IRB Coordinator, IRB # 1
Office for the Protection of Research
Subjects

cc: Jennifer Caplin,
Budi Kusnoto, Orthodontics, M/C 841
Privacy Office, Health Information Management Department, M/C 772

APPENDIX B

Approval to Release Records From Dr. Haas

To Whom It May Concern:

I hereby grant permission to Dr. Michael Seelig and his research team to use cephalometric radiographs taken in my office for his study, "A cephalometric comparison of serial extraction and tandem mechanics". I certify that all radiographs were taken in my office as a component of the standard records required on all patients prior to orthodontic treatment, and that no radiographs were taken for research purposes.

Sincerely, Andrew J. Haas

APPENDIX C

Approval to Release Records From Dr. Stoner

To Whom It May Concern:

I hereby grant permission to Dr. Michael Seelig and his research team to use cephalometric radiographs taken in my office for his study, "A cephalometric comparison of serial extraction and tandem mechanics". I certify that all radiographs were taken in my office as a component of the standard records required on all patients prior to orthodontic treatment, and that no radiographs were taken for research purposes.

Sincerely,

APPENDIX D

Raw Data

TM Descriptives and Subgroup Raw Data					
PT	Gender	Race	Age	AP subgroup	Vertical subgroup
1	1	3	10.11	2	excluded from vertical
2	2	1	9.7	1	1
3	1	1	10.11	1	1
4	2	1	11.11	2	2
5	1	1	14.4	2	1
6	2	1	9.11	1	1
7	2	1	10.1	2	1
8	1	1	11.3	2	2
9	2	1	13	2	2
10	2	1	8.9	2	2
11	2	1	10.6	2	excluded from vertical
12	2	1	9	2	2
13	1	1	13.3	1	1
14	1	1	7.11	1	1
15	1	1	9.11	1	1
16	2	1	13.6	2	1
17	1	1	10.1	1	1
18	2	1	12.1	2	2
19	1	1	10.4	1	1
20	2	1	11.3	1	2
21	2	1	10.1	1	2

APPENDIX D (continued)

22	2	1	10.1	1	1
23	2	1	9.5	1	1
24	1	1	10.1	2	2
25	2	1	9_10	2	2
26	1	1	11.6	2	1
27	1	1	12.3	1	1
28	2	1	10.5	1	1
29	2	2	13.3	1	1
30	2	1	12.4	2	2
31	2	1	10.9	1	1
32	1	1	9.8	2	1
33	1	1	11.7	1	1
34	1	1	14_10	2	1
35	2	1	10.5	2	2
36	1	1	12	2	2
37	1	1	7_10	2	2
38	1	1	9_10	2	2
39	2	1	11.9	2	1
40	2	1	10_10	1	1
41	1	1	13.4	2	2
42	2	1	11.5	1	1

APPENDIX D (continued)

TM Pre-treatment Cephalometric Data															
	Hard tissue														
PT	SNA	SNB	ANB	FMA	PP-SN	SN-MP	OP-SN	U1-SN	L1-MP	Holdaway ratio	U6-PT	L6-PT	U6-SN	L6-SN	LFH/TFH
1	84.9	79.9	5	17.7	5.7	24.4	16	108.2	98.9	0.5	9.6	9.4	75.2	-55.7	57.2
2	82	78.5	3.5	24.3	5.7	31.3	15.7	109.6	96.5	0	11.4	13	73.1	-56	54
3	76	72.3	3.7	24	10.8	35.7	21	92.2	89.5	1.1	10.2	8	69.9	-52.9	53.5
4	76.9	71.1	5.8	36.9	11.8	45.7	26	88	83.4	0.2	11.9	13.7	58.7	-59.8	53.4
5	78.9	72.7	6.1	26.6	8.3	35.3	16	114.3	95.4	0.9	12.1	9.2	71.1	-63.3	50.8
6	77.9	76.8	1.1	27.7	8.4	32.5	22.4	99.1	85.7	-34.5	6.2	7	67.9	-56.5	53.7
7	77.9	73.5	4.4	24.3	9.9	34.2	14.4	97.5	95.1	0.6	11.7	8.8	75	-52.7	52
8	78.4	73.9	4.5	29	5.3	39	21.5	96.4	81.9	1.4	13.9	14.7	66.3	-60.5	57
9	80.3	73.9	6.4	28.5	13.7	40.6	24.8	88.2	95	0	13.8	13.9	59.7	-55.5	51.6
10	78.9	72.8	6.2	26.7	9.8	38.5	22.2	97.1	81.7	0.9	11.1	9.1	61.6	-50.6	54.8
11	87	81.9	5	16.1	4.8	21.6	9	107	95.2	0.9	16.1	11.9	72.3	-56.9	53.3
12	75.6	70.2	5.4	37.7	11.1	47.3	28	91.9	86.6	0.1	7.9	7.9	65.5	-65.1	54.5
13	82	78.3	3.7	20.1	5	29.6	14.3	102.4	91	1.3	17.5	18.6	82.8	-58.3	57.1
14	80.1	76.9	3.2	22.6	7.2	29.3	12.3	102.5	76.2	-1.3	8.2	8.1	65.7	-49.7	51.6
15	77.3	76	1.3	22.6	7.8	29.4	19.3	93.1	88.2	4.1	7.7	7.2	72.5	-56.8	55
16	82	77.2	4.9	30.1	11.7	35.2	14.7	103.1	95.2	0.1	15.8	16.4	74.3	-63.6	52.5
17	77.3	74.4	2.8	24.5	11.1	32.9	20	98	90.9	1.1	12.5	11.2	64.7	-62.1	53.1
18	84	78.7	5.3	32.5	6.9	37.5	14.3	109.9	99.5	0	13.5	14.1	73.6	-59.1	55.4
19	79.6	75.8	3.8	28.9	9.6	36.5	19.2	106.8	95.5	-0.2	15	13.2	70.4	-57.6	56.8
20	76.3	72.3	3.9	25.8	12.4	39.7	20.7	100.6	92.8	0.1	16.4	16	65.4	-55.3	52.6
21	74.9	72.9	2	32.2	12.1	41.2	27.4	109.6	100	-0.1	11.8	11.8	55.3	-58.8	53.3
22	75.2	74.5	0.7	30	12	34.6	21	106.8	90.5	-0.1	10.2	12.5	69.4	-48.7	53.1

APPENDIX D (continued)

23	75.9	73.8	2.1	30.3	5.6	36.6	20.7	103.3	94.6	0.2	8.4	8.5	65.9	-53.7	55.5
24	77	72.9	4.1	31.6	3.6	37.6	22.3	97.8	95.8	0.2	12.7	14	64.3	-52.4	58.2
25	76.9	71.8	5.1	34.4	11	45	21.4	114.9	79.5	0.5	10.5	11.7	61.7	-56.8	52.7
26	86	78.9	7.1	26.1	8	36.9	20.7	100.7	91.7	-0.2	16.9	17.6	74.2	-53.1	55.5
27	77.5	73.5	4	28.6	12.9	36.6	17.2	106.7	98.2	0	18.1	15	66.4	-62.9	51.8
28	77.7	75.4	2.3	25.3	6.3	35.8	18.7	101.3	85	0.9	13.4	12.2	73.8	-50.2	56
29	75.4	74.1	1.4	25.4	8.9	36.4	19.3	101.3	91.4	0.2	13.7	13.3	74.1	-63.1	54.3
30	74.5	70.3	4.2	30.1	7.9	40	23.8	110	99.6	0.1	8.5	8.7	60.5	-57.8	56.7
31	82.8	79.6	3.1	29.7	5.8	33.8	19.8	102.6	88.1	0.7	12.3	12.6	76.2	-60.5	55.8
32	80.3	75.2	5	20.2	8.1	31.5	24	87.6	87.8	0.3	8.5	8.8	63.5	-50.6	54.3
33	84.9	80.9	4	24.6	4.7	28.3	17.5	100.2	94.7	0.5	17	17.7	74.6	-63	55.5
34	83.9	78.9	5	18.9	5.3	27.7	15.1	100.3	89.9	0.8	25.9	23.6	77.4	-67.1	54.5
35	73.5	66.1	7.4	29.8	12.3	42.8	25.8	95.4	91.4	0.2	8.6	6.3	60.8	-49.8	56.1
36	78.4	73.2	5.2	31.1	7.7	43.4	27.2	91.3	86.9	0.1	18.8	19.2	69.8	-59.2	55.4
37	81	71.4	9.6	26.2	7.5	37.2	20.5	111.1	97.6	0	13.9	11.5	68.2	-56	55.4
38	76.1	69.5	6.6	30.5	10.5	41.2	28.5	92.1	93.3	0.1	9.7	8.6	57.3	-55.5	55.2
39	78.7	72.7	6	29.1	8	36.6	21	102.3	91.1	-0.5	12	10.3	67.2	-57.1	52
40	81.2	78.5	2.7	27.2	7.8	33.9	16.7	107.4	91.4	-0.1	14.3	15.8	75.8	-53.5	57
41	78.6	73.1	5.5	31.2	5.7	40.5	22.3	101.6	88.3	0.5	19.6	15.5	70.5	-61.3	55.5
42	75.1	73.7	1.5	20.6	12.6	34.7	22.2	94.6	91.7	1.5	12.6	15	69.3	-60	51.6

APPENDIX D (continued)

TM Pre-treatment Cephalometric Data					
	Soft Tissue				
PT	Facial Convexity	Legan Convexity	Z-angle	Upper lip-E Plane (mm)	Lower lip-E plane (mm)
1	89.3	156	68.2	-1.5	1
2	87.3	166.8	63	0.3	2.8
3	87.2	168.2	76.4	-0.6	-1
4	80.9	164.4	60.2	0.9	1.9
5	84.8	153.2	55.6	1.6	2.6
6	86	174.2	85.3	-5.4	-4.8
7	86	155.2	67.8	0.1	0.2
8	87.6	170.9	73.9	-0.6	0.2
9	87.6	152.1	59.1	-0.4	2.5
10	86.1	162.9	84.4	-2.5	-5.1
11	91	172.5	65.2	0.9	2.3
12	81.4	160.1	60.9	0.8	1.3
13	90.6	165.7	74.8	1.3	0.2
14	86	172.4	79.5	-2.2	-3.2
15	87.7	170.8	72	0.2	0.1
16	84.4	162.9	74.1	-2.5	-2.3
17	86.6	166.3	78	0	-1.6
18	84.9	165.7	55.4	2.7	6.1
19	83.8	165	53.7	3	5.1
20	88	165.8	73.9	0.4	0
21	82.4	172.4	55.6	3.8	6
22	81.1	166.4	61	0	1.9

APPENDIX D (continued)

23	82.2	166.7	60.9	-2.2	1
24	81.3	159.4	55.7	1	2.4
25	84	160.3	59.2	-0.7	1.8
26	89.9	158.4	65.5	0.7	2.3
27	83	159.7	55.9	2.3	4
28	88.5	166.7	73.5	-3	-0.4
29	88.2	172.2	79.4	-1.8	-1.2
30	82.2	166.3	62.9	1.5	3.7
31	85.8	165.7	69.9	0.3	0.3
32	89	163	71.2	1.5	0.1
33	87.1	166.3	75	-3	-1.5
34	89.4	163.8	76.1	-1.4	-0.6
35	81.6	160.9	54.2	1	3
36	87	161.1	72.8	-3.1	-0.8
37	83.9	157	56.9	5.4	3.7
38	81.9	164.9	54.3	2.4	3.9
39	80.9	160.4	65	-0.3	-1
40	86.7	170.1	75.5	-2.7	-0.4
41	84.7	164.7	63.5	0.5	3.6
42	91.7	172.8	87.3	-4.3	-4.4

APPENDIX D (continued)

TM Post-treatment Cephalometric Data															
	Hard tissue														
PT	SNA	SNB	ANB	FMA	PP-SN	SN-MP	OP-SN	U1-SN	L1-MP	Holdaway ratio	U6-PT	L6-PT	U6-SN	L6-SN	LFH/TFH
1	83	78.2	4.8	20.9	6.1	28.8	16.5	101.9	84.4	1.6	5.7	7.4	58.9	-66	55.5
2	79.2	75.7	3.5	22.5	8.2	32.6	15.3	110	91.9	0.3	10.8	12.3	65.7	-59.6	52.1
3	75.4	72.7	2.7	24.9	12.9	35.7	20	102.9	97.3	0.6	8.5	8.8	68.5	-55.6	52.5
4	75.1	72.8	2.3	38.9	12.9	47.2	17	111.4	67.1	0.4	9.9	11.1	64.4	-62.5	54.5
5															
6															
7	74.7	72.7	2	26.9	11.9	36.7	8.9	103.3	79.9	4.6	8.3	8.8	77.9	-54.4	51.5
8	76.4	73.3	3.1	35.5	6.8	41	18.5	101.5	83	1.1	6	7.5	57.3	-55.7	56.2
9	80.2	72.5	7.7	28.7	19.1	48.9	25	89.4	83.1	-0.1	12.3	10.8	64.7	-53.7	51
10	74.6	70.9	3.7	27.4	14.9	40.4	24.3	98.6	95.5	0.3	9.2	9.9	55.3	-58.4	52.4
11	83.4	80.7	2.7	18.9	9.3	22.9	8.7	114.6	81.1	-1.6	13.3	8.4	73.6	-60.7	51.4
12	74.6	70.7	3.9	34.7	13.1	46.3	25	90.1	85.5	0.2	10.1	9.4	70.6	-62	53.2
13	untraceable														
14	75.1	74.8	0.3	20.7	11.6	31.7	14.9	110.4	72.4	-1.9	4.6	8.5	49.2	-61	51.4
15															
16															
17															
18															
19	77.2	74.4	2.8	30.6	9.2	38.6	18.6	98.5	93.7	-0.2	11	11.9	60.2	-61.8	57.3
20	73.6	72.8	0.7	29.4	19.1	41.5	20.7	102.1	88	-0.1	9.3	11.3	67.9	-61.4	51.2
21	71.7	69.9	1.8	36.5	15.2	47.6	18.8	100.5	77	0.1	9.3	8.1	80.5	-59.8	54
22	72.7	71.1	1.6	32.5	14.1	40	17.8	111	82.8	0.7	11	9.3	69.6	-58.9	52.8

APPENDIX D (continued)

23															
24	72.6	68.6	4	33.2	6.3	42.3	24.3	92.3	74.5	-24.4	8.7	6.1	61.3	-62.3	56.2
25															
26	80.1	76.1	4	28.6	12.7	40.3	12	101	74.6	0.2	13.6	12.9	70.2	-65.6	53.5
27	76.2	74.1	2.1	28.6	16	38.2	18.9	104.7	100.5	0	15.1	14.3	65.5	-67.3	53.3
28	77.1	75.6	1.5	27.3	6.2	35	16.6	110.7	96.4	0.5	14.1	13.2	70.2	-60.8	56.6
29	74.8	73.6	1.2	26.1	10.3	36.9	19.2	105.8	100.4	0.1	13.2	13.7	72.9	-65.1	54.1
30	71.5	67.4	4.1	31.2	11.6	40.1	25.5	81.1	81.8	2.6	5.5	3.7	48.6	-60.4	53.7
31															
32															
33	84.7	81.1	3.5	22.9	3.1	27.2	10.5	103.4	101.5	0.2	17.7	17.1	78.1	-73.7	56.4
34	82.8	79.2	3.7	19.4	6	28	14.6	99.7	97.4	0.4	67.4	65.2	74.5	-178.8	55.1
35	74.6	67.5	7.1	31.8	12.5	41.6	22.8	91.6	83.3	0.5	5.1	2.9	59.6	-54.7	55.4
36	75.8	74.1	1.7	32.3	7.5	40.9	23.7	98.6	91.7	0.2	15.7	16.2	71.8	-60.7	54.6
37	73	68.5	4.4	30.8	14.7	43.5	20	94	91.4	0.3	3.8	7.1	50.8	-64.6	52.7
38	71.2	69.3	1.8	30.9	13.8	43	23.4	97.3	90.4	0.2	7.6	8	65.1	-61	54
39	75	70.1	4.8	28.3	9.6	39.1	21.3	94	94.1	0	5.7	9.9	65.8	-54.4	53.3
40															
41															
42	74.1	73.9	0.2	27.8	11	36.3	16.7	95.1	71.4	-1.9	7	4.4	70.3	-63.7	52.9

APPENDIX D (continued)

TM Post-treatment Cephalometric Data					
	Soft tissue				
PT	Facial Convexity	Legan Convexity	Z-angle	Upper lip-E Plane (mm)	Lower lip-E plane (mm)
1	89	158.1	68.3	-1.4	0.1
2	88.3	168.2	69.3	-0.7	0.8
3	87.1	167.3	75.2	-2.9	-2
4	82.2	167.1	65.4	0.1	0.7
5					
6					
7	85.6	158.3	72.5	-2.7	-2
8	82.5	173.8	74.4	-3	-1.3
9	93.5	153.8	65.9	1	2
10	86.6	164.1	78.2	-4.9	-3.5
11	87.9				
12	84.5	162.1	65.3	-2	0.1
13					
14	89.8	176.1	95.8	-4.9	-7.9
15					
16					
17					
18					
19	82.6	166.4	62.2	0.5	2.9
20	85.9	166.1	74.2	-2.6	-1.8
21	82.1	169.3	53.1	2.7	3.8
22	80.4	166.3	62.2	-2.2	0.8

APPENDIX D (continued)

23					
24	80.2	155.9	59.9	0.2	1.2
25					
26	89.1	155	66.3	-0.5	0.2
27	84.9	161.1	69.5	-0.3	0.6
28	86.5	167.5	79.8	-5.7	-2.9
29	87.5	172.8	79.1	-3.2	-0.8
30	80.3	166	66.8	-2.2	-0.2
31					
32					
33	87.7	163.7	74.4	-4.6	-1.6
34	90.3	166.3	83.1	-12.1	-11
35	80.2	161.3	53	0.3	2.7
36	84.6	159	68.4	-2.9	-0.6
37	83.5	161.5	71.7	-1.9	-1.6
38	83.2				
39	83	163.4	72.1	-3.5	-1.4
40					
41					
42	86.1	173.1	85.2	-7.3	-5.5

APPENDIX D (continued)

GE Descriptives and Subgroup Raw Data					
PT	Gender	Race	Age	Skeletal AP subgroup	Skeletal Vertical subgroup SN-MP
1	2	1	9.2	1	1
2	2	1	8.9	1	1
3	2	1	9.2	2	1
4	1	1	9.11	2	2
5	1	1	7.6	2	1
6	2	1	8.1	1	2
7	2	1	8.3	2	1
8	2	1	8	1	2
9	1	1	8.8	1	1
10	1	1	10.9	1	1
11	2	1	9.5	1	2
12	2	1	8.4	2	exclude
13	2	1	7.8	2	1
14	2	1	7_10	2	2
15	2	1	8.6	1	1
16	1	1	10.1	1	1
17	2	1	8.11		
18	2	1	8_10		
19	1	1	11.3	1	1
20	2	1	12.6	1	2
21	2	2	9.3	2	1
22	1	1	10.5	1	1
23	1	1	9	2	1

APPENDIX D (continued)

24	2	1	10.6	1	
25	2	1	9.3	1	1
26	2	1	9.6	2	2
27	1	1	10.7	1	1
28	1	1	8.7	2	1
29	1	1	12	1	1
30	2	1	9.2	2	1

APPENDIX D (continued)

GE Pre-treatment Cephalometric Data															
	Hard tissue														
PT	SNA	SNB	ANB	FMA	Palatal plane-SN	SN-MP	Occlusal plane-SN	U1-SN	L1-MP	Holdaway ratio	U6-PT (mm)	L6-PT (mm)	U6-SN	L6-SN	LFH/TFH
1	82.3	78.3	4	24.7	6.5	30.3	18.1	98.4	93.7	-0.1	9.5	10.5	66	-44	58.3
2	76.8	73.5	3.3	23.2	12.1	32.1	23	89.8	78.7	-1.3	9.2	9	66.6	-55.6	53.8
3	83.6	79.3	4.3	31.8	5.2	36.2	21	97.7	82.5	0.6	8.8	9.3	67	-50.9	56.8
4	75.5	71.2	4.3	33.9	11.6	41.9	25.3	98	93.5	0.1	10.6	10.8	67.9	-54.6	54.4
5	84.2	76.9	7.3	28.3	5.7	33.8	19.7	113.1	98.4	-0.5	14.5	12.9	68.3	-50.5	55.4
6	72.7	68.7	3.9	34.1	13.4	46.2	22.3	101.9	83.2	0.4	7.5	6.9	57	-53.7	53.4
7	86.2	79.8	6.3	29.7	8	34.1	17.2	103.9	96.3	-0.5	12.4	11	70.8	-47.1	55.3
8	87.5	83.7	3.8	29.2	8	37.9	20.3	109.9	92.3	-0.3	13.5	14.3	71.1	-50.3	56
9	78.4	75.2	3.2	25.3	9.7	36.6	21.3	107.1	95.3	0.2	10.6	11.1	71.8	-53.9	55.3
10	78.5	76.9	1.6	24.3	10.4	35	19.9	108.1	88.5	-0.1	15.3	14.7	73.2	-54.6	54
11	78.8	77.2	1.7	29.1	7.6	40.9	21.6	92.4	67.9	0.5	12.1	12.9	62.2	-52.4	54.9
12	86.4	80.1	6.2	24.3	4	24.2	12.9	117.4	102.1	-0.4	7.9	5.6	75.3	-48.7	56.8
13	83.6	77.1	6.6	26.2	7.9	33.9	20.4	90.9	84.1	0.8	10.3	9.5	67.9	-53.7	52.5
14	80.4	73.3	7.1	27.4	10	38	20.1	107.6	88.6	0.3	10.1	8.4	65.8	-53.7	51
15	79.9	76.7	3.2	21.4	6.7	29.5	16.3	103.3	92	0.4	14.3	13.8	72.5	-50.7	54.7
16	71.6	71.5	0.1	20.5	13.8	35.3	25.9	80.8	75.4	-1.1	11.9	11.6	70.4	-46.6	53.9
17															
18															
19	74.1	74	0.1	25.9	5.3	36.4	23.6	104.5	89.2	1.1	8.7	8.8	69.8	-52.9	57.6
20	75.7	72.5	3.2	33.6	9.4	40.9	19.8	98.3	86.1	0.3	9.8	6.7	55.6	-62.6	57.2
21	80.2	75.3	4.9	27	6.3	31.3	19.4	99.6	95.3	0	7.1	4.9	66.2	-54.3	54.3
22	80.6	77.6	3	27	8.2	33.1	17.7	105.5	80.2	10.6	8.6	9.7	72.5	-49.8	52.1

APPENDIX D (continued)

23	82.3	75.8	6.5	25.5	7.1	34.4	19.2	117.9	107.2	-0.1	12.1	8.9	64.7	-52.6	55.2
24	76.2	75.4	0.9	13	5.8	18.2	3.5	83.5	83.9	-0.6	9.2	10.6	75.6	-53.2	53.1
25	79.5	78.4	1.1	25.5	1.9	31.4	16.3	101.8	85.9	1.1	10.3	9.7	67.6	-53.7	57.8
26	76.2	71.6	4.6	31	12.2	41.4	21.3	101.3	91.3	0	12.8	11.6	64.3	-52	52.5
27	85.4	83.8	1.6	21.1	10.8	28.4	14.5	107.1	86.1	0.5	15.9	17.2	76.5	-53.5	52.2
28	77.4	72.4	5	27.4	10	36.1	19.7	86.9	90	0.6	7.3	7	63.1	-39.8	53.8
29	76.8	75.4	1.3	13.7	13.3	27.1	17.5	100.6	94.7	1	16.8	17.7	69	-60.5	52.8
30	84.7	80.5	4.3	22	8.6	29.6	16	103.6	93.1	0.2	14.2	15.2	73.6	-54.3	55.7

APPENDIX D (continued)

GE Pre-treatment Cephalometric Data					
	Soft Tissue				
PT	Facial Convexity	Legan Convexity	Z-angle	Upper lip-E Plane (mm)	Lower lip-E plane (mm)
1	85.1	159.9	71.9	-3.4	-1.8
2	86.2	168.1	75.8	-1.4	-1.8
3	85.1	174	66.5	-1.7	1.5
4	81.1	160.6	51.3	2.2	4.2
5	82.3	161.8	57.7	4.4	3
6	82.2	162.9	69	-2.1	-0.9
7	84.5	157.6	58.4	3.2	3.5
8	92.8	174.2	77.2	1.7	1.3
9	87.9	161.6	67.4	-0.6	1.3
10	89.1	170.3	71.4	0.2	2
11	90	167.9	84.6	-5.6	-3.6
12	81.5	158	55.2	3	3.5
13	87.2	159.4	73.2	-0.6	-1.2
14	85.6	158.8	63.4	1.1	1
15	86.8	166.1	67.1	-0.1	1.6
16	89.5	171.6	90.4	-6.7	-5.6
17					
18					
19	87.5	167.8	74.3	-1.5	-0.5
20	82	168.7	64.2	-0.7	1.4
21	81.9	156.2	57.4	0.5	2.5
22	86.3	165.9	71	-2.3	-0.7

APPENDIX D (continued)

23	86	163.2	50.2	4.7	5.6
24	85.4	170.8	70.2	-2.4	-0.2
25	86.9	172.5	80.1	-1.2	-2.1
26	83	162.7	65.1	-3.3	-0.3
27	93.2	168.4	74.3	-0.9	0.6
28	83.7	167.1	67.6	0.3	0.8
29	93.1	172.5	80.3	-2.3	-0.8
30	90	164.6	70.7	0.3	0.8

APPENDIX D (continued)

GE Post-treatment Cephalometric Data															
		Hard tissue													
PT	SNA	SNB	ANB	FMA	PP-SN	SN-MP	OP-SN	U1-SN	L1-MP	Holdaway Ratio	U6-PT	L6-PT	U6-SN	L6-SN	LFH/TFH
1	81	76.2	4.8	21.3	8.1	26.4	17.8	93.1	101.9	0.2	11.4	11.3	69.7	-48.8	53.7
2	73.7	72	1.8	22.6	12.6	32.9	19.1	83.6	78.8	-2.9	14.6	16.1	66.5	-63.7	54.1
3	82.9	81.1	1.8	26.7	4	34.2	16.9	101.8	81.3	1	17.4	17.5	74.8	-58.2	58.7
4	75.7	72.8	2.9	33.8	8.2	42.2	22.5	95.9	89.5	0.1	12.9	15.2	65.3	-59.1	56.9
5	82.8	76.3	6.5	26.9	4.8	33.8	15.3	112.1	107.1	-0.2	14.9	13.9	66.9	-56.4	55
6	73	69.2	3.7	34.8	13.6	45.3	25.1	95.2	82.7	0.9	7.4	7.5	62.6	-57	52.9
7	87.9	80.5	7.4	27.6	9.5	32.9	18.2	89.9	87.5	-0.5	16	16.1	72	-52	54.3
8	92.5	87.2	5.4	26	9.6	31.4	13.7	105.9	90.3	-0.1	11	12.8	68.1	-55.7	53.5
9	79	76.5	2.6	23.4	9.1	33.6	21.2	102.9	87.9	1	7.6	7.3	63.6	-56.2	55.2
10	82.6	79	3.7	21.7	7.9	31.3	16.2	106.3	88.8	0.3	19.5	19.3	70.2	-58.1	53.2
11	78	78.9	-0.9	25.3	6.9	36.5	18.6	93.5	62.2	-0.9	14.5	16.9	72.5	-58.1	55.1
12	85	77.6	7.5	19.6	4.1	22.2	10	109.9	103.2	0.1	12.7	11.4	74.6	-58	55.6
13	84.4	77.7	6.8	27.5	9.8	31.8	16.2	83.4	80.8	2	6.9	7.4	71.4	-58.8	49.4
14	81.7	73.8	7.9	26.2	8	34.8	15.8	108.7	91.9	0.5	10.8	10.1	61.3	-56.6	51.4
15	82.9	79.4	3.5	20.2	3.7	25.6	10.9	104.7	88.1	0.9	16.4	17.1	77.9	-56.4	55.3
16	73.5	74.1	-0.6	16.6	12.2	33.5	17.9	80	64.9	-0.8	16.7	17	70.2	-53	53.1
17	76.8	75	1.8	27.1	10.7	42.2	24.1	95.2	77.8	0.6	16.6	18.1	62.3	-56.5	55.8
18	82.7	79.1	3.6	18.4	4.9	23.4	13.9	94	93.9	2.3	13.5	14.8	72.6	-55.6	53.7
19	78.6	76	2.6	24.1	4.8	33.8	19.6	99.5	90.4	1.2	11.8	12.3	70.1	-57.3	57.4
20	76.6	72.4	4.2	31.8	11.8	41.1	21.3	94.9	82.9	0.2	12.1	9.5	56.4	-61.9	56.2
21	78.2	74.2	4	24.7	7.7	30.7	17.7	89.7	91.5	0.2	9.1	9.1	62.2	-57.6	53.7
22	79.4	77	2.3	23.1	9.7	34.2	17.2	94.8	76.7	-9.5	17.1	20.6	71.7	-58.8	51.1

APPENDIX D (continued)

23	82	74.9	7.1	25.9	8.4	36.1	18.6	111.9	99	-0.1	14.9	16.1	73.8	-58.1	53.9
24	79.7	76.1	3.6	10.2	4.3	14.8	10.5	81.2	81.8	-0.8	10.9	10.9	81	-51.2	51.7
25	79.1	78.2	0.9	24.8	4	31.7	17.8	100.5	79.5	18.6	13.1	13.4	64.3	-58.1	55.5
26	76.5	71.7	4.8	34.9	11.9	43	20.2	97.7	88.2	0	13.6	12.7	64.4	-54.2	51.4
27	85.9	84.4	1.5	23.1	10.5	26.5	18.9	99	76.9	-11.1	17.5	19.6	81.4	-53.3	52
28	77.3	72.9	4.4	25.7	12	36.4	13	79.3	79.8	6.7	14.6	17.1	77.4	-63.8	54.1
29	77.5	76	1.5	14.7	14.4	28	18.1	98.1	88.3	2.3	18.9	20.3	64.8	-62.2	52.6
30	84.4	81.2	3.1	22.1	8	30.1	14.2	99.4	87.1	0.7	19.3	20.4	77.4	-58.9	55.9

APPENDIX D (continued)

GE Post-treatment Cephalometric Data					
	Soft tissue				
PT	Facial Convexity	Legan Convexity	Z-angle	Upper lip-E Plane	Lower lip-E plane
1	84.3	154.4	64.8	-3	-0.4
2	87.3	170.3	84	-3.7	-5.2
3	91.1	170	74.4	-1.1	0.3
4	83.1	160.5	59.5	1.1	2.9
5	84	159	60.6	1.9	2.6
6	81.9	162.8	70.1	-3.7	-1.7
7	86.6	163.7	66.6	0.7	1.1
8	93.9	165.4	75.8	-0.9	1.4
9	89.5	162.5	71.3	-1.8	0.4
10	90.4	167	79.8	-1.2	-0.8
11	92.9	174	94.4	-7.7	-7.2
12	82.6	159.8	63.6	1	0.5
13	84.3	159.1	71.4	-2.5	-2.1
14	85.2	155.1	55.2	3.8	3
15	87.8	164.6	69.7	-0.2	0.5
16	94.8	173.4	99.4	-8.3	-7.5
17	92.2	165.3	80	-2.4	-1.3
18	88.6	169.3	78.6	-2.4	-2
19	89.9	170.5	82.4	-2.8	-2.2
20	83.9	168.3	67.8	-1.1	0.9
21	83.3	158.2	68.3	-1.1	-0.2
22	90.4	163.6	78.9	-3.4	-2

APPENDIX D (continued)

23	85.5	160.5	53.6	3.7	4.8
24	85.3	165.4	70.7	-1.4	-1
25	88.2	174.6	81.6	-1.8	-2.2
26	80.6	158.6	61.4	-2	0
27	91.5	168.7	73.1	-1.5	0.5
28	88.8	174.5	86.8	-5.5	-5.1
29	92.3	171.6	81.8	-3	-1.7
30	92.2	163.3	81.8	-2.8	-2.6

APPENDIX D (continued)

TM Pre-treatment Model Data															
PT	Molar Classification	Maxillary Arch Length	Mandibular Arch Length	TJ Maxilla	TJ Mandible	Upper Crowding	Lower Crowding	OB	OJ	Inter-molar width maxilla	Inter-molar width mandible	Inter-canine width maxilla	Inter-canine width mandible	Arch Depth Maxilla	Arch Depth Mandible
1	2	81.4	67.4	77.6	67.2	-3.8	-0.2	3.9	5.8	36.9	38.9	28.9	25.6	33.1	27.1
2	1	78.9	67	76.8	68	-2.1	1	3.1	4.8	41.5	41.1	28.2	24.5	28	24.5
3	2	71.2	66.6	81.8	70	10.6	3.4	4.9	6	38.9	40.5	28.6	23.7	27	25
4	2	74	64.6	76.8	68.8	2.8	4.2	3.3	2.9	41	39.6	27.4	23.8	27	23.4
5	2	89.3	68.7	84.2	72.4	-5.1	3.7	4.1	11.1	42.9	43.8	32.6	27.7	33.7	23.3
6	1	75.7	70.9	82.9	70.3	7.2	-0.6	1.8	2.6	42.5	45	28.8	26	28	25.4
7	2	70.2	65.4	77.9	67.6	7.7	2.2	5.5	5.2	34.8	35.6	26	24.3	24.9	24.7
8	2	74.8	65.6	78.5	68.9	3.7	3.3	1.8	7.2	41.6	42.8	28	26	27.9	23
9	3	70	62.9	74.4	64.2	4.4	1.3	2.5	2.6	38.2	38.1	27.9	23.1	26.5	23.1
10	2	77.6	68.9	77.8	70.2	0.2	1.3	0.1	7.8	43.7	44.2	27	24.2	28.8	22.6
11	2	79.7	73.1	80.9	72.6	1.2	-0.5	5.5	8	35.2	38.3	30.4	27.3	29.1	27.9
12	2	79.7	69.7	76.3	68.2	-3.4	-1.5	1.1	4.5	35	37.3	22.4	25.3	30.2	25.1
13	1	75.7	58.8	81.2	71.5	5.5	12.7	5	7.5	39	38.3	26.9	23.6	29.5	21.2
14	1	76.6	63.3	69.9	65.5	-6.7	2.2	1.8	4.1	36.7	39.3	26	21.5	27.4	24.4
15	3	70.9	63.6	75	67.2	4.1	3.6	4.4	3	37.9	38.8	25.4	24.6	27.3	23.8
16	3	72.3	61.4	79.2	68.6	6.9	7.2	2.2	4.7	40.2	41	29.8	27.1	27	20.9
17	3	72.8	67.2	77.8	67.8	5	0.6	2.1	3.9	41.3	42.2	26.3	26.7	26.6	23.8
18	2	84.1	71.6	73.8	65.4	-10.3	-6.2	3.4	5.8	37.7	37.7	31.3	26.5	31.3	26.7
19	1	78	65.4	79.6	70	1.6	4.6	3.6	5.8	40	40.4	30.9	26.1	29.3	24
20	3	68.2	60.2	72.9	64.3	4.7	4.1	2.9	5.5	36.1	36.4	24.7	22.7	26	21.4

APPENDIX D (continued)

21	1	81.1	69.7	76.9	65.6	-4.2	-4.1	2.1	4.9	38.4	40.2	27.6	26.9	30.7	25.8
22	1	76.3	66.5	74.1	66	-2.2	-0.5	3	6	40	39.8	26.3	24.9	27.2	23.2
23	1	77.5	65.3	78	67.9	0.5	2.6	3.7	4.3	40.2	41.5	25.6	25	28.3	24.6
24	1	79.5	65.7	78.5	68.7	-1	3	2.1	6.4	35.8	38.2	28.6	23.6	31.4	24.4
25	2	77.1	58.2	74.5	65.3	-2.6	7.1	1.9	12.1	35.6	36.6	24.4	23.4	31.9	21.6
26	1	79.2	65.9	81.2	70.4	2	4.5	4.7	4	40.7	40.6	30	26.2	28.9	23.6
27	2	78	72.1	84.5	75.3	6.5	3.2	4.1	7.6	43.2	46.2	33.4	33.1	28	25.5
28	2	72.5	63.7	78.1	67.8	5.6	4.1	4.1	5.2	39.1	39.9	26.5	21.3	27.6	24.1
29	1	72.5	60.7	76.6	68.6	4.1	7.9	3	3.8	37	38.3	27	24	27	23.5
30	2	75.1	65.9	78	68.6	2.9	2.7	-3.3	6.9	36.3	38	27	27.9	28.5	23.8
31	1	80.5	67.9	80.1	69.4	-0.4	1.5	2.4	5.5	42.8	42.9	31.6	25.7	29.7	24
32	1	79.5	69.6	83.5	74.7	4	5.1	3.7	3.9	42.4	42.5	30.8	27	28.3	25.2
33	1	75	63.8	78.5	69.3	3.5	5.5	4.4	4.2	39.8	39.7	32.3	27.5	27.1	22.6
34	2	77.3	63.5	79.1	70.1	1.8	6.6	7.8	10.1	37.1	39.7	30.3	25.3	26.6	21.3
35	3	76.4	66.3	76.6	67	0.2	0.7	4.6	5.8	39.5	41.7	29	23.2	29.8	22.4
36	1	74.6	63.1	73.7	63.9	-0.9	0.8	2.3	5	42.8	43.1	30	25.7	26.6	20.8
37	2	80.7	66.1	80.4	71.1	-0.3	5	2.1	12.5	36	39.2	23.8	25.3	32.3	24.2
38	2	76.8	63.7	77.5	68.7	0.7	5	5.7	6.5	36.5	37.3	27	22.6	30.7	23.4
39	2	73.6	59.4	75.9	65.1	2.3	5.7	3.5	10.9	33.4	35.5	28	25.5	29.8	21.4
40	2	72.1	63.6	75.2	66	3.1	2.4	2.7	6.3	36.4	37.5	26.2	25.8	27.3	22.1
41	2	77.7	69.3	83.1	73.4	5.4	4.1	6.6	7.4	36	42.8	31.4	27.3	29.1	23.8
42	1	77.1	65.6	78.2	68.8	1.1	3.2	4.2	3.3	40.8	41.5	28.5	24.9	26.7	22.8

APPENDIX D (continued)

GE Pre-treatment Model Data															
PT	Molar Classification	Maxillary Arch Length	Mandibular Arch Length	TJ Maxilla	TJ Mandible	Upper Crowding	Lower Crowding	OB	OJ	Inter-molar width maxilla	Inter-molar width mandible	Inter-canine width maxilla	Inter-canine width mandible	Arch Depth Maxilla	Arch Depth Mandible
1		76.6				-76.6	0			40.9		29.2		28.9	
2	2	75.3	67.5	80.5	68.8	5.2	1.3	5	4.4	39.3	40.6	29.9	23.5	28.8	25.7
3	1	73.5	64.7	79.4	69.4	5.9	4.7	3.9	3.9	37	37.1	27.6	23.4	29	24.9
4	1	81.5	70.5	83.8	73	2.3	2.5	1.2	3.6	39.6	39.5	27.9	23.5	32.2	27.1
5						0	0								
6	1	71.2	61.3	74.1	65.3	2.9	4	-1	5.9	38.4	39.2	26.2	23.5	25.4	20.8
7						0	0								
8						0	0								
9						0	0								
10	1	76.6	68.8	81.6	73.1	5	4.3	1.9	4	43.3	44.1	30.2	25.3	28.5	24.1
11	1	72.1	63.8	70.1	63.1	-2	-0.7	-0.5	3.4	41.5	41	24.5	21.4	27.3	22.8
12	2	78	68.8	82.8	70.9	4.8	2.1	1.3	8.6	37.2	38.8	25.1	23.8	30.7	25.4
13	1	73.6	61.1	78.2	69	4.6	7.9	5.4	4.8	38.4	38.8	29.2	23.3	28.1	22
14	2	79.2	66.4	79	70	-0.2	3.6	2	9.6	39.6	40.8	29.4	24.2	29.9	23.7
15	1	71.9	63.3	78.8	68.9	6.9	5.6	5.3	3.1	33.8	35.6	28.3	23.8	26.4	22.8
16	3	68.2	61.5	71.5	64.6	3.3	3.1	4.2	3	41.4	41.2	28.2	22	22.3	20.4
17						0	0								
18						0	0								
19	1	77.7	67.8	77.6	65.5	-0.1	-2.3	2.5	5.5	41.9	43	28.6	25.2	28.7	23.6
20	2	74.5	68.7	77.1	68.2	2.6	-0.5	0.9	5.7	36.6	40	29.5	25.4	27.2	24.1

APPENDIX D (continued)

21	2	80.7	71	80.5	71.2	-0.2	0.2	4	4.2	45.9	45.2	30.9	26.1	29.1	26.4
22	3	72.7	63.3	76.4	67.5	3.7	4.2	3.2	5.3	38.5	44.2	27	25.9	26.6	21.9
23	2	82.9	75.5	80.5	73.5	-2.4	-2	2.2	8.2	40.9	43.8	27.8	25.2	30.6	27.7
24	2	68.8	56.5	75.4	65.7	6.6	9.2	8.7	6.1	38.6	38.6	26.1	21.6	25.8	20.5
25						0	0								
26						0	0								
27						0	0								
28		31.9				-31.9	0			38.4		27.2		26.4	
29	2	71.6	62.1	81.6	70.8	10	8.7	3.4	4.3	40	40.4	28.6	25.3	25.9	22.8
30	1	76	64.4	75.5	68.7	-0.5	4.3	3.6	3.7	37.9	38.5	27.3	23.7	28.1	23.8

APPENDIX D (continued)

GE Post-treatment Model Data															
PT	Molar Classification	Maxillary Arch Length	Mandibular Arch Length	TJ Maxilla	TJ Mandible	Upper Crowding	Lower Crowding	OB	OJ	Inter-molar width maxilla	Inter-molar width mandible	Inter-canine width maxilla	Inter-canine width mandible	Arch Depth Maxilla	Arch Depth Mandible
1	3	73	62.3	79.6	70.6	6.6	8.3	5.4	4.1	40.4	39.1	29.8	27.1	28.2	23.5
2	1	69.3	53.9	80.6	69.7	11.3	15.8	4.7	4.2	39.5	38.4	31.2	28.2	26.2	19
3	1	72.7	58.6	78.9	68.6	6.2	10	5.1	5.2	36.9	36.6	28.8	25.7	28.5	22
4	1	77.2	66.6	82.5	71.4	5.3	4.8	3.3	4.6	40.4	39.4	31.3	26.9	31.1	25.1
5						0	0								
6	1	65.9	55	74.6	65.7	8.7	10.7	1.9	5.1	38.1	38.8	28.3	26.5	24.9	18.4
7						0	0								
8						0	0								
9						0	0								
10	1	74	62.7	80.8	72	6.8	9.3	4.4	4.7	43.6	43.3	30.6	28.8	26.8	21.6
11	3	64.2	58.1	75.1	65.6	10.9	7.5	1.5	2.3	35.4	42.2	27.4	25.9	23.8	18.5
12	2	71.9	60.8	82.5	70.6	10.6	9.8	4.5	9	38.4	38.8	29.3	27.1	29.2	20.9
13	1	69.5	56.1	78.6	69.3	9.1	13.2	6.4	5.8	39.5	38.9	30.5	28.5	25.4	19.3
14	3	81.4	60.3	79.1	70.3	-2.3	10	4.7	14	38.8	39.4	31.4	30.5	31.4	21
15	1	64.5	52.9	78.5	68.1	14	15.2	5.4	3.8	35.6	35.4	29.1	26.9	24.3	18.7
16	2	58.9	54.8	72	64.7	13.1	9.9	3.9	3.7	39.6	39.7	29.4	24.4	18.4	18.6
17						0	0								
18	1	68	53.4	76	66.7	8	13.3	5.4	4.3	41.3	38.6	31	26.5	24.7	18.3
19	1	75.5	60.6	79.7	70.6	4.2	10	4.8	4.4	46.2	45.7	33.7	28.5	26.2	19.8
20	3	72.5	63.6	77.3	68.6	4.8	5	3.7	6.3	37.6	39.5	29.6	26	28	22.2

APPENDIX D (continued)

21	1	77.3	61.6	81	70	3.7	8.4	4.8	5.2	46.9	43.4	31.7	29	27.7	22.2
22	1	67.8	53.4	76.2	67.4	8.4	14	6.4	6.3	37.8	42.6	28.7	26.4	25.4	17.7
23	3	78.9	67.1	80.9	73.8	2	6.7	4.1	10.6	42	44	32.6	34	29.3	23.7
24	1	68	53	75.7	65.6	7.7	12.6	8.3	6.2	38.3	37.2	29.4	20.7	25.1	19.3
25						0	0								
26						0	0								
27						0	0								
28	1	63.2	49.5	79.5	69.6	16.3	20.1	6.1	4.5	37.8	37.5	31.3	28.4	22	16.7
29	1	67.2	57.3	82.8	70.9	15.6	13.6	3.4	4.9	40.7	39.7	27.7	27.7	23.1	20.6
30	1	66.8	56.1	76.3	69.1	9.5	13	3.2	3.5	36.1	36	27.3	24.7	24.3	19.9

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