Assessment of Vertical Changes During Palatal Expansion Using Quad

Helix or Bonded Rapid Palatal Expander

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THESIS

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LIST OF ABBREVIATIONS

2D   Two-Dimensional

3D   Three-Dimensional

CBCT   Cone Beam Computed Tomography

IRB   Institutional Review Board

JPEG   Joint Photographic Experts Group

PHI   Protected Health Information

RMO®   Rocky Mountain Orthodontics

SARPE   Surgically Assisted Rapid Palatal Expansion

SUMMARY

Palatal expansion is a widely accepted treatment option in orthodontics, as it allows the maxillary transverse dimension to be increased. There are several different types of palatal expansion appliances that are used by practitioners, and two of these are the quad helix expander and the bonded rapid palatal expander. However, there are no studies in the literature that examine the changes in vertical dimension using these two expanders, especially in regards to phase I treatment.

This retrospective study looked at two treatment groups, a quad helix expander group and a bonded rapid palatal expander group, before treatment (T1) and after the completion of phase I treatment (T2) to assess changes in the vertical dimension after palatal expansion treatment. Each treatment group was also compared to an untreated predicted growth model, based on each group's mean age prior to treatment and mean treatment time, to compare changes in vertical dimension as result of phase I expansion treatment to untreated predicted growth. All subjects were growing patients with either a class I or class II skeletal pattern. Lateral cephalograms taken before treatment and after the completion of expansion and phase I treatment were traced using Dolphin Imaging, and these cephalometric tracings were used to analyze the changes in vertical dimension.

When the quad helix and bonded rapid palatal expander groups were compared to each other, no difference was found at T1, but significant differences at T2 were found for the variables convexity, lower facial height, total facial height, facial axis, and FMA. The differences in these variables suggested that the quad helix expander

SUMMARY (CONTINUED)

maintained better control over skeletal vertical measurements than the bonded rapid palatal expander, based on this sample.

When the two treatment groups at T2 were compared to their respective untreated predicted growth models, a significant difference was found for the variable lower facial height for the quad helix group and for the variable U6-PP for the bonded expander group. The significant intrusion of U6-PP for the bonded expander group indicated better maintenance of dental vertical control than the quad helix group, and the significant decrease in lower facial height for the quad helix group indicated better maintenance of skeletal vertical control than the bonded expander group.

Overall, both the quad helix expander and the bonded rapid palatal expander showed minimal vertical changes during palatal expansion treatment. Therefore, based on this sample, it can be said that both expanders adequately maintained the vertical dimension in growing skeletal class I and class II subjects after palatal expansion during phase I orthodontic treatment.

1.   INTRODUCTION

1.1   Background and Significance

Palatal expansion is a commonly used treatment modality in orthodontics to correct dental and skeletal crossbites and to increase the transverse dimension of narrow maxillary arches. Palatal expansion can also be used to create additional space in the dental arches to relieve crowding (Lagravere, Heo, Major, & Flores-Mir, 2006). McNamara has further illustrated this point by maintaining that crowding and crossbites can often be due to maxillary transverse deficiency, and that "maxillary transverse deficiency…may be one of the most pervasive skeletal problems in the craniofacial region" (McNamara, 2000).

The quad helix expander and the bonded rapid palatal expander are two expansion appliances that are commonly used for palatal expansion in orthodontics. The basis for rapid palatal expansion, as achieved with the bonded rapid palatal expander, is to achieve immediate separation of the midpalatal suture and subsequent deposition of new bone in the suture (Haas, 1961). The quad helix expander is designed to work more slowly than a rapid palatal expander, and its construction is less rigid (Ladner & Muhl, 1995).

An often undesirable side effect of palatal expansion is the extrusion of maxillary molar teeth, which consequently increases the vertical dimension. Both rapid palatal expansion with a bonded expander and slow palatal expansion with a quad helix expander have been thought to minimize vertical changes following expansion. This is

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especially important for patients who have an increased anterior facial height and/or an increased mandibular plane angle prior to orthodontic treatment because it would be undesirable to increase facial height further or to open the mandibular plane angle as a result of palatal expansion.

This study will compare the vertical changes in growing children with a class I or class II skeletal pattern treated with a quad helix expander or a bonded rapid palatal expander. This study is significant because there are no studies in the literature that compare the treatment effects of these two specific expansion appliances during phase I treatment, and there are few studies in the literature that examine comprehensive vertical changes after expansion. In addition, there are few studies that evaluate subjects after expansion and before comprehensive orthodontic treatment as most studies look at subjects before treatment and after comprehensive treatment is completed. Ultimately, we want to know what the best expansion protocol is for our sample of growing skeletal class I and class II subjects in terms of minimizing vertical changes.

1.2   Statement of the Problem

The differences in the effect of palatal expansion on vertical changes using a quad helix expander versus a bonded rapid palatal expander are unknown. There have been no studies done comparing vertical measurements from before treatment and after palatal expansion for these two expanders, and this study aims to show the effect of palatal expansion on vertical changes after expansion and phase I treatment only, not comprehensive orthodontic treatment.

1.3   Purpose of the Study

The goal of this study is to determine if there is a significantly different effect on vertical changes during palatal expansion in phase I treatment using a quad helix expander or a bonded rapid palatal expander in growing skeletal class I and class II subjects.

1.4   Null Hypotheses

1. There is no statistically significant mean difference in vertical dimension changes between the quad helix expander and the bonded rapid palatal expander during phase I treatment for growing skeletal class I and class II subjects.

2. There is no statistically significant mean difference in vertical dimension changes between the quad helix expander and the bonded rapid palatal expander after phase I treatment for growing skeletal class I and class II subjects.

3. There is no statistically significant mean difference in vertical dimension changes between the quad helix expander and the bonded rapid palatal expander after phase I treatment for growing skeletal class I and class II subjects when compared to untreated predicted growth values.

2.   REVIEW OF THE LITERATURE

2.1   History of Palatal Expansion

Palatal expansion appliances have a long history in the field of orthodontics with the first known published use of an expansion appliance being in 1860 by Angell. He used a jackscrew that sat in the palate and was attached to clasps that fit around the teeth, and a key was used to open the jackscrew (Angell, 1860). This elementary appliance is very similar to the current rapid palatal expanders that are used in practice today.

Rapid palatal expansion was re-popularized in the 1960s after the studies and publications of Haas. In 1961, Haas's study of rapid palatal expansion on both animal and human models showed how easily the midpalatal suture can be opened and the significant increases that can occur in intermaxillary and nasal width (Haas, 1961). His early clinical studies showed that the maxilla moved downward and forward and convexity increased following rapid palatal expansion (Haas, 1961). Regarding the benefits of palatal expansion, he stated that "cases that would ordinarily be considered among the most difficult become relatively routine problems following suture opening" (Haas, 1965). Haas also maintains that the "prime objective of palate expansion is to coordinate the maxillary and mandibular denture bases", which is necessary for successful orthodontic treatment (Haas, 1970).

In 1970, Wertz examined the skeletal and dental changes that occurred as a result of rapid palatal expansion on patients as well as on two dried skulls. He used a

banded appliance with acrylic pads, and his results showed that "the mandibular plane angle almost always opened, and usually this opening was accompanied by a diminished SNB angle" (Wertz, 1970). The dried skulls were also found to have a downward and backward rotation of the mandible after simulating expansion. For the live subjects studied, the explanation cited for the increase in the mandibular plane angle was "disruption of occlusion and possible extrusion of teeth, together with the dropping downward of the maxilla" (Wertz, 1970). However, no posterior dental measurements were included in the study so the amount of influence from vertical dental changes is unknown.

The downward and backward rotation of the mandible and subsequent increase in lower facial height following rapid palatal expansion treatment is well documented and has been studied by several authors (Haas, 1961; Haas, 1965; Haas, 1970; Majourau & Nanda, 1994; Wertz, 1970). In his 1970 paper, Haas even stated that as a result of rapid palatal expansion, "the change in maxillary posture invariably causes a downward and backward rotation of the mandible which decreases the effective length of the mandible and increases the vertical dimension of the lower face" (Haas, 1970). These negative effects are a major reason why other palatal expansion options are necessary, as it would be advantageous to counteract such undesired outcomes.

2.2 Quad Helix Expander

The quad helix appliance was first described by Ricketts (Brandt & Ricketts, 1975), and has gained popularity since as an expansion appliance. The mechanism of action of the quad helix includes rotating the maxillary molars distally, expanding the

maxillary molars buccally, and adjusting the anterior arms to expand the maxillary premolar and canine regions (Bench, 1998). There are several cited advantages of using a quad helix appliance over a rapid palatal expanders, including decreased effects on the patient's speech, no reliance on the patient or parent for activation, and the delivery of continuous force (Bell & LeCompte, 1981).

The mechanism of action of the quad helix expander is slow palatal expansion, which is said to be more physiologic than rapid palatal expansion and may exhibit less relapse (Hicks, 1978; Storey, 1973). Slow palatal expansion has also been said to maintain the integrity of sutural tissue better than with rapid palatal expansion (Akkaya, Lorenzon, & Ucem, 1999; Bell, 1982; Hicks, 1978; Storey, 1973). Huynh et al. studied slow palatal expansion using Haas, hyrax, and quad helix expanders, and the results indicated that the three expanders all had similar effects (2009).

In terms of vertical dental changes, Kobayashi et al. (2012) examined patients before and after quad helix treatment and compared them to non-treated controls to determine the treatment effects on the position of maxillary molars. They found that there was a significant "impeded extrusion" of the maxillary first molar in the quad helix treatment group versus the non-treated controls, indicating that treatment with a quad helix expander may help maintain vertical control of the maxillary first molar (Kobayashi et al., 2012).

However, Shundo et al. (2012) found no significant difference in the vertical position of the maxillary first molar when comparing quad helix treatment group with matched untreated controls. Additionally, no significant difference was found for the vertical position of the mandibular first molar between the quad helix treatment group

and the untreated controls. Erdinç et al. (1999) also found no significant difference in the vertical position of the maxillary first molar in subjects treated with a quad helix appliance versus untreated controls. These results, although showing no statistically significant mean difference, may have important clinical implications. Since there were no significant differences between subjects treated with a quad helix and untreated subjects, the authors concluded that the quad helix expansion appliance may be effective in maintaining the vertical maxillary first molar position.

Looking at a more complete lateral cephalometric analysis comparing subjects before and after quad helix expansion treatment to untreated predicted growth values, Frank and Engel (1982) have shown that there are significant differences between the two groups for mandibular plane angle and facial axis. The mandibular plane angle and facial axis both opened slightly, showing a small amount of bite opening in the quad helix treatment group versus the untreated predicted growth values. No significant differences were found for lower facial height or convexity between the two groups. It is also important to note that there was a significant increase in maxillary width before and after quad helix treatment, and the authors "concluded that moderate orthopedic expansion is definitely possibly with the quad-helix" (Frank & Engel, 1982).

Both orthopedic and orthodontic expansion with the quad helix expander was also shown by Bell and LeCompte, who studied the effects of phase I quad helix treatment on growing children (1981). They had a deciduous dentition treatment group and a mixed dentition treatment group, and all subjects showed significant maxillary expansion with an opening of the midpalatal suture radiographically. There were no significant differences in expansion found between the deciduous dentition and mixed

dentition groups, therefore the quad helix expander was shown to be an effective appliance for orthodontic and orthopedic maxillary expansion in growing children.

2.3   <u>**Bonded Rapid Palatal Expander**</u>

Looking specifically at the bonded rapid palatal expander, Sarver and Johnston examined patients treated with bonded rapid palatal expanders and compared them to 60 subjects from Wertz's study that were treated with banded rapid palatal expanders (1989). Lateral cephalometric radiographs were taken before and after palatal expansion, and their results showed that the bonded expander group has less inferior displacement of the maxilla than the banded expander group. This finding further suggested that the bonded expander had less dental extrusion than the banded expander.

Reed et al. also compared patients treated with banded rapid palatal expanders to patients treated with bonded rapid palatal expanders, but the study only looked at pretreatment and post comprehensive treatment changes rather than just after expansion (1999). Results showed that there was no statistically significant difference in maxillary molar extrusion between the two groups, but they did find a statistically significant increase in mandibular plane angle in the banded group versus the bonded group. Since results were examined after comprehensive treatment, additional treatment mechanics outside of expansion likely influenced the treatment outcomes.

Pearson and Pearson looked at patients treated with bonded rapid palatal expanders to see if there were any vertical changes after phase I treatment (1999). They also used an intrusion arch with modified 2 x 4 brackets to intrude maxillary

incisors and a vertical pull chin cup for additional anchorage. They found no increase in vertical dimension or in the mandibular plane angle, and the maxillary molar measurement to the palatal plane stayed the same or even intruded slightly. Although this study did include the addition of a vertical pull chin cup, the overall treatment effect including the bonded palatal expander was promising in terms of maintaining the vertical dimension.

Wendling et al. examined the short-term effects of bonded maxillary expanders and lower Schwarz appliances by comparing patients treated with both a bonded expander and a lower Schwarz with patients only treated with a bonded expander (2005). The bonded expander used had posterior occlusal coverage, which was said to have the effect of "bite closure through the presumed intrusive force produced by the posterior bite block effect of the acrylic splint design" (Wendling et al., 2005). All subjects studied had either a class I or class II malocclusion. In terms of vertical dental changes, the U6 (measured from the palatal plane) in the bonded expander plus Schwarz group has no significant change; there was only 0.1mm of extrusion post-expansion. The bonded expander only group showed a statistically significant decrease in the U6 value, meaning that the U6 intruded 0.8 mm. The results of both groups indicated that the bonded rapid palatal expander was effective at controlling extrusion of the U6.

In the same study, lower facial height only increased 0.2mm in the bonded expander only group and increased 1.5mm in the bonded expander plus Schwartz group, which both fell within the normal range. The mandibular plane angle increased less than one degree for both groups as well, further showing that the bonded rapid

palatal expander effectively maintained the vertical dimension (Wendling et al., 2005).

It is widely suggested that the posterior occlusal coverage component of the bonded expander is what controls the maxillary molars. Schulz et al. studied the treatment effects of bonded rapid palatal expanders and vertical pull chin cups, with one treatment group having only a bonded expander and the other having both a bonded expander and a vertical pull chin cup (2005). The authors state that bonded expanders have a "posterior bite block effect", which has also been shown by Sarver and Johnston (1989) and Asanza et al. (1997), and that the bonded expander also "minimizes tipping of the posterior maxillary teeth, thereby providing better control over the vertical dimension" (Schulz et al., 2005). This adds the element of decreased tipping of maxillary molars as another reason why the bonded expander may be used to minimize vertical changes.

Vertical control with a bonded expander was also examined by Basciftci and Karaman, who compared a bonded rapid palatal expander group with a bonded rapid palatal expander plus chin cap group (2002). They found that there was a downward and backward rotation of the mandible in the bonded expander only group, but there was no change in mandibular position in the bonded expander plus chin cap group. No significant difference was shown for L6-MP, the vertical measurement for the mandibular first molar, for either group. The authors also found that the bonded expander only group had significant downward movement of the maxillary first molar and increase in lower facial height, while there were no changes in the vertical maxillary first molar distance or in lower facial height for the bonded expander plus chin cap group. However, in contrast to the these findings, Proffit et al. has stated that the

posterior occlusal coverage that is incorporated into the bonded rapid palatal expander allows for less maxillary molar extrusion due to occlusal forces being directed against the acrylic, and therefore less downward and backward rotation of the mandible (2007).

2.4 Ricketts Growth Prediction

It is important to compare treatment results with untreated growth values, and growth prediction models are an extremely helpful way to accomplish this goal. Matched, non-treated control groups are not always available, and growth prediction models are readily available and are usually based on the actual data of the sample groups. In as early as 1972, Ricketts described computerized cephalometric tracings and even growth predictions, stating that "judgment is no longer contingent upon immediate results; instead, the effects of probable individual maturation and development now can be taken into account" (Ricketts, 1972).

Sagun studied the accuracy of growth predictions in Dolphin Imaging by comparing untreated control subjects to the untreated predicted growth based on Ricketts's predicted growth algorithm (2012). The lateral cephalograms of the untreated subjects at the initial timepoint (T1) were traced in Dolphin Imaging, and the Treatment Simulation module was utilized in order to obtain the Ricketts untreated predicted growth values. The study then compared the actual growth of the untreated subjects with the untreated predicted growth values at both 2 year and 4 year intervals. The findings of the study showed that the Ricketts growth prediction algorithm was accurate when compared with untreated control subjects (Sagun, 2012).

3.   MATERIALS AND METHODS

3.1 <u>Study Design</u>

This was a retrospective study that compared the effects of palatal expansion with a quad helix expander or a bonded rapid palatal expander in terms of vertical changes in subjects with class I or class II skeletal patterns.

The subjects' lateral cephalometric radiographs were de-identified and classified into two groups: subjects treated with a quad helix expander and subjects treated with a bonded rapid palatal expander. The treated subjects' lateral cephalograms were evaluated at two time points; T1 - prior to the start of treatment and T2 - after expansion and stabilization were completed, prior to the start of comprehensive orthodontic treatment. Specific cephalometric measurements were compared from T1 to T2 within each group and between the two groups to determine if there is a significant difference in vertical changes.

3.2   <u>Setting</u>

The study was carried out in the orthodontic department of the University of Illinois at Chicago using cephalometric radiographs taken at two outside orthodontic offices. All radiographs were de-identified prior to the start of any data collection, and there was no access to any protected health information (PHI).

3.3   Sample

3.3.1 Inclusion Criteria

The inclusion criteria are as follows:

1.   Females age 7-12 and males age 7-13

2.   Class I or class II skeletal pattern

3.   Convexity (A-NPo) > 0 mm

4.   Facial axis (NaBa-PtGn) ≤ 88 degrees

5.   Ricketts total facial height (NaBa-PmXi) ≥ 60 degrees

6.   Treated with palatal expansion as phase I treatment

7.   Lateral cephalometric radiographs taken before treatment and after completion of expansion

8.   Phase I orthodontic treatment only, prior to any phase II orthodontic treatment

3.3.2 Exclusion Criteria

The exclusion criteria are as follows:

1.   Patients outside of the age range of 7-12 for females and 7-13 for males

2.   Any skeletal pattern other than class I or class II

3.   Convexity (A-NPo) < 0 mm

4.   Facial axis (NaBa-PtGn) > 88 degrees

5.   Ricketts total facial height (NaBa-PmXi) < 60 degrees

6.   Missing pre-treatment or post-treatment cephalometric films

7.   Craniofacial anomalies that may impact cephalometric tracings

8.   Any patients treated with SARPE

3.3.3 <u>Data Collection</u>

Initially, the records of 53 subjects were obtained: 30 subjects in the quad helix group and 23 subjects in the bonded expander group. The quad helix subjects were obtained from a single practitioner private orthodontic office in Brazil and the bonded expander group subjects were obtained from a single practitioner private orthodontic office in Colorado. After the subjects' lateral cephalograms were uploaded to Dolphin Imaging (Version 11.0.03.37, Chatsworth, CA) and the initial cephalograms were traced, 13 subjects from the quad helix group and 5 subjects from the bonded expander group were excluded because they did not meet the inclusion criteria. A total of 35 subjects met the inclusion criteria and were used in this study, 17 subjects for the quad helix group and 18 subjects for the bonded expander group.

Out of the 17 subjects for the quad helix group, 5 subjects were male and 12 subjects were female. Out of the 18 subjects for the bonded expander group, 4 subjects were males and 14 subjects were female. The mean age at T1 and mean treatment time for both the quad helix group and the bonded expander group were calculated, and this data was used for the untreated growth predictions later described.

For the quad helix group, each lateral cephalogram was taken on a traditional x-ray machine so they needed to be scanned in order to be digitized. Each cephalogram was de-identified prior to scanning, and the digital scanning was completed by the private practice orthodontist. All images were saved in a JPEG format. The de-identified

cephalograms were then uploaded to Dolphin Imaging (Version 11.0.03.37) by the principal investigator.

For the bonded rapid palatal expander group, each lateral cephalogram was constructed from a cone beam computed tomography (CBCT) scan. After the lateral cephalograms were constructed, de-identified, and saved in a JPEG format, the principal investigator uploaded them to Dolphin Imaging (Version 11.0.03.37).

Several studies have been conducted that evaluated the accuracy of constructed two-dimensional lateral cephalograms from three-dimensional CBCTs. Kumar et al. examined both linear and angular measurements in comparing conventional lateral cephalograms and lateral cephalograms constructed from CBCTs (2008). The study found 16 out of 17 measurements to have no statistically significant differences between conventional lateral cephalograms and lateral cephalograms constructed from CBCTs and concluded "synthesized cephalometric images from CBCT may be used to bridge the transition from 2D to 3D image analysis" (Kumar et al., 2008).

Moshiri et al. also studied conventional lateral cephalograms and lateral cephalograms constructed from CBCTs, but first the measurements evaluated in the study were measured on a dry skull to assess anatomical accuracy for both radiographic methods (2007). The results showed that the lateral cephalograms constructed from CBCTs were actually more accurate than conventional lateral cephalograms for the majority of measurements studied. Therefore, based on the findings from Kumar et al. and Moshiri et al., the use of lateral cephalograms constructed from CBCTs are generally accurate and can be used in the place of conventional lateral cephalograms (2008; 2007).

3.4 Anticipated Risks and Benefits

The anticipated risks for this study were minimal. Radiographs utilized by this study were pre-existing and were only taken for the purpose of treatment of the malocclusion. No radiographs were taken for research purposes. There was the risk of potential loss of confidentiality, and measures were taken to reduce this risk. No protected health information (PHI) was obtained and no direct identifiers were used. All radiographs were de-identified prior to the primary investigator starting the study and were assigned a code so records would be able to be returned to the correct patient's chart after the conclusion of the study. All radiographs were identified by this code only, and the investigator did not have access to the coded list that identified the subjects.

Subjects will not benefit directly from this study. The patients involved in the study have already been treated for their malocclusions. The overall benefit would be to the general population if it is shown that one palatal expansion appliance is more beneficial than the other in terms of vertical control.

3.5 Treatment Protocol

All subjects were determined to need palatal expansion treatment due to an insufficient maxillary transverse dimension by the private practice orthodontists from whom their records were obtained.

The quad helix expansion appliance used was a prefabricated, removable Wilson 3D® quad helix made from .038 blue elgiloy (RMO®) that is inserted into vertical slots on the maxillary first molar bands, as described by Wilson and Wilson (1983). The quad helix was expanded approximately 2-3 mm/month at each activation appointment, and

patients were seen for activation appointments approximately every four weeks. Generally around 6mm of expansion was initially achieved, and activation was continued until approximately 2-3 mm of over-expansion was achieved, as suggested by Bell and LeCompte (1981). Once 2-3 mm of over-expansion was achieved, the quad helix was left in the mouth in a passive state for a minimum of 3 months to allow for stabilization of expansion.

The bonded rapid palatal expander used was an acrylic splint type expander with acrylic posterior coverage and an expansion screw located in the center of the palate. The bonded rapid palatal expander was activated two turns per day (0.25 mm per turn, 0.5 mm per day) until the desired amount of expansion was achieved, typically around 6 mm. Generally, subjects in this treatment group were not over-expanded. Once the desired expansion was achieved, the bonded expander was stabilized in a passive state for a minimum of 5 months to allow for stabilization of expansion.

3.6 Uploading Radiographs to Dolphin Imaging

Prior to uploading the lateral cephalograms to Dolphin Imaging, each subject was added as a patient in axiUm (Version 5.11.06.354). Numerical codes were assigned to each subject in axiUm, and each numerical code was linked to a second numerical code in Dolphin Imaging. Once the Dolphin Imaging link was created, each subject was named with a coded identifier. Their initial cephalograms taken prior to the start of treatment (T1) and their cephalograms that were taken after expansion and stabilization were complete (T2) were uploaded in JPEG format under tabs labeled T1 and T2, respectively. The dates the T1 and T2 radiographs were taken were inputted

into Dolphin Imaging as they were uploaded, and each subject's birthdate and gender was added immediately after the radiographs were uploaded.

3.7 Intra- and Inter-reliability Testing

Intra-reliability of the primary investigator in regards to cephalometric tracing was tested by tracing and comparing 10 different lateral cephalograms at two different time points, approximately two weeks apart. Inter-reliability was also tested between the primary investigator and an orthodontic faculty member at the University of Illinois at Chicago. The primary investigator and the faculty member each traced the same 10 lateral cephalograms and the two tracings were compared. Statistical analysis was performed for both intra- and inter-reliability using the Pearson Correlation coefficient.

3.8 Cephalometric Analysis

Both linear and angular cephalometric measurements were used in the cephalometric analysis, and these measurements were based on defined cephalometric landmarks.

The two sample groups were obtained from two different private orthodontic offices, and the lateral cephalograms for each subject group were taken on two different x-ray machines. Therefore, in order to correct any differences in magnification between the two x-ray machines, the lateral cephalograms were calibrated using a ruler and fiduciary points.

3.8.1 <u>Landmarks</u>

The landmarks used in the cephalometric analysis are listed in Table I. These landmarks can also be seen in Figure 1. All definitions are cited from Jacobson (1995) unless otherwise indicated:

TABLE I

CEPHALOMETRIC LANDMARKS

Cephalometric Landmark	Abbreviation	Definition
Anterior nasal spine	ANS	The anterior tip of the nasal spine
A point	A	The most posterior point in the concavity between ANS and the maxillary alveolar process
Basion	Ba	The most posterior point in the concavity between ANS and the maxillary alveolar process
B point	B	The most posterior point in the concavity between the chin and the mandibular alveolar process
Gnathion	Gn	A point midway between pogonion and menton on the outline of the symphysis
Gonion	Go	A point at the intersection of the ramus and the mandibular plane (from Go-Gn)
L6 occlusal	L6	Mesial buccal cusp tip of the mandibular molar (Fushima et al., 1996).
Menton	Me	The lowest point on the symphyseal shadow of the mandible
Nasion	Na	The most anterior point on the frontonasal suture in the midsagittal plane
Orbitale	Or	The lowest point on the inferior rim of the orbit
Pogonion	Pog	The most anterior point on the chin
Porion	Po	The most superiorly positioned point of the external auditory meatus
Posterior nasal spine	PNS	The posterior spine of the palatine bone constituting the hard palate
PT point	PT	The junction of the pterygomaxillary fissure and the foramen rotundum
R1	R1	Deepest point on the anterior border of the ramus, located halfway between the superior and the inferior curves
R2	R2	Located on the posterior border of the ramus, opposite R1
R3	R3	Deepest point of the sigmoid notch, halfway between the anterior and posterior curves
R4	R4	Opposite R3 on the inferior border of the mandible
Suprapogonion	PM	The point at which the shape of the symphysis mentalis changes from convex to concave
U6 occlusal	U6	Mesial buccal cusp tip of the maxillary molar (Fushima et al., 1996).
Xi point	Xi	Located in the center of the rectangle created by R1, R2, R3, and R4 at the intersection of the diagonals

Figure 1.   Cephalometric Landmarks

3.8.2 <u>Cephalometric Measurements</u>

The vertical dimension changes in this study were assessed using the cephalometric measurements listed below:

1. Convexity (A-NPog), mm: Measured from Point A to the facial plane (N-Pog) (Jacobson, 1995).

2. U6 to PP (vertical distance), mm: Vertical distance from U6 point to palatal plane (ANS-PNS) (Fushima et al., 1996).

3. L6-MP (vertical distance), mm: Vertical distance from L6 point to mandibular plane (Me-Go) (Fushima et al., 1996).

4. Ricketts total facial height (NaBa-PMXi), degrees: The angle formed between the nasion-basion line (Na-Ba) and the line formed from PM-Xi (Ricketts et al., 1979).

5. Lower facial height (ANS-Xi-PM), degrees: The angle formed between ANS, Xi, and PM (Jacobson, 1995).

6. Facial axis (NaBa-PtGn), degrees: The angle formed between the basion-nasion plane and the plane from foramen rotundum (PT) to gnathion (Jacobson, 1995).

7. ANB, degrees: The difference between SNA and SNB angles (Jacobson, 1995).

8. Frankfort-mandibular plane angle (MP-FH): The angle between Frankfort horizontal (Po-Or) and the mandibular plane (Me-Go) (Jacobson, 1995).

3.9   <u>Transfer Structures</u>

To minimize landmark identification error and to ensure that each cephalometric tracing was as accurate as possible, especially in regards to comparison with other tracings, the transfer structures function in Dolphin Imaging was utilized. After all cephalograms were traced, they were calibrated, oriented parallel to the Frankfort-horizontal plane, and the magnification was confirmed to be the same so the tracings were as accurate as possible. The best fit function in Dolphin Imaging was then used, along with fiducials, to determine the best fit structures and to ensure that all landmarks were identified correctly. Once the best fit structures were determined on the cephalogram from T1 for each subject, they were transferred to the T2 cephalogram for that subject. This process was then repeated for all subjects. The order of transferring structures is listed below:

1. Cranial base: Sella, Nasion, Basion, Roof of Orbit

2. PT point

3. Porion and Orbitale (Frankfort-horizontal landmarks)

4. Zygomatic ridge

5. Maxilla

6. Symphysis

7. Internal Symphysis

8. Condyle

9. Mandible

10. U6 and L6 (dental landmarks)

Once all structures were transferred for all cephalometric radiographs for both the quad helix and bonded expander groups at T1 and T2, the radiographs were ready to be accurately analyzed.

3.10 Creating Average Composite Tracings

Average composite tracings were created for the quad helix group and bonded expander group prior to creating the untreated growth predictions. The superimposition module in Dolphin Imaging was opened and all of the T1 lateral cephalogram tracings from the quad helix group were selected. All of the T1 lateral cephalogram tracings were superimposed on each other and the average function was selected to create an average composite cephalometric tracing for the quad helix group at T1. The superimposed tracings of all T1 lateral cephalograms for the quad helix group can be seen in Figure 2 and the average composite cephalometric tracing for quad helix group at T1 can be seen in Figure 3.

For the bonded expander group, the superimposition module in Dolphin Imaging was opened and all of the T1 lateral cephalogram tracings from the bonded expander group were selected. All of the T1 lateral cephalogram tracings were superimposed on each other and the average function was selected to create an average composite cephalometric tracing for the bonded expander group at T1. The superimposed tracings of all T1 lateral cephalograms for the bonded expander group can be seen in Figure 4 and the average composite cephalometric tracing for bonded expander group at T1 can be seen in Figure 5.

Figure 2.   Superimposed cephalometric tracings of quad helix group at T1

Average T1 Composite Tracing
Average T1 Composite Tracing + 1 Standard Deviation
Average T1 Composite Tracing - 1 Standard Deviation

Figure 3.   Average composite cephalometric tracing for quad helix group at T1
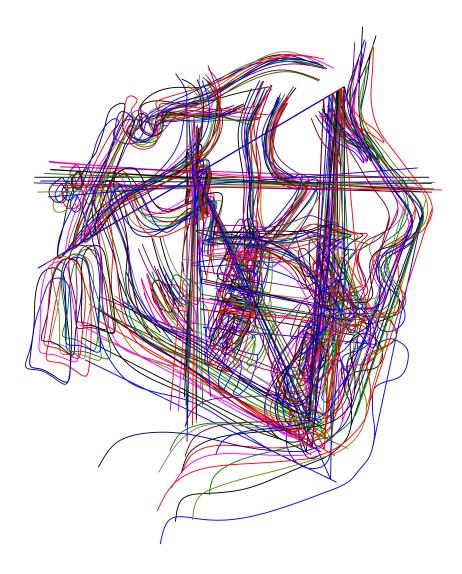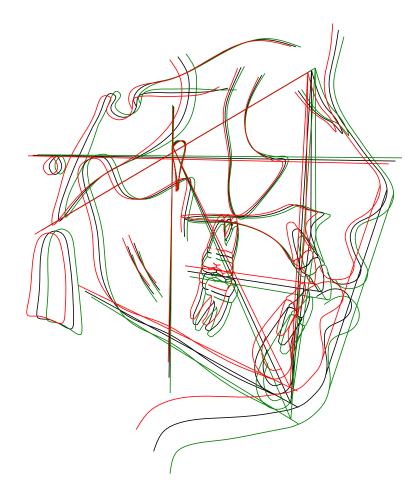
Figure 4.   Superimposed cephalometric tracings of bonded expander group at T1

Average T1 Composite Tracing
Average T1 Composite Tracing + 1 Standard Deviation
Average T1 Composite Tracing - 1 Standard Deviation

Figure 5.   Average composite cephalometric tracing for bonded expander group at T1

3.11 <u>Dolphin Imaging Growth Predictions</u>

To determine the untreated predicted growth of the quad helix group and the bonded expander group, the Ricketts growth prediction module in Dolphin Imaging was utilized. This Ricketts growth prediction module has been studied and shown to be effective in predicting growth within two years, which is the treatment time range into which our sample falls (Sagun, 2012). First, the average composite cephalometric tracing for the quad helix group at T1 was selected. Then the Treatment Simulation module was opened and the Ricketts growth module was selected. The mean age at T1 and mean treatment time was entered for the quad helix group, and then the Growth option was selected to give the untreated predicted growth values based on Ricketts's normative data. The process was then repeated with the mean age at T1 and mean treatment time for the bonded expander group, and the Growth option was again selected to give the untreated predicted growth values based on Ricketts's normative data.

3.12 <u>Data Analysis and Statistics</u>

All cephalometric radiographs were traced and analyzed at two different time points, before treatment (T1) and after expansion and stabilization were complete (T2). Data analysis was performed in the orthodontic department at the University of Illinois at Chicago College of Dentistry on a password protected computer. Data was analyzed to determine if any significant differences exist between the quad helix expander and the bonded rapid palatal expander groups, especially regarding vertical changes during treatment. SPSS Version 22.0 (Chicago, IL) was used for the statistical analysis.

4.   RESULTS

4.1 Descriptive Statistics

Descriptive statistics were computed for all variables used in the study and the Shapiro-Wilk test showed that the variables have an approximately normal distribution.

4.2 Descriptive Age and Treatment Time Statistics

Mean age at T1 and mean treatment time were calculated for each group. For the quad helix group, the mean age and standard deviation at T1 was 9 years, 6 months ± 21 months and the mean treatment time and standard deviation was 1 year, 8 months ± 9 months. For the bonded expander group, the mean age and standard deviation at T1 was 8 years, 6 months ± 9 months and the mean treatment time and standard deviation was 1 year ± 8 months.

An independent t-test was performed to evaluate whether there was a statistically significant mean difference between the mean age of the quad helix group at T1 and the mean age of the bonded expander group at T1. A p-value of less than or equal to 0.05 was set for statistical significance. An independent t-test was also performed to evaluate whether there was a statistically significant mean difference between the mean treatment time of the quad helix group and the mean treatment time of the bonded expander group. A p-value of less than or equal to 0.05 was set for statistical significance. Table 2 summarizes the means, mean differences, and p-values for these variables.

TABLE II

INDEPENDENT T-TESTS BETWEEN MEAN AGE AT T1 AND
MEAN TREATMENT TIME (MONTHS)

Groups / Variables	Quad Helix		Bonded Expander		Mean Difference	p-value
	Mean	SD	Mean	SD		
Age at T1	114.82	20.96	102.89	8.90	11.94	0.041*
Treatment Time	20.00	9.13	12.28	8.29	7.72	0.013*

*Statistically significant, p-value $\leq$ 0.05

Both mean age at T1 and mean treatment time showed statistically significant mean differences between the quad helix group and the bonded expander group. Age at T1 showed a mean difference of 11.94 months (p=0.041) with a higher mean for the quad helix group. Treatment time showed a mean difference of 7.72 months (p=0.013) with a higher mean for the quad helix group.

4.3 Intra- and Inter-reliability

The Pearson Correlation coefficients were all positive (r ≥ 0.8) and statistically significant, providing good support for both intra-reliability and inter-reliability testing.

4.4 <u>Paired Samples t-tests</u>

A paired samples t-test was performed to evaluate whether there was a statistically significant mean difference between time points T1 and T2 within each treatment group, the quad helix expander group and the bonded rapid palatal expander group. A p-value of less than or equal to 0.05 was set for statistical significance. Table 3 and Table 4 summarize the means, standard deviations, mean differences, and p-values from T1 to T2 within each treatment group.

TABLE III

PAIRED SAMPLES T-TEST BETWEEN T1 AND T2 FOR QUAD
HELIX GROUP (N=17)

Cephalometric Measurements	T1		T2		T2 - T1	
	Mean	SD	Mean	SD	Mean Difference	p-value
Convexity (A-NPo) mm	3.44	2.01	3.47	1.90	0.04	0.887
U6-PP mm	19.94	3.07	20.26	2.77	0.33	0.379
L6-MP mm	27.45	2.53	28.15	2.85	0.70	0.095
Total Facial Height (NaBa-PmXi)°	64.41	2.83	63.56	2.88	-0.85	0.227
Lower Facial Height (ANS-Xi-Pm)°	47.39	3.10	46.16	3.27	-1.24	0.109
Facial Axis (NaBa-PtGn)°	84.88	2.14	85.49	2.66	0.61	0.234
ANB°	4.15	1.67	4.14	1.49	-0.01	0.967
FMA (MP-FH)°	27.45	4.15	26.52	4.21	-0.92	0.138

TABLE IV

PAIRED SAMPLES T-TEST BETWEEN T1 AND T2 FOR BONDED
EXPANDER GROUP (N=18)

Cephalometric Measurements	T1		T2		T2 – T1	
	Mean	SD	Mean	SD	Mean Difference	p-value
Convexity (A-NPo) mm	4.48	2.25	4.93	2.12	0.44	0.072
U6-PP mm	19.62	1.79	19.29	2.07	-0.33	0.338
L6-MP mm	26.79	2.61	27.66	2.62	0.87	0.004*
Total Facial Height (NaBa-PmXi)°	65.92	2.27	65.84	2.49	-0.07	0.861
Lower Facial Height (ANS-Xi-Pm)°	48.28	3.13	48.67	3.16	0.38	0.322
Facial Axis (NaBa-PtGn)°	84.07	2.22	83.64	2.38	-0.43	0.063
ANB°	4.96	2.11	5.11	1.93	0.15	0.587
FMA (MP-FH)°	29.26	2.32	29.55	2.60	0.29	0.311

*Statistically significant, p-value $\leq$ 0.05

For the quad helix expander group, no statistically significant differences were found for any variables from T1 to T2. For the bonded rapid palatal expander group, a statistically significant difference was found for the variable L6-MP, which showed a mean difference of 0.87 mm (p=0.004) with a higher mean at T2.

4.5 <u>Independent t-tests</u>

An independent t-test was performed to evaluate if there was a statistically significant mean difference between the quad helix expander and the bonded rapid palatal expander for the difference from T1 to T2 for any of the variables tested. Table 5 summarizes the means, standard deviations, mean differences, and p-values for differences from T1 to T2 between the quad helix group and the bonded expander group.

Independent t-tests were performed to evaluate whether there was a statistically significant mean difference between the quad helix expander group and the bonded rapid palatal expander group at both T1 and T2. Table 6 summarizes the means, standard deviations, mean differences, and p-values between the quad helix group and the bonded expander group at T1. Table 7 summarizes the means, standard deviations, mean differences, and p-values between the quad helix group and the bonded expander group at T2.

TABLE V

INDEPENDENT T-TEST FOR DIFFERENCES BETWEEN QUAD
HELIX AND BONDED EXPANDER GROUPS FROM T1 TO T2

Cephalometric Measurements	Quad Helix (n=17)		Bonded Expander (n=18)		Group Difference	
	Mean	SD	Mean	SD	Mean Difference	p-value
Convexity (A-NPo) mm	0.04	1.00	0.44	0.98	-0.41	0.232
U6-PP mm	0.33	1.50	-0.33	1.43	0.66	0.191
L6-MP mm	0.70	1.62	0.87	1.12	-0.17	0.716
Total Facial Height (NaBa-PmXi)°	-0.85	2.78	-0.07	1.73	-0.77	0.326
Lower Facial Height (ANS-Xi-Pm)°	-1.24	3.00	0.38	1.59	-1.62	0.053
Facial Axis (NaBa-PtGn)°	0.61	2.04	-0.43	0.92	1.05	0.066
ANB°	-0.01	1.14	0.15	1.15	-0.16	0.679
FMA (MP-FH)°	-0.92	2.44	0.29	1.20	-1.22	0.076

TABLE VI

INDEPENDENT T-TEST FOR QUAD HELIX AND BONDED
EXPANDER GROUPS AT T1

Cephalometric Measurements	Quad Helix (n=17)		Bonded Expander (n=18)		Group Difference	
	Mean	SD	Mean	SD	Mean Difference	p-value
Convexity (A-NPo) mm	3.44	2.01	4.48	2.25	-1.05	0.157
U6-PP mm	19.94	3.07	19.62	1.79	0.31	0.713
L6-MP mm	27.45	2.53	26.79	2.61	0.66	0.451
Total Facial Height (NaBa-PmXi)°	64.41	2.83	65.92	2.27	-1.50	0.091
Lower Facial Height (ANS-Xi-Pm)°	47.39	3.10	48.28	3.13	-0.89	0.405
Facial Axis (NaBa-PtGn)°	84.88	2.14	84.07	2.22	0.80	0.284
ANB°	4.15	1.67	4.96	2.11	-0.81	0.216
FMA (MP-FH)°	27.45	4.15	29.26	2.32	-1.81	0.119

TABLE VII

INDEPENDENT T-TEST FOR QUAD HELIX AND BONDED
EXPANDER GROUPS AT T2

Cephalometric Measurements	Quad Helix (n=17)		Bonded Expander (n=18)		Group Difference	
	Mean	SD	Mean	SD	Mean Difference	p-value
Convexity (A-NPo) mm	3.47	1.90	4.93	2.12	-1.46	0.040*
U6-PP mm	20.26	2.77	19.29	2.07	0.98	0.245
L6-MP mm	28.15	2.85	27.66	2.62	0.49	0.599
Total Facial Height (NaBa-PmXi)°	63.56	2.88	65.84	2.49	-2.28	0.017*
Lower Facial Height (ANS-Xi-Pm)°	46.16	3.27	48.67	3.16	-2.51	0.027*
Facial Axis (NaBa-PtGn)°	85.49	2.66	83.64	2.38	1.85	0.037*
ANB°	4.14	1.49	5.11	1.93	-0.98	0.104
FMA (MP-FH)°	26.52	4.21	29.55	2.60	-3.03	0.015*

*Statistically significant, p-value $\leq$ 0.05

No variables were found to have statistically significant mean differences for the difference from T1 to T2 between the quad helix expander group and the bonded rapid palatal expander group. No variables were found to have statistically significant mean differences at T1 between the two groups. Five variables were found to have statistically significant mean differences at T2 between the two groups. Convexity showed a mean difference of -1.46 mm (p=0.040) with a higher mean for the bonded expander group. Total facial height showed a mean difference of -2.28° (p=0.017) with a higher mean for

the bonded expander group. Lower facial height showed a mean difference of -2.28° (p=0.027) with a higher mean for the bonded expander group. Facial axis showed a mean difference of 1.85° (p=0.037) with a higher mean for the quad helix expander group. FMA showed a mean difference of -3.03° (p=0.015), with a higher mean for the bonded expander group.

4.6 <u>Ricketts Growth Prediction Comparison</u>

One-sample t-tests were performed to evaluate whether there was a statistically significant mean difference between the Ricketts growth prediction for T2, based on the initial T1 values and the actual results that were found at T2 for each group. Table 8 summarizes the means, mean differences, and p-values between the Ricketts growth prediction values for the quad helix group for T2 and the actual results for the quad helix group at T2. Table 9 summarizes the means, mean differences, and p-values between the Ricketts growth prediction values for the bonded expander group for T2 and the actual results for the bonded expander group at T2.

TABLE VIII

ONE-SAMPLE T-TESTS FOR RICKETTS UNTREATED
PREDICTED GROWTH FOR QUAD HELIX AND ACTUAL
VALUES FOR QUAD HELIX GROUP AT T2

Cephalometric Measurements	Untreated Predicted Growth	Quad Helix	Group Difference	
	Mean	Mean	Mean Difference	p-value
Convexity (A-NPo) mm	3.42	3.47	0.05	0.914
U6-PP mm	21.55	20.26	-1.29	0.074
L6-MP mm	28.83	28.15	-0.68	0.342
Total Facial Height (NaBa-PmXi)°	64.42	63.56	-0.86	0.238
Lower Facial Height (ANS-Xi-Pm)°	48.28	46.16	-2.12	0.017*
Facial Axis (NaBa-PtGn)°	84.89	85.49	0.60	0.368
ANB°	3.98	4.14	0.16	0.672
FMA (MP-FH)°	28.18	26.52	-1.66	0.125

*Statistically significant, p-value $\leq$ 0.05

TABLE IX

ONE-SAMPLE T-TESTS FOR RICKETTS UNTREATED
PREDICTED GROWTH FOR BONDED EXPANDER AND ACTUAL
VALUES FOR BONDED EXPANDER GROUP AT T2

Cephalometric Measurements	Untreated Predicted Growth	Bonded Expander	Group Difference	
	Mean	Mean	Mean Difference	p-value
Convexity (A-NPo) mm	4.47	4.93	0.46	0.372
U6-PP mm	20.50	19.29	-1.21	0.024*
L6-MP mm	27.52	27.66	0.14	0.822
Total Facial Height (NaBa-PmXi)°	65.92	65.84	-0.08	0.899
Lower Facial Height (ANS-Xi-Pm)°	48.80	48.67	-0.13	0.860
Facial Axis (NaBa-PtGn)°	84.17	83.64	-0.53	0.356
ANB°	4.8	5.11	0.31	0.503
FMA (MP-FH)°	29.75	29.55	-0.20	0.748

*Statistically significant, p-value $\leq$ 0.05

For the quad helix group, a statistically significant mean difference was found for the variable lower facial height, which showed a mean difference of -2.12° (p=0.017) with a higher mean for Ricketts untreated predicted growth for T2. For the bonded rapid palatal expander group, a statistically significant mean difference was found for the variable U6-PP, which showed a mean difference of -1.21 mm (p=0.024) with a higher mean for Ricketts untreated predicted growth for T2.

5. DISCUSSION

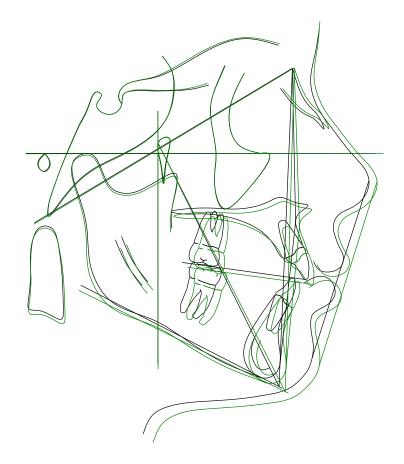## 5.1 <u>Comparison of Age and Treatment Time</u>

When the mean age at T1 was compared for the quad helix group and the bonded rapid palatal expander group, a statistically significant mean difference was found. This was expected since the mean age of the quad helix expander group was one year older than the bonded rapid palatal expander group. Clinically, this significant difference may be important since it is generally easier and more beneficial to do palatal expansion at a younger age, prior to puberty (Bell, 1982). Therefore, if the quad helix expander group started palatal expansion treatment one year earlier to equal the age of the bonded rapid palatal expander group, the results may have been different.

When the mean treatment time was compared for the quad helix group and the bonded rapid palatal expander group, a statistically significant mean difference was found. This was expected since the quad helix group had a mean treatment time that was 8 months longer than the bonded rapid palatal expander group. Since the quad helix group had a significantly longer treatment time, the influence of growth may have been greater. In order to assess the influence of growth, the quad helix and bonded expander groups were compared to untreated predicted growth values. The results of this comparison are discussed in sections 5.6 and 5.7.

It should also be noted that since the quad helix group had a significantly older mean age and longer mean treatment time, the cephalometric tracings of the quad helix group appear to be larger than bonded rapid palatal expander group. However,

proportionally the amount of change from T1 to T2 between the treatment groups was not significantly different, which is further discussed in section 5.4. Therefore, the two groups were able to be compared to each other in spite of these visual differences.

5.2   Comparison of Quad Helix Group from T1 to T2

When the quad helix expander treatment group was compared from T1 to T2, no statistically significant mean differences were found. The average cephalometric tracings for T1 and T2 can be seen in Figure 6; the tracings are registered at sella and superimposed on the anterior cranial base. These findings indicate that there were no significant changes, especially in the vertical dimension that occurred following treatment with a quad helix expander. Since there were no significant changes found, it can be said that the quad helix expansion treatment can be used confidently on growing class I and class II skeletal patients knowing that their vertical skeletal and dental measurements will not be altered due to treatment.
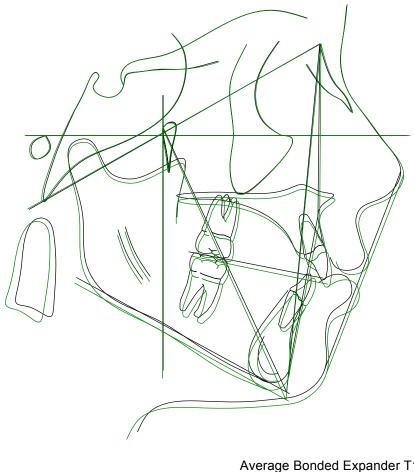
Average Quad Helix T1
Average Quad Helix T2

Figure 6.   Average cephalometric tracings for quad helix group at T1 and T2

5.3   Comparison of Bonded Expander Group from T1 to T2

When the bonded rapid palatal expander group was compared from T1 to T2, only one variable was found to have a statistically significant mean difference, L6-MP. The average cephalometric tracings for T1 and T2 can be seen in Figure 7; the tracings are registered at sella and superimposed on the anterior cranial base. The variable L6-MP, which measures the vertical height of the mandibular first molar, increased from T1 to T2, indicating that the mandibular first molar extruded after expansion was complete. Even though the change in U6-PP was not statistically significant, it did show a slight intrusion from T1 to T2. This slight intrusion of the maxillary first molar, which has also been documented by Wendling et al. (2005), is a possible explanation for the extrusion of the mandibular first molar because contact between maxillary and mandibular molars in a vertical plane is physiologic and desirable. These findings are in contrast to the findings of Basciftci and Karaman, who found no significant change in the L6-MP vertical measurement, but a significant extrusion of the maxillary molar when a bonded rapid palatal expander was used (2002).

Average Bonded Expander T1
Average Bonded Expander T2

Figure 7.   Average cephalometric tracings for bonded expander group at T1 and T2
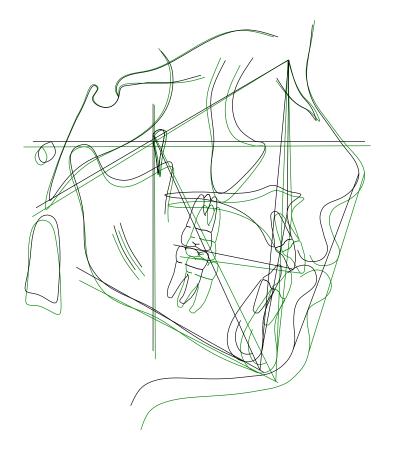
5.4 Comparison of the difference from T1 to T2 between the treatment groups

The independent t-test that compared the mean difference from T1 to T2 between the quad helix expander group and the bonded rapid palatal expander group showed no significant mean differences between the two treatment groups. This result shows that the amount of change that occurred between T1 and T2 for the quad helix group and the bonded expander group were not significantly different, therefore the difference in treatment time between the two groups did not appear to greatly influence the amount of change.

5.5 Comparison of treatment groups at T1

Looking at the independent t-test that compared the quad helix expander group and the bonded rapid palatal expander group at T1, the results showed that there were no significant mean differences between the two groups. The average cephalometric tracings for both groups at T1 can be seen in Figure 8; the tracings are registered at sella and superimposed on the anterior cranial base. This is the ideal result we would like to see because since there are no cephalometric mean differences between the two treatment groups prior to treatment, the groups are similar enough to compare to each other.

Average Quad Helix T1
Average Bonded Expander T1

Figure 8.   Average cephalometric tracings for quad helix group at T1 and bonded expander group at T1

5.6 Comparison of treatment groups at T2
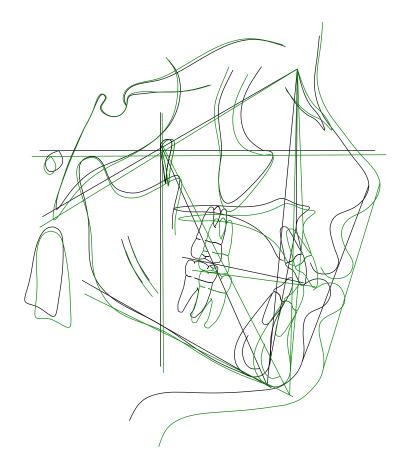
The independent t-test that compared the quad helix expander group and the bonded rapid palatal expander group at T2 showed significant mean differences for five of the variables: convexity, lower facial height, total facial height, facial axis, and FMA. The average cephalometric tracings for both groups at T2 can be seen in Figure 9; the tracings are registered at sella and superimposed on the anterior cranial base.

Average Bonded Expander T2
Average Quad Helix T2

Figure 9.   Average cephalometric tracings for quad helix group at T2 and bonded expander group at T2

5.6.1 Convexity

Convexity was significantly greater for the bonded expander group at T2 than the quad helix group. Convexity is a measure of the relationship of the maxilla and the mandible in the horizontal dimension. The higher the convexity value, the greater the

tendency for a class II skeletal pattern, and the lower the convexity, the greater tendency for a class III skeletal pattern (Jacobson, 1995). The normal value at age 9 is 2 mm ± 2 mm and it decreases 1 mm every 3-5 years (Jacobson, 1995).

Since the bonded expander group had a higher convexity value, it also has a greater difference in the relationship between the maxilla and mandible, and therefore a greater tendency towards a class II skeletal pattern. The quad helix group fell within the normal convexity value at T2, but the bonded expander group convexity value was higher than the normal range. These findings indicate that treatment with a bonded expander may not be indicated for patients with a class II skeletal pattern.

5.6.2 <u>Lower Facial Height</u>

Lower facial height was significantly greater for the bonded expander group at T2 than the quad helix group. Lower facial height is a measurement of the maxilla and the mandible in the vertical dimension (Ricketts et al., 1979). Higher values indicate a tendency towards skeletal open bite and lower values indicate a tendency towards skeletal deep bite. The normal value is 45 degrees ± 4 degrees, and it should not change significantly with age. Since the average age of both groups are within 6 months of 9 years of age, the normal value should be accurate.

The quad helix and bonded expander groups both fall within the normal range; however, since the bonded expander group was significantly greater, it indicates that there is a more of a tendency towards a skeletal open bite than a skeletal deep bite with the bonded expander group. This is especially true because it is supposed to remain

consistent with age, suggesting that the increase in lower facial height is due to the treatment effects of the bonded expander.

5.6.3 Total Facial Height

Total facial height was significantly greater for the bonded expander group at T2 than the quad helix group. Total facial height is a measurement of the body of the mandible in reference to the cranial base (Ricketts et al., 1979). The normal value is 60 degrees ± 3 degrees, and it should not significantly change with age (Ricketts et al., 1979). The quad helix group was within the normal limit at T2, but the bonded expander group was higher than the normal value at T2. Since the bonded expander was slightly above the normal range, it indicates a slightly increased total facial height and therefore a slightly increased mandibular body position with respect to the cranial base.

5.6.4 Facial Axis

The facial axis value was significantly greater for the quad helix group at T2 than the bonded expander group. The facial axis measurement describes the growth direction of the chin (Jacobson, 1995). The normal value is 90 degrees ± 3.5 degrees, and it should not significantly change with age (Jacobson, 1995). Since the average age of both groups are within 6 months of 9 years of age, the normal value should be accurate. An increased angle indicates mandibular growth is greater in the horizontal direction and a decreased angle indicates mandibular growth is greater in the vertical direction.

The quad helix and bonded expander groups both fall below the normal range, indicating that mandibular growth is more vertical than horizontal. Since the quad helix group had a higher facial axis value and was therefore closer to the normal value, the growth tendency for the mandible and chin was less vertical than for the bonded expander group. Since the bonded expander group had a significantly lower value and was outside of the normal range of values, the tendency for vertical mandibular growth is greater, which is an important consideration in treatment planning orthodontic cases.
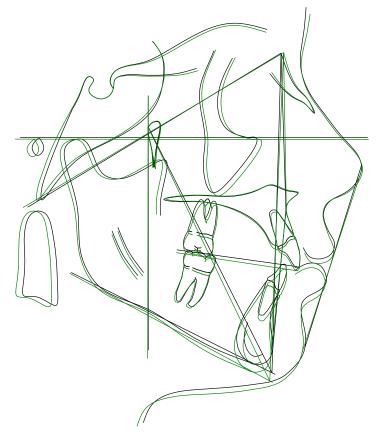
5.6.5 Frankfort Mandibular Plane Angle

The FMA value was significantly greater for the bonded expander group at T2 than the quad helix group. FMA describes the angulation of the mandible. A higher FMA value indicates a more vertical growth pattern and therefore a greater tendency towards a skeletal open bite, and a lower FMA value indicates a more horizontal growth pattern and therefore a greater tendency towards a skeletal deep bite (Jacobson, 1995). The normal value for a 9 year old is 26 degrees ± 4.5 degrees, and every three years it decreases by one degree until growth is complete (Jacobson, 1995). Since the average age of both groups are within 6 months of 9 years of age, the normal value should be accurate. The FMA values for both groups are within the normal range, however the bonded expander group value is at the upper limit of the range, indicating a tendency towards a more vertical growth pattern. This significantly greater FMA value in the bonded expander group may be attributed to the extrusion of the mandibular first molar, which can cause the mandibular plane to steepen.

5.7 <u>Comparison of Quad Helix Treatment to Ricketts Untreated</u>

<u>Predicted Growth</u>

To compare the effects of quad helix treatment to untreated predicted growth, the Ricketts growth prediction analysis was used to assess how an untreated subject would grow based on the mean T1 values of the quad helix group. The only statistically significant variable found between the untreated predicted growth and the actual treatment value at T2 was lower facial height, which was significantly lower for the quad helix actual treatment value. The average cephalometric tracings for both groups can be seen in Figure 10; the tracings are registered at sella and superimposed on the anterior cranial base.

Since lower facial height is a measurement indicating skeletal open bite or deep bite, it is advantageous to maintain lower facial height within the normal range during treatment so an ideal skeletal bite is achieved. The quad helix treatment appears to have maintained a more ideal lower facial height than untreated growth alone, therefore treatment with a quad helix expander appears to maintain or even improve lower facial height.
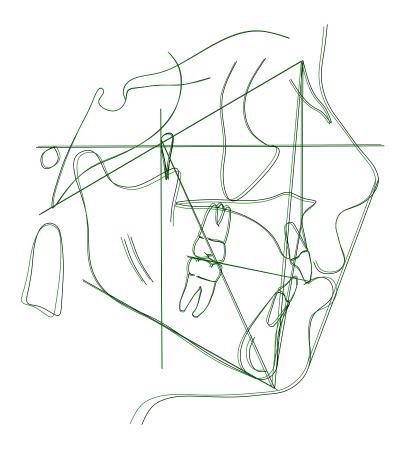
Average Quad Helix T2
Quad Helix Untreated Growth Prediction

Figure 10.   Cephalometric tracings for Ricketts untreated predicted growth for quad helix group and average quad helix group at T2

5.8 <u>Comparison of Bonded Expander Treatment to Ricketts Untreated</u>

   <u>Predicted Growth</u>

To compare the effects of bonded expander treatment to untreated predicted growth, the Ricketts growth prediction analysis was again used to assess how an untreated subject would grow based on the mean T1 values of the bonded expander group. The only statistically significant variable found between the untreated predicted growth and the actual treatment value at T2 was U6-PP, which was significantly lower for the bonded expander actual treatment value. The average cephalometric tracings for both groups at can be seen in Figure 11; the tracings are registered at sella and superimposed on the anterior cranial base.

The U6-PP measurement describes the vertical distance of the maxillary first molar to the palatal plane; an increase in the vertical distance indicates extrusion and a decrease in the vertical distance indicates intrusion. Since the bonded expander treatment group had a significantly lower value for U6-PP than the untreated predicted growth value, it indicates that treatment with a bonded expander can result in significant intrusion of the maxillary first molar. Wendling et al. showed a similar significant intrusion of the maxillary first molar using a bonded rapid palatal expander (2005). In patients with an existing increased vertical dimension, whether it is skeletal or dental in origin, intrusion of the maxillary first molar would be beneficial during orthodontic treatment so that the vertical dimension can be maintained or improved, rather than worsen.

Bonded Expander Untreated Growth Prediction
Average Bonded Expander T2

Figure 11.   Cephalometric tracings for Ricketts untreated predicted growth for bonded expander group and average bonded expander group at T2

5.9 <u>Limitations</u>

One of the limitations of this study was the utilization of a computerized growth prediction control group. In order to truly assess treatment outcomes versus untreated controls, an untreated control group with well matched subjects for each of the subjects in the quad helix and bonded expander groups would ideally be used. Even though the Ricketts growth prediction analysis has been shown to be accurate for the treatment times studied (Sagun, 2012), an untreated control group is the gold standard in orthodontic literature.

A second limitation was that the lateral cephalograms for each group were taken on two different radiographic machines: a conventional lateral cephalogram machine for the quad helix group and a digital CBCT machine for the bonded expander group. Even though all cephalograms were calibrated with rulers and fiduciary points, there still may be differences between the conventional lateral cephalograms and the constructed lateral cephalograms from CBCTs, as indicated by Moshiri et al. who found the constructed lateral cephalograms from CBCTs to be more accurate than conventional lateral cephalograms (2007). Ideally, the same x-ray machine would be used for each sample with the same settings for each lateral cephalogram to ensure the greatest possible accuracy between all radiographs.

Another limitation of this study was the statistically significant mean differences in age at T1 and treatment time between the quad helix group and the bonded expander group. It would have been ideal to have well matched ages at T1 and treatment times between the two groups to better assess the treatment effects due to the expansion

treatment alone, rather than having differences in age and treatment time possibly being influencing factors on the results.

This study was inclusive of patients that only went through phase I orthodontic treatment, and obviously all of the subjects were treated with palatal expansion. However, some of the patients in each of the treatment groups were also treated with limited brackets on the maxillary anterior teeth. This is a limitation since only some of the subjects had treatment that included brackets, which in theory could have affected the treatment outcomes. Since the brackets used were only in the maxillary anterior region, the effect on overall treatment, specifically on the vertical measurements that were assessed, is likely minimal.

It is also important to note that chronologic age was used to assess the age of the subjects, without taking into account their skeletal age. Palatal expansion has both orthopedic and orthodontic effects, and it would have been advantageous to have the skeletal age of each patient to better determine the timing of their growth spurt. Majourau and Nanda found that "growth of the face tends to have its circumpubertal maximum slightly later than that for general body height", therefore knowing the skeletal age in terms of general body height could give a good indication of the circumpubertal growth spurt for the face (1955). The hand-wrist radiograph or the cervical vertebral analysis are the two most commonly used methods to determine skeletal age in orthodontic patients, and the inclusion of either of these methods in this study would have added to the true age determination of the subjects.

5.10 <u>Clinical Significance</u>

This study attempted to determine if there is a significantly different effect on vertical changes during palatal expansion using a quad helix expander or a bonded rapid palatal expander in growing skeletal class I and class II subjects. The results of the study showed that both expanders appear to control the vertical dimension, with the quad helix expander having no significant changes from T1 to T2, as well when compared to untreated predicted growth for most of the variables assessed. The bonded expander group had similar findings, with a significant change shown only for the variable L6-MP from T1 to T2 (slight extrusion) and no significant differences when compared to untreated predicted growth for most of the variables assessed.

When the quad helix group was compared to its untreated growth prediction, the results were more favorable in regards to lower facial height. This is clinically significant because often times we do not want to alter the patient's vertical skeletal pattern during expansion, and treatment with a quad helix expander appears to maintain vertical control and may even improve a patient's lower facial height. This may especially be true if a patient has a skeletal open bite tendency because the quad helix treatment appeared to significantly decrease lower facial height from pre- to post-treatment.

When the bonded expander group was compared to its untreated growth prediction, the results showed a significant intrusion of the U6. This is clinically significant because if a patient has a vertical growth tendency and needs palatal expansion, intrusion of the U6 would be beneficial to maintain or improve the vertical dimension.

5.11 <u>Clinical Application</u>

In a clinical setting, there are differences that exist between treatment with a quad helix expander and with a bonded rapid palatal expander. Since the quad helix expander is active continuously after an activation appointment and there is no reliance on the patient or parent to activate the expander, patients only need to be seen for an appointment approximately once every four weeks. The bonded expander has a jackscrew incorporated into its design that requires the patient or the parent to activate it and the expansion is achieved faster, therefore patients need to be seen for appointments approximately every one to two weeks. The appointments discussed here are only in reference to appointments during the active palatal expansion phase of treatment.

As far as treatment time is concerned, the quad helix expander is slower in achieving expansion due to its mechanism of action, and it usually results in a longer phase I treatment time than the bonded rapid palatal expander. The bonded rapid palatal expander works more quickly to achieve expansion, and it usually results in a shorter phase I treatment time compared to the quad helix expander.

The quad helix expander used in this study was a preformed, removable appliance that comes in a variety of sizes and does not require any outside lab costs or any additional time to be fabricated by a lab. If the quad helix is broken in any way, a new quad helix can be inserted the same day since it is preformed. The bonded rapid palatal expander used in this study was fabricated by an outside lab, which requires additional time for fabrication, and for an additional lab fee. If the bonded expander is broken in any way, it may have to be sent back to the lab to be repaired or remade; again, this would incur additional time and cost to the practitioner.

5.12 <u>Strengths</u>

A major strength of this study was the sample for each individual treatment group. Each sample, for the quad helix group and the bonded expander group, was well controlled through the inclusion and exclusion criteria for normal skeletal patterns. This is important because it minimizes other influences, such as facial musculature and abnormal growth patterns that may affect treatment. The sample size of 35, 17 for the quad helix group and 18 for the bonded expander group is also a strength because the subjects in each treatment group were more or less equal in number and many of the published expansion comparison studies have a similar number of subjects.

Another strength of this study is the fact that it is the first study to compare the quad helix expander and the bonded rapid palatal expander in terms of their vertical effects. The vast majority of expansion literature is regarding the transverse dimension, however expansion treatment can also significantly affect the vertical dimension. This study gives a basis for clinicians to help determine the proper treatment for patients who need both palatal expansion and maintenance of the vertical dimension.

5.13 <u>Future studies</u>

A valuable future study would be to repeat this study with additional palatal expansion appliances and more subjects in each treatment group. The addition of appliances such as a Haas rapid palatal expander, a hyrax rapid palatal expander, a Minne-type slow palatal expander, and a nickel titanium palatal expander would give a more complete analysis of the palatal expansion appliances used in orthodontic treatment. Adding more expander types would also allow for a true comprehensive side-

by-side comparison of the vertical effects of palatal expansion. Increasing the number of subjects in each group would further strengthen the study and would add to the value of the results.

The inclusion of the exact amount of transverse expansion between expansion appliances would also be beneficial in a future study. This could be accomplished by measuring the transverse width of the maxillary first molars, either on study models or posteroanterior cephalograms, at T1 and T2. If the amount of expansion was found to be similar for the different treatment groups, then the groups would be even better matched to be compared to each other in terms of vertical dimension changes.

6. CONCLUSION

Overall, both the quad helix expander and the bonded rapid palatal expander showed minimal vertical changes during palatal expansion treatment.

When comparing treatment results after phase I orthodontic treatment, five variables were found to be statistically significantly different between the quad helix group and the bonded expander group: convexity, lower facial height, total facial height, facial axis, and FMA. The differences in these variables suggested that the quad helix expander had more control over skeletal vertical measurements than the bonded rapid palatal expander, based on this sample.

When comparing treatment results to untreated predicted growth values, the quad helix expander appeared to maintain lower facial height better than the bonded rapid palatal expander, and the bonded rapid palatal expander appeared to maintain the maxillary first molar vertical height better than the quad helix expander. Therefore, it can be said that both quad helix expander treatment and bonded rapid palatal expander treatment during phase I orthodontic treatment adequately maintained the vertical dimension in growing skeletal class I and class II subjects.

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APPENDIX

Determination Notice
Research Activity Does Not Involve "Human Subjects"

November 25, 2013

Cara Conroy, DMD
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Phone: (856) 905-7526 / Fax: (312) 996-0873

RE: Research Protocol # 2013-1147
          **"Comparison of Vertical Control During Palatal Expansion Using Quad Helix
versus Haas Rapid Palatal Expander"**

Sponsor: None

Dear Dr. Conroy:

The above proposal was reviewed on November 24, 2013 by OPRS staff/members of
IRB #2. From the information you have provided, the proposal does not appear to
involve "human subjects" as defined in 45 CFR 46. 102(f).

The specific definition of human subject under 45 CFR 46.102(f) is:

> *Human subject* means a living individual about whom an investigator (whether professional or student)
> conducting research obtains
>
> (1) data through intervention or interaction with the individual, or
> (2) identifiable private information.
>
> *Intervention* includes both physical procedures by which data are gathered (for example, venipuncture) and
> **manipulations of the subject or the subject's environment that are performed for research purposes.**
> *Interaction* includes communication or interpersonal contact between investigator and subject. *Private
> information* includes information about behavior that occurs in a context in which an individual can
> reasonably expect that no observation or recording is taking place, and information which has been
> provided for specific purposes by an individual and which the individual can reasonably expect will not be
> made public (for example, a medical record). Private information must be individually identifiable (i.e., the
> identity of the subject is or may readily be ascertained by the investigator or associated with the
> information) in order for obtaining the information to constitute research involving human subjects.

APPENDIX (CONTINUED)

2013-1147   Page 2 of 2   November 25, 2013

All the documents associated with this proposal will be kept on file in the OPRS and a copy of this letter is being provided to your Department Head for the department's research files.

If you have any questions or need further help, please contact the OPRS office at (312) 996-1711 or me at (312) 355-2908. Please send any correspondence about this protocol to OPRS at 203 AOB, M/C 672.

Sincerely,

Charles W. Hoehne, B.S., C.I.P.
Assistant Director
Office for the Protection of Research Subjects

cc: Carlotta A. Evans, Orthodontics, M/C 841
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