Subsequent Expansion in the Mandibular Intercanine Distance with Rapid Maxillary Expansion

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THESIS

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This thesis is dedicated to my wife, Jess, without whom it would never have been accomplished, and to my son, Jack, whose arrival brought great hope, motivation, and perspective.

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LIST OF ABBREVIATIONS

AMID	Alveolar Mandibular Intercanine Distance
CMID	Cuspal Mandibular Intercanine Distance
IRB	Institutional Review Board
LMID	Lingual Mandibular Intercanine Distance
m	Months
MIII	Mandibular Incisor Irregularity Index
mm	Millimeters
MxID	Maxillary Intermolar Distance
PHI	Protected Health Information
RME	Rapid Maxillary Expansion
RPE	Rapid Palatal Expansion
T1	Pre-Treatment Time Point
T2	Time Point at Expander Stabilization or Removal
T3	Time Point at the End of Active Treatment and Start of Retention
T4	Long-Term Post-Retention Time Point
y	Years

SUMMARY

A study of the short-term and long-term effects of rapid maxillary expansion on the mandibular anterior teeth was carried out using a retrospective approach. The patient records of 19 patients that met the inclusion criteria were isolated from a pool of 400 who had the treatment. The patients were selected according to dental development so that they were not expected to have an increase in mandibular intercanine distance due to growth.

Dental casts were measured at four time-points: initiation of treatment, expander stabilization or removal, the end of treatment, and an average of over eight years after retention was discontinued. Changes in mandibular canine width and incisor crowding with no lower treatment during the expansion period, with fixed appliance therapy, and after retention were examined. The changes during expansion and after retention were tested for correlation to age, duration of expansion treatment, and amount of maxillary expansion. Long-term stability of the orthodontic result was also examined.

There was significant spontaneous increase in mandibular intercanine width as well as spontaneous incisor alignment from expansion treatment. There was also significant relapse long-term of the width gained in treatment, but the relapse was to an acceptable extent and was not beyond the spontaneously expanded distance. No significant correlations were noted between age, duration of expansion, or amount of expansion versus the changes in the lower anterior teeth in the short or long term with the treatment. The mandibular incisor alignment remained stable long-term.

1. INTRODUCTION

1.1 **Background**

In orthodontics, the goal is to produce a healthy and aesthetic result which is also stable over time (Bishara *et al*., 1973). In order to produce a stable final result, the position of the teeth must be in harmony with the surrounding and supporting structures of the face (Little *et al*., 1981). Even after orthodontic treatment and retention, the teeth will continue moving until they are in equilibrium between the forces of the lips, cheeks and tongue (Brodie, 1950; 1952).

While orthopedic maxillary expansion treatment was initially met with opposition, it is now a generally accepted method to correct maxillary transverse dental arch discrepancies or to gain arch width and circumference (Haas, 1961). Haas (1980) helped to revive the long lost maxillary expansion technique in the 1960s. He claims that with maxillary expansion there is spontaneous and stable mandibular arch widening that occurs without placing any appliances on the mandibular teeth.

In apparent conflict with Haas' findings is the University of Washington stability study published by Little (1999) which indicated that any mandibular intercanine expansion that occurs during orthodontic treatment will relapse to its initial dimension. Since mandibular intercanine width is generally established by eight years of age, after eruption of the lower incisors (Bishara *et al*., 1997), one could therefore assume that any expansion in this dimension is bound to relapse. One of the aims of this study is to examine factors which may modify short-term lower canine expansion and incisor alignment subsequent to maxillary expansion. The long-term effects of maxillary expansion on the stability of mandibular intercanine width and incisor alignment will also be studied.

1.2 Specific Aims

The present study is a retrospective examination of Dr. Andrew Haas' maxillary expansion cases to identify which factors will predict this phenomenon of spontaneous mandibular intercanine expansion and incisor alignment concomitant with maxillary expansion. The factors to be examined will include patient age, time that the expander is in place, and extent of maxillary expansion. The secondary aim of the study is to examine the degree of long term stability of this mandibular intercanine expansion, if it is indeed found.

The mandibular intercanine expansion and its stability over time was examined using study casts taken before maxillary expansion, between the completion of expansion and placement of orthodontic appliances on the lower teeth, at the end of treatment, and at least two years after retention is complete. It is hypothesized that following maxillary expansion, the muscular framework in the cheeks is also favorably remodeled, giving the mandibular teeth the opportunity to expand and remain stable in this new position. Also, the mandibular intercanine expansion that occurs before lower appliances are placed establishes a new baseline dimension, beyond which, further expansion will relapse.

1.3 Hypotheses

1. Mandibular intercanine distance expands and the mandibular incisors align with maxillary expansion.
2. Patient age affects the extent of spontaneous mandibular intercanine expansion and its stability following maxillary expansion.

3. Duration of expansion affects the extent of spontaneous mandibular intercanine expansion and its stability following maxillary expansion.
4. Magnitude of maxillary expansion affects the extent of spontaneous mandibular intercanine expansion and its stability following maxillary expansion.
5. The mandibular intercanine distance does not relapse beyond the spontaneously expanded distance, and mandibular incisor irregularity remains acceptable during the post-retention follow-up period.

2. REVIEW OF LITERATURE

2.1 Rapid Maxillary Expansion

Rapid maxillary expansion (RME), when timed appropriately, provides orthodontists the opportunity to rapidly widen the maxilla extending from the level of the teeth superiorly to the nasal cavity (Baccetti *et al*., 2001). While this procedure has ostensibly been used to correct crossbites, it has been used to create arch length in the treatment of borderline extraction cases. McNamara (2002) discussed that auxiliary justification for its use include the facilitation of maxillary canine eruption, improvement of nasal airflow, reduction of “buccal corridors” in the smile, and to allow for reduction of the curve of Wilson when the mandibular molars are lingually inclined.

Lagrevere *et al*. (2005, 2006) reviewed the stability of maxillary expansion and its skeletal and dental effects. The study reviewed clinical trials that assessed dental arch changes through measurements on dental casts or cephalometric radiographs. A similar maxillary response was noted in adolescents and young adults. However, significant overall gain in the maxillary and mandibular arch perimeter was only found in adolescents who underwent expansion. This is in accordance with the conclusions of Baccetti *et al*. (2001) who showed that pre-pubertal patients experienced greater long-term skeletal change in the maxilla subsequent to expansion than their post-pubertal sample. Two notable studies, one by Cameron *et al*. (2002), and another by McNamara *et al*. (2003) - using the “Haas” tooth-and-tissue borne expander - showed that in younger children, the suture widens resulting in transverse orthopedic distraction. They also showed that this transverse change is relatively stable throughout growth.

Post-pubertal expansion can be successful, but the treatment effect shifts from a distraction osteogenesis type response toward a dento-alveolar response with age. Gurel *et* *al*. (2010) found 17-19% relapse in the posterior teeth and 37% relapse at the maxillary canines in adolescents. Handelman *et al*. (2000) found that adult expansion using the Haas expander yielded expansion at the dento-alveolar level. The stability at five years post-retention was found to be comparable to that found in expansion of growing patients which is 85-90%. Most of this relapse was attributed to crown uprighting following buccal tipping during treatment.

2.2 Stability of Mandibular Canine Position

2.2.1 Stability of Mandibular Canine Position without Orthopedic Expansion

When studying the stability of mandibular canine expansion that occurs with orthopedic maxillary expansion, it is important to examine the transverse width of the mandibular canines over time, both those that are expanded with orthodontic treatment and those that are untreated. Moorees *et al*. (1969) showed that dimensional changes of the dental arches in untreated subjects occur in coordination with the eruption of the teeth, and this change depends more on the patient's "dental age" than biological age. They also noted that with the eruption of the maxillary canine there was a significant increase in maxillary intercanine distance, while in the mandibular arch, there was a plateau which preceded the eruption of the mandibular canine, and subsequently, there was a slight reduction of mandibular intercanine width over time. This finding was corroborated by subsequent studies (Little, 1990; Bishara *et al*., 1997; Thilander, 2009).

Bishara *et al*. (1973) examined the stability of intercanine width, overbite, and overjet correction in thirty patients treated orthodontically without orthopedic maxillary expansion. Throughout treatment, maxillary canines were expanded 3mm and mandibular intercanine width increased roughly 0.75mm. The mandibular canines relapsed a little more than 0.5mm, yet this represented a 71 percent relapse of the treatment change after only 15 months post-retention.

Little (1999) found that with and without orthodontic expansion, the mandibular intercanine distance decreases with time and it is unusual for it to be maintained. He also concluded that mandibular anterior crowding during the post-treatment phase is a phenomenon that continues well into the 20-to-40 age bracket and probably beyond and has little to do with the eruption of third molars. Little *et* al. (1981) arbitrarily established that a cut-off measurement of long-term stability would be an irregularity of less than 3.5mm. This study showed that, according to those guidelines, after ten years, more than 70% of cases treated with extractions were unstable. This notion that the degree of crowding that occurs after retention is unpredictable has led many orthodontists to advocate lifelong retention.

2.2.2 <u>Maxillary Expansion and Stability of Mandibular Canine Expansion</u>

McNamara *et al*. (2003) showed a significant increase from initial to six years post-retention in mandibular intercanine distance of 1.5 millimeters (after 0.5 millimeters of relapse) over the untreated group. This study followed a similar maxillary expansion protocol as Dr. Haas advocates, but did not record measurements of the mandibular teeth between expansion and placement of fixed appliances on the mandibular teeth. This precludes the study of “spontaneous” or “indirect” expansion in the mandibular arch. The expanders in the study were left for an average of 65 days while Dr. Haas usually leaves the expander on from 100 days to one year (Haas, 2011, personal communication).

Haas (2000) notes that when maxillary apical base expansion occurs, either by rapid maxillary expansion, or slow expansion using the inner bow of a Kloehn cervical-pull headgear, there is a concomitant widening of the mandibular arch. Azizi and others (1999) found, in a study comparing this type of headgear expansion and Haas palatal expansion, that there was relative stability with both treatment modalities. The study showed greater long-term stability of mandibular canine expansion in the RME group. Spontaneous expansion was not evaluated in this study.

A study of facial type in 28 Haas expansion patients was subdivided further into 17 patients who had their permanent canines at the start of expansion. This subsample was then evaluated for treatment changes after maxillary expansion and fixed appliance treatment. The subsequent relapse was also evaluated at an average of 5.6 years out of retention. The study found that while the mandibular canines underwent slightly more relapse than the other teeth, there was a significant maintenance of 1.1mm of intercanine expansion beyond the initial measurement. No correlations were found between facial type and mandibular canine expansion (Sandstrom *et al*., 1988).

In a long-term post-retention study of Haas expansion patients, that also did not look at spontaneous lower arch expansion, found that in these patients, there was an average long-term gain in mandibular intercanine distance of 0.7mm. This study noted a mandibular intercanine relapse of 1.1mm and an acceptable mandibular incisor irregularity relapse approximately eight years out of retention (Moussa *et al.*, 1995).

2.2.3 Mandibular Canine Position Changes Subsequent to Orthopedic Maxillary Expansion

Haas discussed cases in which he noted the most substantial expansion of over three millimeters at the lower canines were ones in which the expander was stabilized for longer than usual - between six and twelve months (Haas, 2011, personal communication). Wertz

(1970) noted in his study that “Although the majority of cases failed to demonstrate lower arch width gain, a longer study might be expected to disclose such a gain...”

In a study comparing different rates of maxillary expansion, slower expansion was shown to produce indirect expansion on the mandibular teeth in ten patients in the mixed dentition. The authors presumed this was due to the 7 month retention period that the appliance was maintained in place (Sandikçioglu and Hazar, 1997). While this study supports the hypothesis of a time-dependent response, there was no evaluation of the lower canines because the subjects were in the transitional dentition. Also, the appliances used were a removable expansion plate, a quad helix, and a hyrax, but no Haas expander.

Gryson (1977) studied a sample of patients started between age four to fourteen who had orthopedic maxillary expansion averaging less than six millimeters. He examined the relationship between lower expansion and bucco-lingual occlusal relationships (ie.: crossbite, edge-to-edge, normal occlusion, and out-of-occlusion). He found no correlation between the occlusal relationships and the spontaneous lower intercanine expansion. Since he recognized that his sample was too young to be examined for treatment effects without taking into account normal growth, he used Moorrees’ (1959) data to correct for this contribution. Slight mandibular intercanine expansion was noted; however, the expansion was not carried out nearly to the extent that Dr. Haas (1980) has described. For this reason, the study does not reflect the effects one would expect with a more substantial skeletal expansion. Long-term stability and incisor alignment were not examined.

Lima and others (2004) studied the spontaneous mandibular widening subsequent to maxillary expansion as the sole treatment rendered on patients in the early to mid mixed dentition. Patients were approximately eight years of age at the start of treatment. In this study, the sample was limited to patients with little or no lower incisor crowding which precludes the study of spontaneous lower incisor alignment. Twenty eight of the thirty subjects had some form of crossbite initially, so the sample was not representative of all expansion patients. Also, two patients were noted to still not have lower permanent canines erupted 14 months after expansion was initiated. It was not noted how many did not have permanent canines erupted at the start of treatment, though at an average age of eight, there were probably many without fully erupted permanent canines. While this study was effective in assessing other aspects of indirect mandibular effects from expansion, it does not adequately assess the mandibular anterior dentition, as the sample was still expected to have transverse growth in this region considering the age at the start of treatment (Moorees *et al.*, 1969; Thilander, 2009). For this reason, the findings obtained cannot be attributed, with any degree of certainty, to treatment versus growth, nor can the findings of the study be generalized to patients with lower crowding or to patients without crossbite.

3. MATERIALS AND METHODS

3.1 Study design

The patient treatment records of 19 subjects were studied from the private practice of Dr. A.J. Haas which fit the inclusion criteria outlined below. Dental models made at four time points for each patient were measured with a digital caliper: pre-treatment (T1), at expander stabilization or subsequently at expander removal if there was still no treatment on the lower arch (T2), after active treatment at the start of retention (T3), and at least two years after retention is complete (T4).

3.2 Selection criteria

The initial sample search of the records of patients treated by Dr. Haas was conducted based on the following criteria:

1. Patient treated with Haas-type rapid palatal expander
2. Patient treated without orthognathic surgery
3. Patient treated without surgically assisted maxillary expansion
4. Patient treated without extractions
5. Permanent mandibular canines present in pre-treatment dental casts
6. Treatment notes available
7. Dental casts available for the following time points: pre-treatment (T1), at expander stabilization or at expander removal (T2), after active treatment at the start of retention (T3), at least two years after retention was completed (T4)
8. No treatment on the lower arch before T2

3.3 Sample

The sample was isolated from a pool of 400 male and female expansion patients, of whom 60 were able to return to the office for long-term post-retention records (Moussa *et al*., 1995). Subjects were eliminated according to the selection criteria. Five subjects' models were unable to be located for at least one of the four time points. Thirty-one subjects either had unerupted permanent mandibular canines at T1 or had active treatment on the lower arch before T2. Two subjects had extractions, two subjects had surgically assisted expansion, and one paper chart was unable to be located.

3.4 Clinical Protocol

The maxillary expander appliance used in patients in this study was fabricated with palatal acrylic rests and soldered buccal bars for stability (Figure 1). After appliance cementation, it was turned four one-quarter turns in the office, waiting five minutes between activations, and achieving approximately one millimeter of opening (Moussa *et al*., 1995). The appliance was then activated one-quarter turn twice per day, and an additional four one-quarter turns at weekly office visits, until between eleven and fourteen millimeters opening (measured at the jackscrew) had been achieved in 18-21 days.

Figure 1. Haas expansion appliance (Haas, 2011)

The appliance was left in place for a minimum of 100 days. Upon expander removal, a removable loose-fitting palatal acrylic plate was worn by the patient for approximately six months, and in some patients, for the remainder of active treatment to be replaced at debanding by the Hawley retainer. The maxillary retainer was worn for two years along with a fixed lower lingual retainer from canine to canine which was worn for six to seven years (Haas, 2011, personal communication).

3.5 Measurement of Variables

3.5.1 Instrumentation

Linear measurements were conducted under 2.5x magnification using Orascoptic ® dental loupes. Mitutoyo Digimatic ® No. 500 electronic caliper with Universal Serial Bus (USB) data output switch to Microsoft Excel ®. Figure 2 shows the Mitutoyo digital caliper (Mitutoyo Corporation, Kawasaki, Japan).

Figure 2. Mitutoyo Digimatic ® caliper with USB data output switch

3.5.2 Maxillary Intermolar Distance

Maxillary intermolar distance (MxID) was measured as the linear distance between the gingival margins adjacent to the lingual grooves of the permanent first molars. This measurement was recorded at each time point (T1-T4) from the maxillary models. Figure 3 depicts the lingual maxillary intermolar distance measurement.

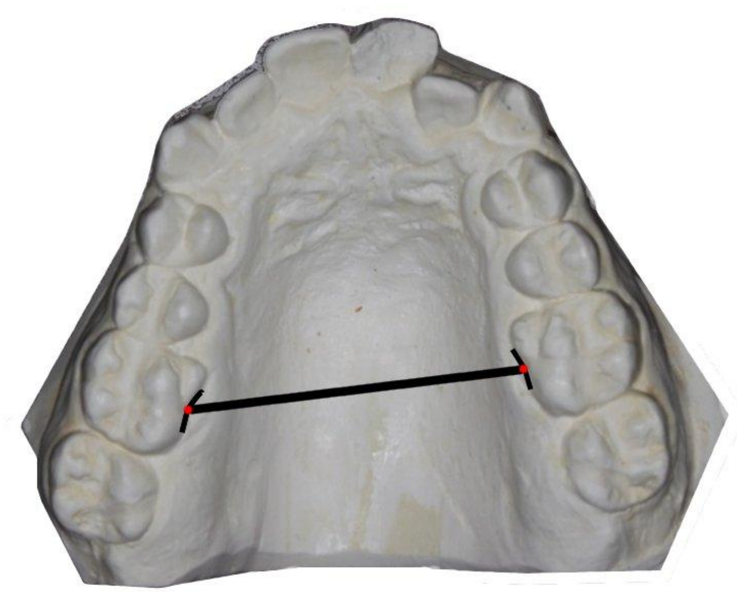

Figure 3. Maxillary intermolar distance (MxID)

3.5.3 Mandibular Intercanine Distances

Three landmarks were examined to measure mandibular intercanine distance. The linguo-gingival mandibular intercanine distance (LMID) was measured as the linear distance between canine gingival margins at the most medial (lingual) point. This was recorded on fully erupted teeth only. This measurement was recorded at each time point (T1-T4) from the mandibular models. Figure 4 depicts the lingual mandibular intercanine measurement.

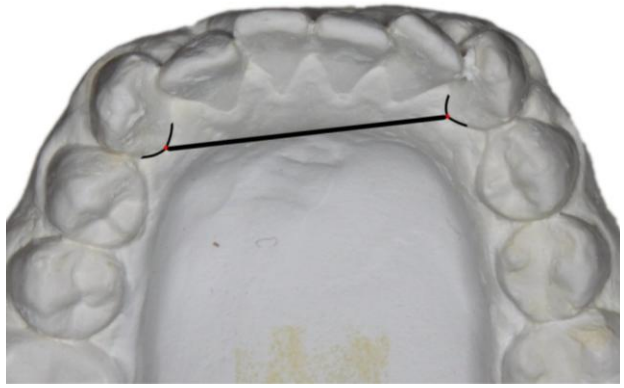

Figure 4. Lingual mandibular intercanine distance (LMID)

The cuspal (or cusp-tip) mandibular intercanine distance (CMID) was measured as the linear distance between the cusp tips, or between the centers of wear facets if the cusp tips were worn (Moorees, 1959). This measurement was recorded at each time point (T1-T4) from the mandibular models. Figure 5 shows the cuspal mandibular intercanine measurement.

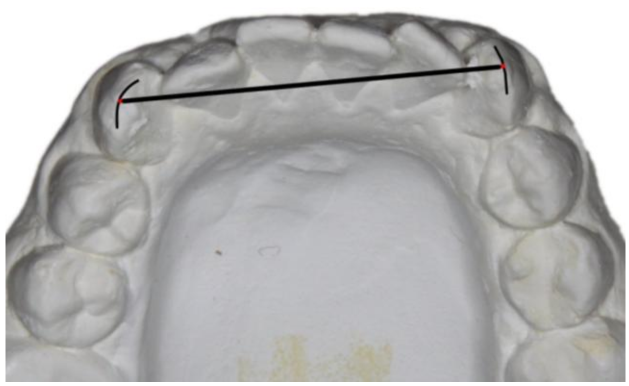

Figure 5. Cuspal Mandibular Intercanine Distance (CMID)

The alveolar mandibular intercanine distance (AMID) was measured as the shortest distance at the greatest concavity of the mandibular canine eminence (Figure 6c). The eminence was measured on a plane passing through the mandibular canine cusp tips and perpendicular to the occlusal plane (Figure 6a). This measurement was recorded at each time point (T1-T4) from the mandibular models. Figure 6 illustrates the alveolar mandibular intercanine measurement from multiple views.

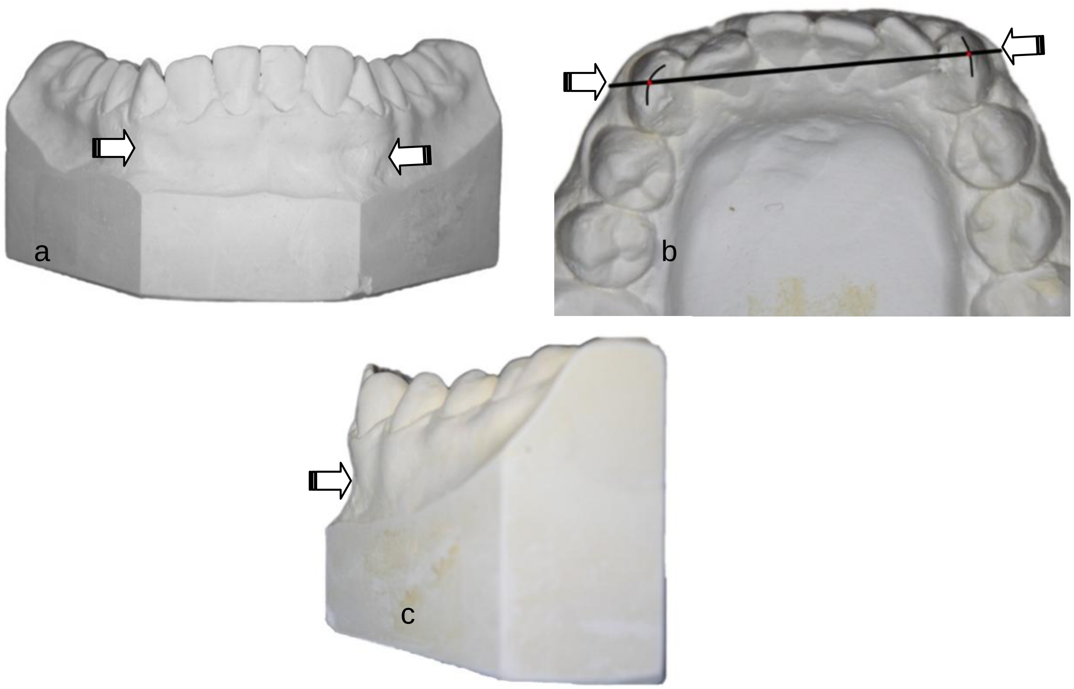

Figure 6. Alveolar mandibular intercanine distance (AMID). (a) Frontal view of canine eminences. (b) Occlusal registration of AMID measurement. (c) Oblique view of greatest concavity of the left canine eminence.

3.5.4 Mandibular Incisor Irregularity Index

Mandibular incisor irregularity index (MIII) was used to quantify linear anatomic contact point displacement as described by Little in 1975. Contact point displacement from the adjacent contact was measured. Each distance was summed from the mesial anatomic contact point of the mandibular left canine to the mesial anatomic contact point of the mandibular right canine. Mandibular incisor irregularity index was calculated in the T1, T2, T3, and T4 models. Figure 7 depicts the mandibular incisor irregularity index measurement.

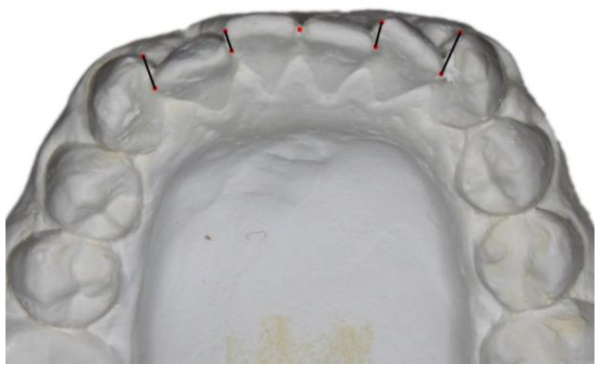

Figure 7. Mandibular incisor irregularity index (MIII)

3.5.5 Patient Age

Age of the patient was recorded in units of months from birth until the time of initiation of expansion treatment.

3.5.6 <u>Crossbite at the Mandibular Canines</u>

Presence or absence of crossbite at the mandibular canines was judged as an all-or-none value from the T1 models. If either mandibular canine was judged more labial than the opposing maxillary lateral incisor and/or canine, it was counted as a crossbite case.

3.5.7 <u>Duration from T1 to T2 used for Spontaneous Mandibular Expansion Correlation</u>

For all spontaneous expansion calculations, the duration of expansion treatment was recorded differently for patients who had no mandibular appliances placed or treatment, other than lower first molar bands, versus patients who had mandibular appliances placed shortly after stabilization. The T2 timepoint was selected as the later of the two available records - before lower treatment was initiated – at either expander stabilization or at expander removal. In those patients who had no mandibular appliances placed prior to expander removal, the time was recorded as the duration from expander placement until removal in months to one decimal place. In those patients who had mandibular appliances placed soon after expander stabilization (and before expander removal), the time was recorded as the duration from expander placement until stabilization in months to one decimal place.

3.5.8 <u>Duration from T1 to T2 Used for Stability Correlation</u>

For all stability calculations, the duration of expansion was recorded in the same manner for all patients. This duration was recorded as the time from expander placement until expander removal in months to one decimal place.

3.5.9 Calculation of Differences

Spontaneous expansion of the intercanine distance was measured as T2 -T1 for each subject in each of the four mandibular measurements: LMID, CMID, AMID, and MIII. Total treatment change was measured as T3-T1 for each subject in each of the four mandibular measurements: LMID, CMID, AMID, and MIII. Relapse was measured as T4 -T3 for each subject in each of the five measurements: MxID, LMID, CMID, AMID, and MIII.

The measuring instrument was a Mitutoyo electronic caliper with computer output to Microsoft Excel, and statistical analysis was performed using IBM SPSS version 19 (IBM SPSS, Chicago IL).

3.6 Statistical Methods

3.6.1 Error of the Method

To verify accuracy of the method, the maxillary intermolar distance change, and the three mandibular intercanine distance changes were measured on ten randomly selected pairs of casts (calculated as: LMID[T2] - LMID[T1], CMID[T2] - CMID[T1], AMID[T2] - AMID[T1]). The ten pairs of casts were then re-measured one week later. The mandibular incisor irregularity index was measured on ten casts, and then re-measured one week later. The Student's paired sample *t*-test was used on each of the three samples to assess reliability.

Mitutoyo Corporation reports accuracy of the Mitutoyo Digimatic ® No. 500 electronic caliper is ±0.02 millimeters, and repeatability is ± 0.01 millimeters.

3.6.2 Pilot study

Given the dearth of studies which examine spontaneous mandibular intercanine expansion with maxillary expansion at comparable ages, extent, and clinical management, a minimum sample size calculation was performed to determine appropriate sample size. The values from the second test of the error of the method analysis were used to determine effect size. CMID[T2]-CMID[T1] which is the landmark used to represent spontaneous expansion measured at the canine cusp tip, was the primary determinant of the sample size. Effect size was calculated as $\bar{x}/\sigma$ for a power of 0.80, or 0.709mm / 0.711mm = 0.99. This effect size corresponds with a minimum sample size of 17.

3.6.3 Statistical Analysis of Data

Shapiro-Wilk tests were conducted to examine normal distribution of the dental cast linear measurement data at each time point: pre-treatment (T1), at expander stabilization or at expander removal (T2), after active treatment at the start of retention (T3), and at least two years after retention is complete (T4).

Descriptive statistics were carried out to assess mean, median, range, and standard deviations of the following values: age in months at start of treatment, total time with the expander in place, time from placement of the expander until the T2 records used in the present study, time from cessation of all retention until T4 records used in the present study, and each of the linear measurements (MxID 1…4 2-1, 3-1, and 4-3; LMID 1…4, 2-1, 3-1, and 4-3; CMID 1…4, 2-1, 3-1, and 4-3; AMID 1…4, 2-1, 3-1, and 4-3; and MIII 1…4, 2-1, 3-1, and 4-3).

One sample *t*-tests were carried out to test spontaneous expansion and relapse data versus no change. Spontaneous expansion of the intercanine distance was measured as T2-

T1 for each subject in each of the four mandibular measurements: LMID, CMID, AMID, and MIII (spontaneous incisor alignment). Total treatment change was measured as T3-T1 for each subject in each of the four mandibular measurements: LMID, CMID, AMID, and MIII. Relapse was measured as T4 -T3 for each subject in each of the four measurements: LMID, CMID, AMID, and MIII (lower incisor crowding relapse).

Correlations were carried out to examine the relationship between the independent variables of age, amount of maxillary expansion (MxID), and duration of expander stabilization versus the dependent variables of spontaneous expansion and relapse. Correlation analysis was also performed on spontaneous expansion versus stability.

3.7 Data Management

Dr. Haas' log containing expansion patients with long-term post-retention records was examined by Dr. Haas' staff for the isolation of appropriate records. The necessary records were deidentified, and recoded on a coded sheet (case 1, 2, 3, etc.). The treating doctor retained the coded list of patients for the purpose of returning the records to the appropriate places once the study was completed. A second sheet for the principal investigator that only contained the code number, the patient's demographic information (gender, age – not date of birth, and race), and history of orthodontic treatment was made. Following completion of data collection, all records, data, and code sheet were returned to the private practice. The data was not made available to anyone other than the principal investigator and the research staff. Once the data collection was complete, the code sheet which associates each study case with PHI was destroyed.

IRB Exemption status for this study (Protocol # 2011-0403) was granted for the period of June 2, 2011 to June 1, 2014. Exemption was granted under category four, in which the collection and study of existing diagnostic specimens and records is allowed if these sources are recorded by the investigator in such a manner that subjects cannot be identified (Appendix A).

4. RESULTS

4.1 Reliability Tests

The measurements for reliability were recorded on ten randomly selected cases at the T1 and T2 timepoints and were repeated one week later for comparison. Correlations and paired sample *t*-tests were considered significantly different if $p \leq 0.05$.

Table I shows the degree of the relationship between the first and second trials. All measurements and differences between the measurements were significantly correlated ($p < 0.05$). The correlation coefficients were greater than 0.95 for all measurements except AMID T1 and AMID T2-T1, though all measurements were highly significantly correlated.

TABLE I
PAIRED SAMPLES CORRELATIONS (N = 10)

Trial 1 & Trial 2	Correlation	Sig.
MxID T1 & MxID T1	.999	.000*
MxID T2 & MxID T2	.999	.000*
MxID2-1 & MxID2-1	.996	.000*
CMID T1 & CMID T1	.988	.000*
CMID T2 & CMID T2	.987	.000*
CMID2-1 & CMID2-1	.964	.000*
AMID T1 & AMID T1	.914	.000*
AMID T2 & AMID T2	.986	.000*
AMID2-1 & AMID2-1	.716	.020*
LMID T1 & LMID T1	.999	.000*
LMID T2 & LMID T2	.995	.000*
LMID2-1 & LMID2-1	.977	.000*
MIIISUM & MIIISUM	.989	.000*

* $p < 0.05$

Table II shows the results of the repeated measures paired samples *t*-tests. The 95% confidence interval shows that the measurement error ranged from ±0.05mm for MxID and LMID, ±0.14mm for CMID measurement, to ±0.35mm for the MIII summed measurement, to ±0.5mm for the AMID measurements. However, the only statistically significant difference between measurements was in the MxID at T2 ($p = 0.048$).

TABLE II
PAIRED SAMPLES *T*-TEST

Trial 1 & Trial 2	95% Confidence Interval of the Difference		t	df	Sig
	Lower	Upper			
MxID T1 - MxID T1	-.11079	.01079	-1.861	9	.096
MxID T2 - MxID T2	-.15916	-.00084	-2.286	9	.048*
MxID2-1 - MxID2-1	-.08353	.02353	-1.268	9	.237
CMID T1 - CMID T1	-.11690	.16290	.372	9	.719
CMID T2 - CMID T2	-.14641	.14441	-.016	9	.988
CMID2-1 - CMID2-1	-.15435	.10635	-.416	9	.687
AMID T1 - AMID T1	-.47433	.54033	.147	9	.886
AMID T2 - AMID T2	-.12566	.33766	1.035	9	.328
AMID2-1 - AMID2-1	-.45833	.60433	.311	9	.763
LMID T1 - LMID T1	-.00461	.09661	2.056	9	.070
LMID T2 - LMID T2	-.15928	.02728	-1.601	9	.144
LMID2-1 - LMID2-1	-.22545	.00145	-2.233	9	.052
MIIISUM - MIIISUM	-.39996	.32196	-.244	9	.812

*$p < 0.05$

4.2 Study Sample Distribution

The sample consisted of 6 males and 13 females. There were 9 cases with crossbite at the mandibular canines and 10 without crossbite. The average age at initiation of treatment was 15y4m (SD 6y). The total time with the expander averaged 5.9m (SD 1.9m). The average time between T1 and T2 was 3m (SD 2.4m). Eight subjects who had no lower treatment until expander removal averaged 5.1m (SD 1.5m). Eleven subjects who had appliances placed soon after stabilization had a T1 to T2 span of 1.4m (SD 1.1m). The average time post-retention (labeled “offling” for off lower lingual retainer) was 8y2m (SD 4y) . Figure 8 shows the time points as they relate to treatment phase and the duration of time between points. Table III shows the range, mean and standard deviation of the measured continuous variables and their changes.

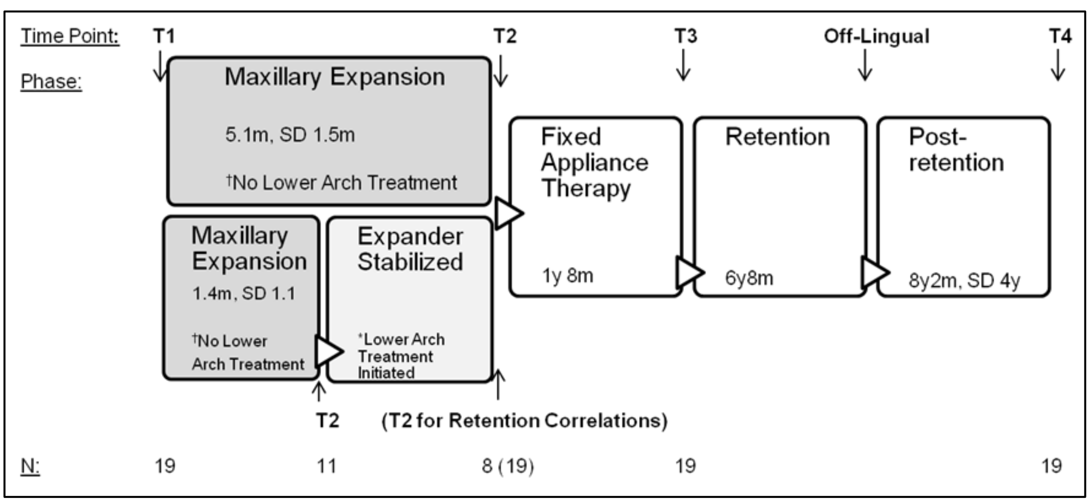

Figure 8. Time point relationship to treatment phase and treatment time

TABLE III
DESCRIPTIVE STATISTICS (N = 19)

	Minimum	Maximum	Mean	Std. Deviation
age	129	433	183.16	72.18
T(exp)	3.0	9.3	5.90	1.91
T(1-2)	.5	7.6	3.079	2.39
OffLing	29	180	98.61	48.60
MxIDT1	26.88	37.60	32.77	2.56
MxIDT2-1	7.36	11.89	9.41	1.22
LMID1	15.81	20.32	18.88	1.07
LMID2	16.05	21.25	19.24	1.17
LMID3	17.60	21.81	20.15	1.12
LMID4	16.8	21.9	19.54	1.47
CMID1	22.04	27.13	25.15	1.20
CMID2	22.76	27.92	25.72	1.11
CMID3	24.33	29.16	26.84	1.34
CMID4	23.94	29.08	26.06	1.34
AMID1	28.35	36.40	30.80	2.00
AMID2	28.41	37.29	31.47	1.99
AMID3	27.16	35.99	30.93	2.19
AMID4	26.45	35.65	30.39	2.17
MIII1	1.7	13.3	6.40	3.00
MIII2	1.14	9.53	5.12	2.54
MIII3	0.3	3.1	1.36	0.78
MIII4	0.82	3.89	1.96	0.88
LMID2-1	-0.41	1.52	0.35	0.55
CMID2-1	-0.28	2.15	0.57	0.56
AMID2-1	-0.58	3.04	0.66	1.00
MIII2-1	-3.77	0.04	-1.28	0.97
LMID3-1	-0.94	3.14	1.26	0.90
CMID3-1	-0.61	5.44	1.69	1.45
AMID3-1	-2.99	3.42	0.12	1.39
MIII3-1	-11.6	-1.2	-5.0	2.79
LMID4-3	-3.75	0.29	-0.61	0.87
CMID4-3	-2.47	0.38	-0.78	0.76
AMID4-3	-2.20	1.38	-0.54	0.71
MIII4-3	-0.70	2.25	0.59	0.79

Figure 9 shows the distribution of the lingual mandibular intercanine distance (LMID) over the four time points. The box plots graphically display the range, median, and spread of the related data sets and how they relate to one another. Each horizontal hash of the boxplot delineates a quartile, with the bold middle hash being the median. The outliers are displayed above or below the whiskers as a circle if they are greater than 1.5x the range of the middle two quartiles (shaded box portion). The outliers are displayed as an asterisk if they are greater than 3x the spread of the middle two quartiles. Skewness and kurtosis can also be visualized in the symmetry and spread of the tails. Once again, the average span between T1 and T2 was 3 months, and the average time between T3 and T4 was a sum of 8 years average post-retention, plus the 6 years of average retention time after final records, totaling a 14 year span.

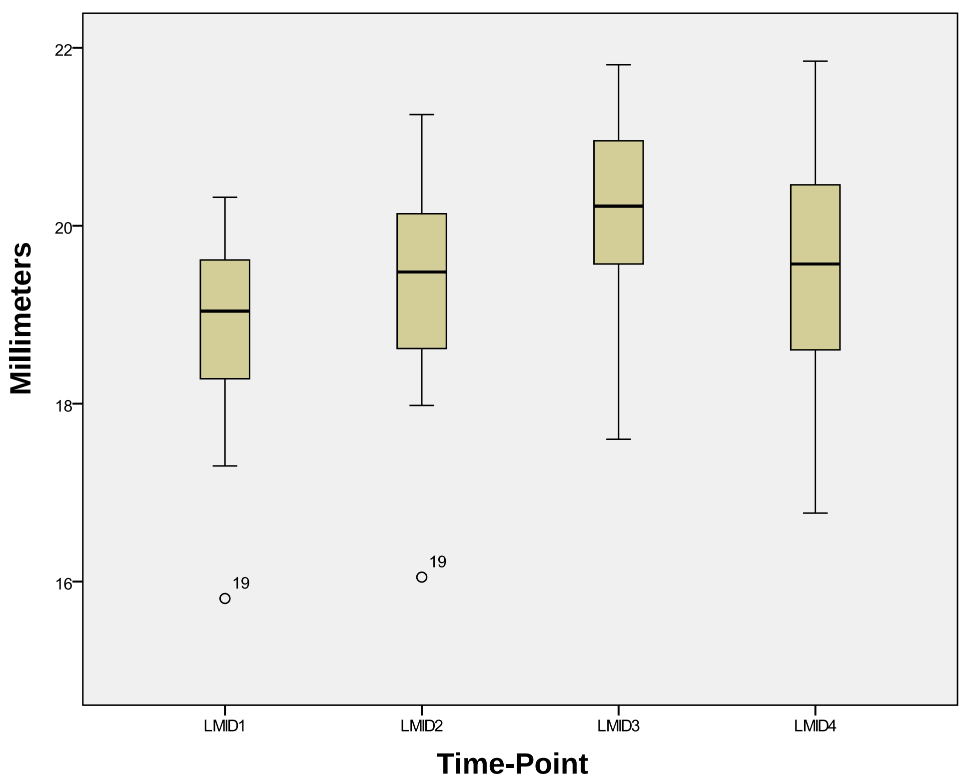

Figure 9. Lingual mandibular intercanine distance vs. time

Figure 10 shows the cuspal mandibular intercanine distance (CMID) over the four time points. Just as in Figure 9, case 19 was counted as an outlier in timepoints 1 and 2, while in timepoints 3 and 4 this measurement was increased to within 1.5x the box range so as not to be included as an outlier. At T4 there are three outliers that showed exceptional maintenance of the intercanine expansion. As in Figure 9, one can visualize the pattern of expansion from T1 to T2 to T3, then relapse in T4.

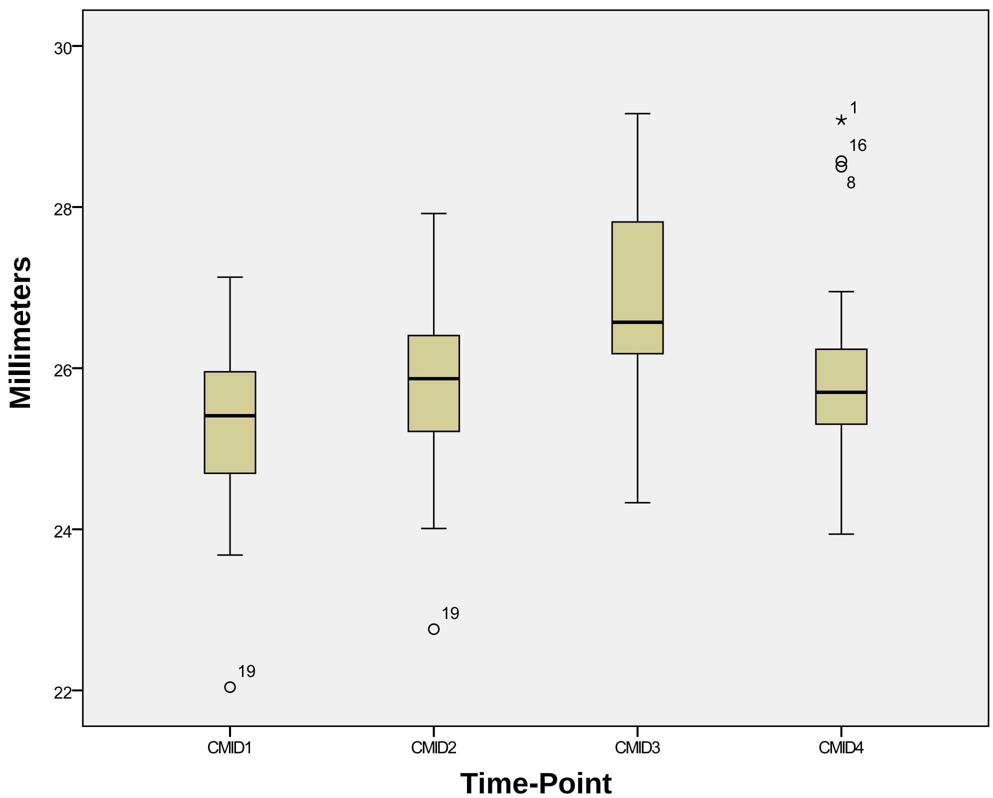

Figure 10. Cuspal mandibular intercanine distance vs. time

Figure 11 shows the alveolar mandibular intercanine distance (AMID) over the four time points. There is modest expansion from T1 to T2; however, unlike figures 9 and 10, there is an apparent decrease from T2 to T4. Case 11 is an outlier in timepoints 1, 2 and 4; however, in T3, Case 11 is within 1.5x the width of the box, so it is included in the boxplot.

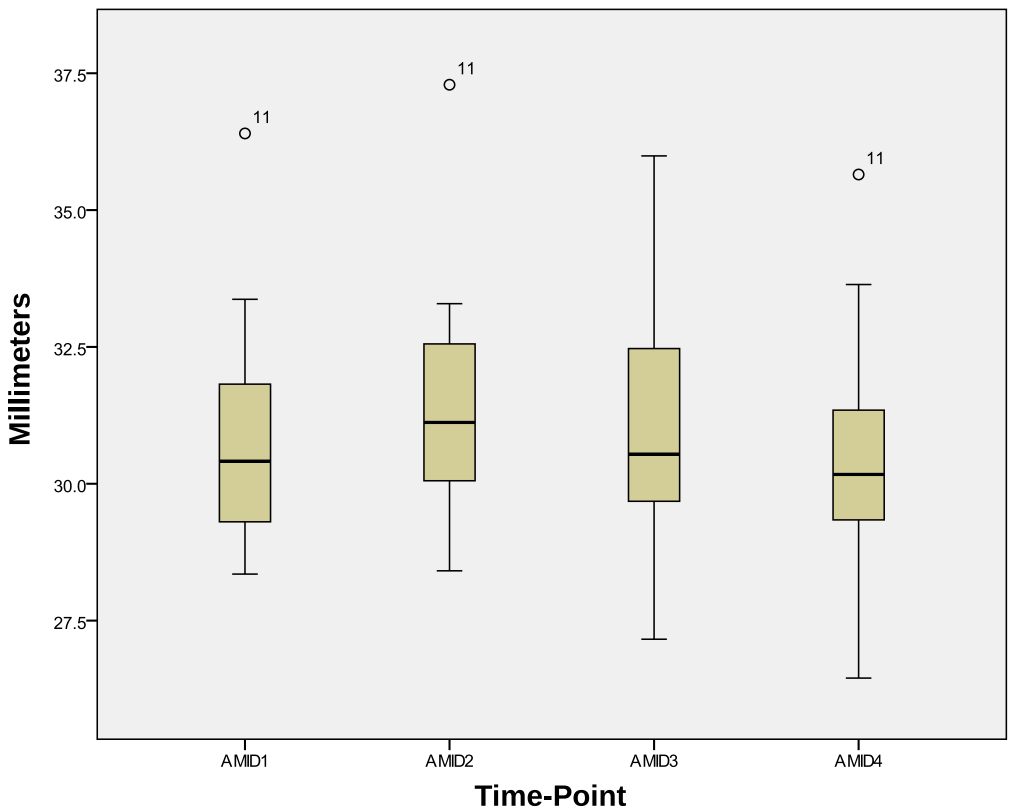

Figure 11. Alveolar mandibular intercanine distance vs. time

Figure 12 shows the mandibular incisor irregularity index (MIII) over the four time points. In timepoints 1 and 2, there is a wider range of irregularity, while at timepoints 3 and 4 there is decreased range. Whereas in figures 9 and 10 there is a pattern of increased intercanine distance in T1-3 and a decrease at T4, with the MIII, there is the inverse relationship. There were no outliers in this box-plot.

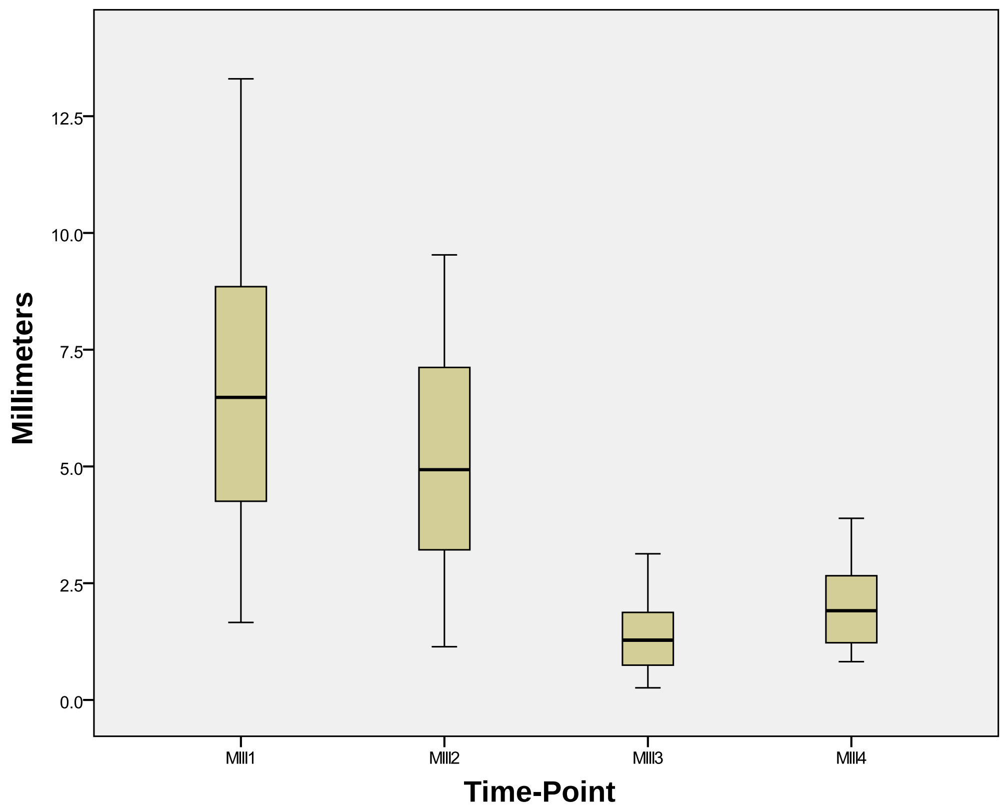

Figure 12. Mandibular incisor irregularity index vs. time

Figure 13 shows the change in mandibular incisor irregularity index (MIII) for patients with crossbites at the mandibular canines (right) and for those without crossbites (left). While both groups exhibit approximately the same median decrease in irregularity, approximately 1mm, the non-crossbite group distribution is skewed towards a greater decrease. Despite the appearance, there is not a statistically significant difference between the two groups (p = 0.07)

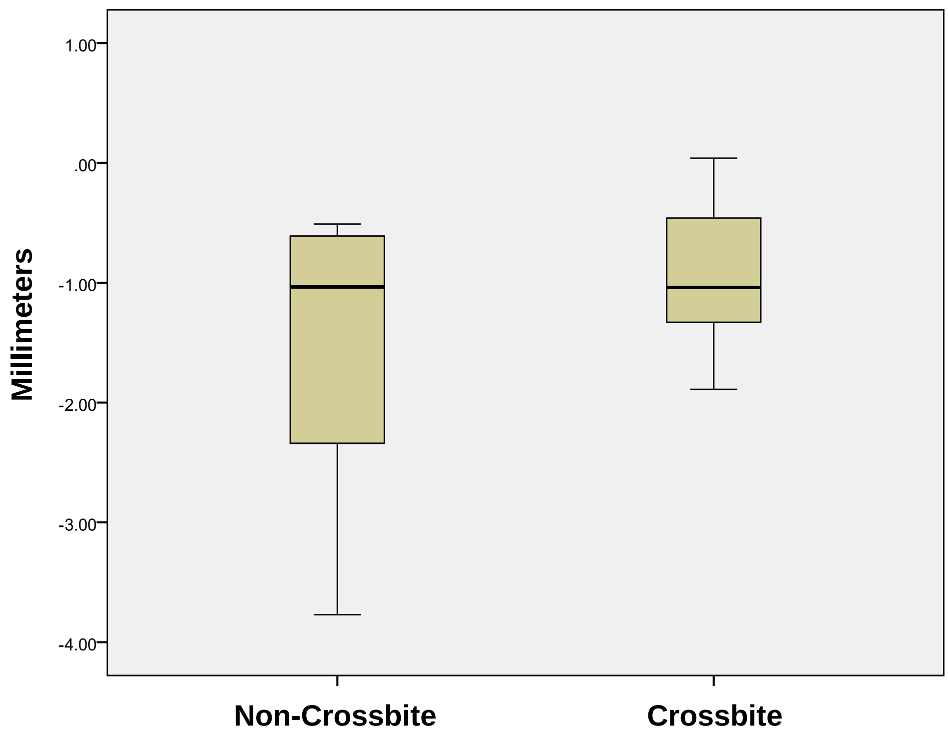

Figure 13. Change in mandibular incisor irregularity index (MIII) from T1 to T2 for mandibular canine crossbite vs non-crossbite relationships

4.3 Normality Tests

All of the starting values and change calculations were normally distributed except the following: initial age, time between T1 and T2, change in MIII and AMID from T1 to T2, and T3 to T4, and the change in LMID from T3 to T4 ($p < 0.05$).

TABLE IV
SHAPIRO-WILK TESTS

	Statistic	Sig.
Age	.661	.000*
T(exp)	.951	.416
T(1-2)	.888	.030*
OffLing	.948	.368
MxIDT1	.979	.925
MxIDT2-1	.977	.901
LMID1	.902	.053
CMID1	.957	.507
AMID1	.912	.082
MIII1	.967	.713
LMID2-1	.923	.126
CMID2-1	.922	.122
AMID2-1	.869	.014*
MIII2-1	.889	.030*
LMID 3-1	.953	.440
CMID3-1	.935	.218
AMID3-1	.971	.804
MIII3-1	.953	.438
LMID4-3	.697	.000*
CMID4-3	.932	.187
AMID4-3	.899	.048*
MIII4-3	.975	.871

4.4 One Sample and Paired Sample *t*-Tests

Table V shows that there was significant expansion in all the mandibular intercanine distance measurements from T1 to T2 ($p < 0.02$). There was a significant decrease in the mandibular incisor irregularity index (MIII) between these timepoints ($p < 0.001$).

TABLE V
ONE-SAMPLE *T*-TESTS OF SPONTANEOUS EXPANSION

	Test Value = 0					
	t	df	Sig.	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
LMID T2-1	2.809	18	.012*	.35632	.0898	.6228
CMID T2-1	4.447	18	.000*	.57158	.3015	.8416
AMID T2-1	2.900	18	.010*	.66789	.1840	1.1518
MIII T2-1	-5.740	18	.000*	-1.28421	-1.7543	-.8142

*p < 0.05

As opposed to Table V, Table VI shows significant constriction in the mandibular intercanine distance measurements from T3 to T4 ($p < 0.01$). Additionally, there was significant increase in the mandibular incisor irregularity index (MIII) between these timepoints ($p < 0.01$).

TABLE VI
ONE-SAMPLE *T*-TESTS OF RELAPSE

	Test Value = 0					
	t	df	Sig.	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
LMID T4-3	-3.063	18	.007*	-.61211	-1.0319	-.1923
CMID T4-3	-4.479	18	.000*	-.78105	-1.1474	-.4147
AMID T4-3	-3.294	18	.004*	-.54053	-.8853	-.1958
MIII T4-3	3.305	18	.004*	.59684	.2175	.9762

*p < 0.01

Table VII shows the long-term maintenance of expansion in the intercanine measurements compared to both the spontaneously expanded distance, T2, and compared to initial, T1. There is a significantly greater distance of AMID at T2 versus T4 ($p = 0.003$). In the T4 versus T1 pairings, there is a significant maintenance of 0.66mm at LMID of ($p = 0.049$) and 0.91mm at CMID ($p = 0.018$).

TABLE VII
PAIRED SAMPLE T-TEST OF LONG-TERM STABILITY OF INTERCANINE MEASUREMENTS

		Mean	Std. Deviation	Std. Error	95% CI of Difference Lower	95% CI of Difference Upper	t	sig
Pair 1	LMID4 - LMID2	.30053	1.23539	.28342	-.29491	.89596	1.060	.303
Pair 2	CMID4 - CMID2	.33737	1.27728	.29303	-.27826	.95300	1.151	.265
Pair 3	AMID4 - AMID2	-1.08421	1.34854	.30938	-1.73419	-.43424	-3.505	.003*
Pair 4	LMID4 - LMID1	.65684	1.35933	.31185	.00167	1.31202	2.106	.049*
Pair 5	CMID4 - CMID1	.90895	1.52069	.34887	.17600	1.64190	2.605	.018*
Pair 6	AMID4 - AMID1	.41632	1.35670	.31125	-1.07023	.23759	-1.338	.198

*p < 0.05

Table VIII tests the value of 3.5mm which represents the maximum acceptable MIII against the sample MIII T4 long-term post-retention timepoint. The study sample irregularity index is significantly less than 3.5mm ($p < 0.001$).

TABLE VIII
ONE SAMPLE *T*-TEST OF LONG-TERM ACCEPTABILITY

	Test Value = 3.5					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper
MIII4	-7.556	18	.000*	-1.53421	-1.9608	-1.1076

*p < 0.001

4.5 Correlation

Table IX shows the correlation between the independent variables of age at the start of expansion, the duration of maxillary expansion, and the amount of maxillary expansion, versus the dependent measurements of mandibular intercanine distance and incisor irregularity. Spontaneous expansion was defined as the change in these measurements between T1 and T2. No significant correlations were found between dependent and independent variables. There were, however, highly significant correlations noted between the independent variable pairs LMID & CMID ($p = 0.004$), and CMID & MIII ($p = 0.003$).

TABLE IX
CORRELATION OF AGE, AMOUNT AND DURATION OF MAXILLARY EXPANSION VS. SPONTANEOUS MANDIBULAR INTERCANINE EXPANSION AND INCISOR ALIGNMENT (N = 19)

		Age	MxIDT2-1	T(1-2)	LMID2-1	CMID2-1	AMID2-1	MIII2-1
Age	Pearson Correlation	1	-.208	-.064	-.155	.053	.190	-.169
	Sig. (2-tailed)		.392	.793	.527	.831	.437	.490
MxIDT2-1	Pearson Correlation	-.208	1	.167	.149	.001	-.322	-.084
	Sig. (2-tailed)	.392		.495	.543	.996	.179	.733
T(1-2)	Pearson Correlation	-.064	.167	1	.077	.208	-.366	-.093
	Sig. (2-tailed)	.793	.495		.756	.393	.123	.705
LMID2-1	Pearson Correlation	-.155	.149	.077	1	.623**	.013	-.454
	Sig. (2-tailed)	.527	.543	.756		.004	.959	.051
CMID2-1	Pearson Correlation	.053	.001	.208	.623**	1	-.251	-.642**
	Sig. (2-tailed)	.831	.996	.393	.004		.301	.003
AMID2-1	Pearson Correlation	.190	-.322	-.366	.013	-.251	1	.159
	Sig. (2-tailed)	.437	.179	.123	.959	.301		.515
MIII2-1	Pearson Correlation	-.169	-.084	-.093	-.454	-.642**	.159	1
	Sig. (2-tailed)	.490	.733	.705	.051	.003	.515	

**$p < 0.01$

Table X shows the correlation between the independent variables of age at the start of expansion, the duration of maxillary expansion, and the amount of maxillary expansion, versus the dependent mandibular relapse measurements. Relapse of the mandibular expansion was defined as the change in these measurements between T4 and T3. Significant correlation existed between AMID and duration of expansion ($p = 0.04$) and there also, as in Table IX, between the independent variable pair LMID & CMID ($p = 0.008$).

TABLE X
CORRELATION OF AGE, AMOUNT AND DURATION OF MAXILLARY EXPANSION VS. MANDIBULAR INTERCANINE AND INCISOR RELAPSE (N = 19)

		Age	T(exp)	MxIDT2-1	LMID4-3	CMID4-3	AMID4-3	MIII4-3
Age	Pearson Correlation	1	.137	-.208	.173	.106	.149	-.032
	Sig. (2-tailed)		.575	.392	.478	.665	.543	.896
T(exp)	Pearson Correlation	.137	1	.285	.238	.278	.466*	-.339
	Sig. (2-tailed)	.575		.237	.326	.250	.044	.155
MxIDT2-1	Pearson Correlation	-.208	.285	1	-.181	-.035	-.098	-.406
	Sig. (2-tailed)	.392	.237		.458	.888	.690	.084
LMID4-3	Pearson Correlation	.173	.238	-.181	1	.586**	.236	-.151
	Sig. (2-tailed)	.478	.326	.458		.008	.330	.537
CMID4-3	Pearson Correlation	.106	.278	-.035	.586**	1	.284	-.365
	Sig. (2-tailed)	.665	.250	.888	.008		.238	.124
AMID4-3	Pearson Correlation	.149	.466*	-.098	.236	.284	1	-.177
	Sig. (2-tailed)	.543	.044	.690	.330	.238		.470
MIII4-3	Pearson Correlation	-.032	-.339	-.406	-.151	-.365	-.177	1
	Sig. (2-tailed)	.896	.155	.084	.537	.124	.470	

*$p < 0.05$
**$p < 0.01$

Table XI shows the correlation among the dependent variables between the two time spans: amount of spontaneous expansion (T2-T1) and relapse (T4-T3). As in Tables IX and X, there were significant correlations between the independent variable pairs MIII & CMID and LMID & CMID at T2-T1, and between pair LMID & CMID at T4-T3. There were no significant relationships between measurements taken at T2-T1 versus T4-T3.

TABLE XI
CORRELATION BETWEEN MANDIBULAR INTERCANINE SPONTANEOUS EXPANSION VS. RELAPSE

		LMID4-3	CMID4-3	AMID4-3	MIII4-3	LMID2-1	CMID2-1	AMID2-1	MIII2-1
LMID4-3	Pearson Correlation	1	.586**	.236	-.151	.300	-.201	.295	-.016
	Sig. (2-tailed)		.008	.330	.537	.213	.409	.221	.949
CMID4-3	Pearson Correlation	.586**	1	.284	-.365	.007	-.295	-.024	-.075
	Sig. (2-tailed)	.008		.238	.124	.976	.221	.921	.759
AMID4-3	Pearson Correlation	.236	.284	1	-.177	.018	-.195	.009	.396
	Sig. (2-tailed)	.330	.238		.470	.941	.424	.971	.093
MIII4-3	Pearson Correlation	-.151	-.365	-.177	1	-.049	.202	-.075	-.189
	Sig. (2-tailed)	.537	.124	.470		.841	.407	.759	.439
LMID2-1	Pearson Correlation	.300	.007	.018	-.049	1	.623**	.013	.454
	Sig. (2-tailed)	.213	.976	.941	.841		.004	.959	.051
CMID2-1	Pearson Correlation	-.201	-.295	-.195	.202	.623**	1	-.251	-.642**
	Sig. (2-tailed)	.409	.221	.424	.407	.004		.301	.003
AMID2-1	Pearson Correlation	.295	-.024	.009	-.075	.013	-.251	1	.159
	Sig. (2-tailed)	.221	.921	.971	.759	.959	.301		.515
MIII2-1	Pearson Correlation	-.016	-.075	.396	-.189	-.454	-.642**	.159	1
	Sig. (2-tailed)	.949	.759	.093	.439	.051	.003	.515	

** $p < 0.01$

5. DISCUSSION

5.1 Reliability

The difference of the alveolar measurement AMID T2-T1 had a correlation of 0.72 which was significant (p = 0.02), while the other measurements correlations were greater than 0.9. The correlation coefficient of AMID at T1 when measured twice showed slightly less consistency, and subsequently the difference of AMID T2-T1, when calculated for the a second trial, also showed less consistency.

In the paired samples *t*-test, the maxillary intermolar distance at T2 (MxID2) showed a statistically significant difference in the reliability testing (p = 0.048). While the 95% confidence interval of the difference was wholly negative, the upper limit was -0.00084 which is essentially zero, especially when considering other sources of error. Also, the range of this measurement was ±0.075mm which is an acceptably small error range. One possible explanation for this difference being at T2 specifically was most likely a result of eleven of the maxillary models at T2 having the expander in place, making landmark identification less consistent. Some variation in identification of the gingival margin positions was also noted due to inflammation from the expander's recent removal.

The 95% confidence interval showed that the measurement error ranged from ±0.05mm for MxID and LMID, ±0.14mm for CMID measurement, to ±0.35mm for the MIII summed measurement, and ±0.5mm for the AMID measurements. The MxID and LMID measurements showed the most accuracy. CMID, which is the most commonly used measurement in the literature, is not repeatable as accurately, but it still showed an acceptable level of repeatability. The MIII measurements showed increased variation of 0.35mm which is likely a result of being a sum of five measurements, each of which having inherent error. While this is a greater value, its meaning is diminished by the observed changes being significantly larger than the other mandibular canine measurement changes.

The AMID measurement had the largest range of the confidence interval, and this will be discussed further with the limitations of the model measurements.

Lima *et al.* (2004) reported the reliability trial of ten casts measured twice using one standard deviation (68% of the distribution) of 0.07mm to 0.18mm. The measurements tested in this study included lower molar measurements and equivalent measurements of LMID and CMID, but the reliability of each is not specified. In the present study, LMID and CMID were within the same range of error as reported by Lima *et al.,* except at a level of confidence of two standard deviations versus one.

5.2 Normality

The time between T1 and T2 was not normally distributed. This is a result of the variation in individual treatment plan of the subjects. While eight subjects had no lower arch treatment throughout expansion treatment, eleven had appliances placed shortly after stabilization records were taken. The resulting unequal time-spans between T1 and T2 are evident in Figure 8. Since the T1-T2 time span was an independent variable used in the correlation of spontaneous expansion, a non-normal distribution is acceptable. Starting age was also an independent variable used for correlations, and it too was not normally distributed.

The change in MIII from T1 to T2 was not normally distributed (Figure 13, Table IV). There are two factors that likely contributed to this: an uneven distribution of MIII values at T1, and disproportionate change. Further investigation showed at T1 the non-crossbite subgroup had MIII of 8.1mm (SD 2.4mm), versus the crossbite subgroup which had MIII of 4.4mm (SD 2.2), though when combined, the MIII data set at T1 was normally distributed. Table IV and Figure 13 showed that there was a disproportionately greater change from T1 to

T2 of mandibular incisor irregularity (MIII) in the non-crossbite group, although this was not statistically significant ($p=0.07$).

LMID changes from T3 to T4 were not normally distributed. This can be attributed in part to LMID at T4 which had the most outliers of any measurement. Changes in AMID from T1 to T2, and T3 to T4 were not normally distributed, and this will be discussed further with the limitations of the study.

5.3 Mandibular Intercanine Distance

The T1 to T4 means for the LMID were 18.88mm, 19.24mm, 20.15mm, and 19.54mm respectively. The LMID measurement showed significant spontaneous expansion from T1 to T2 of 0.35mm ($p = 0.012$) with a range of -0.4mm to +1.5mm (Figure 9, Table V). Further expansion was noted from T2 to T3 (Figure 9). Significant relapse of 0.6mm was noted from T3 to T4 ($p = 0.007$). At a mean of over eight years post-retention the final width was 0.3mm greater than the spontaneously expanded dimension, T2, and 0.66mm greater than T1.

LMID and CMID were very highly correlated ($p < 0.01$) (Table X). This finding is in agreement with Lima *et al.* (2004). This result is expected because the landmarks are closely related on the tooth's surface and are both located incisally to the center of resistance of the tooth.

The T1 to T4 means for the CMID followed the same pattern as LMID. The measurements averaged 25.15mm, 25.72mm, 26.84mm, and 26.06mm.respectively. The CMID measurement showed significant spontaneous expansion from T1 to T2 of 0.57mm ($p < 0.001$) with a range of -0.28mm to +2.15mm (Figure 10, Table V). For this reason, null hypothesis one was rejected. Further expansion was noted from T2 to T3 (Figure 10). Significant relapse of 0.78mm was noted from T3 to T4 ($p < 0.001$) (Table VI). There was an average long-term gain of 0.91mm versus T1, and this was 0.34mm greater than the spontaneously expanded dimension at T2. The total average expansion of the intercanine distance was 1.69mm over the course of total treatment. The relatively greater response at the cusp tip versus the lingual landmark suggests an uprighting or buccal tipping of the mandibular cuspid.

The spontaneous expansion measured 0.35mm at the lingual gingival margin (LMID) and 0.57mm at the canine cusp tip (CMID) is consistent with that found in other studies. Lima *et al*. (2004) reported 0.39mm spontaneous lower intercanine expansion; however, this study had a younger sample that was expected to have some growth in this dimension, and growth was not taken into account. Growth would have caused this expansion to be erroneously high. Also, this sample was made up predominantly of crossbite cases which might have caused the mean expansion to be lower. Gryson (1977) did take growth into account, and he found a smaller spontaneous lower intercanine expansion of 0.2mm, but the average maxillary expansion was only 5.8mm.

The present study's findings of 0.91mm of residual cusp-tip expansion an average of 8 years out of retention is similar to the 1.1mm found by Sandstrom *et al.* (1988) whose sample was measured 5.6 years out of retention. Azizi *et al*. (1999) found a significant maintenance of 0.4mm of residual expansion at the mandibular canine cusp tips in the maxillary expansion group, and 0.5mm in the headgear expansion group nearly eight years after the end of retention.

When comparing the long term gains of this study to studies of long-term stability without expansion, 0.91mm is a more unusual figure. After a similar post-retention duration, Glenn *et al.* (1987) found approximately 1mm relapse after 0.6mm intercanine expansion in 28 non-extraction and non-expansion cases. This amounts to a long-term net change of -0.4mm. The highest reported stability was by Shapiro (1974) in nine Class II division 2 cases of which there were three treated non-extraction and six treated with expansion. This Class II division 2 subsample showed a mean maintenance of 1.5mm intercanine expansion, after relapse of 1mm, ten years post-retention. In the present study, there were no Class II division 2 malocclusions.

When comparing long-term gain in the present study of 0.91mm in CMID to that of untreated samples with a comparable time span, the benefit to this treatment is more apparent. Bishara *et al*. (1997) in a longitudinal study found a net decrease of 0.75mm averaged between 15 males and 15 females. Thilander (2009) in a cross-sectional study also noted a net decrease of 0.75mm averaged between 11 males and 19 females.

5.4 Alveolar Mandibular Intercanine Distance

In Figure 11, it appears as though there is less change in the AMID measurement between timepoints. In actuality, the AMID has significant change between timepoints, but there is a greater range of values in comparison to figures 9 (LMID) and 10 (CMID). This caused the scale on the y-axis of the box-plot to appear relatively compressed.

The alveolar measurement, AMID, follows a slightly different pattern to the other measurements. As opposed to the other measurements which show peak expansion at T3 (Figures 9 and 10), AMID shows a peak at T2 (Figure 11). The most likely explanation for AMID being greatest at T2 whereas the other canine measurements are greatest at T3 is the differences in the basing and trimming of the models. At T1, T3, and T4 the models were based trimmed, maximizing the depth of the vestibule, while in T2 the models were not based. A model's presence or absence of a base would not impact the LMID or CMID measurements which were taken from the teeth portion of the model. At T2, however, the models were not based and were not poured to the same extent of the other time points. This results in a shallower apparent vestibule, which in the transverse dimension leaves a broader portion of the canine eminence for measurement.

5.5 Mandibular Incisor Irregularity Index

The MIII at T1 had a very wide distribution that was not normal. Some of this can be explained by the variation between the subjects with and without crossbites at the lower canines (Figure 13). In Figure 12, the proportionate constriction and lowering of the box-plots from T1 to T2 suggests a proportionate mandibular expansion response to the degree of pre-treatment crowding.

One common thread which explains the relapse in intercanine distance yet relative stability of the MIII measurement was the fact that the treating doctor left some lower incisor spacing in twelve of the nineteen subjects. This technique may allow for relapse in the intercanine distance while preventing crowding. A treatment variable which was not measured in this study is the practice of interproximal reduction in the mandibular anterior region to help prevent relapse (Peck and Peck, 1972; Boese, 1980). The treating doctor reported doing this routinely following removal of the lower fixed retainer.

The determinant of a successful long-term outcome was MIII at T4 less than 3.5mm (Little *et al.*, 1981). Eighteen of the nineteen subjects fulfilled this criteria. The outcomes in the present study were acceptable eight years post-retention at a remarkable rate of 95%. The one case which did not meet the 3.5mm threshold for stability had canine rotations that were not corrected fully at T3. This case had the highest MIII at T3 of 2.3mm and at T4 MIII relapsed to just 3.9mm after 15 years of no lower retainer. This increase in incisor irregularity from T3 to T4 of 1.6mm in such a long time was still greater than the mean MIII relapse of 0.56mm (Table III, Appendix B). Null hypothesis five was rejected.

Little *et al*. (1981) found that MIII increased to a mean of 4.6mm approximately ten years post retention in four bicuspid extraction cases, and while this is only a slightly longer recall than the present study, the mean irregularity was substantially greater. More than 70% of the sample was considered to have less-than-acceptable incisor irregularity (MIII >

3.5mm). Azizi *et al*. (1999) found a significant reduction from 5.1mm to 1.2mm irregularity in Haas expansion patients, and non-significant (p = 0.054) relapse in irregularity of 0.5mm to 1.7mm after eight years of retention. These results agree with the present study that incisor irregularity in Haas expansion cases are quite stable and show acceptable results long-term.

5.6 Correlations

The independent variables of age at treatment initiation, amount of expansion, and duration of expansion were correlated against spontaneous expansion and relapse. The only significant correlation was between the AMID relapse and the duration of expansion. The lack of significance of the other correlations is due, in part, to the limitations of the study. Null hypotheses two, three and four were retained.

AMID constriction corresponds to published growth and development depictions of mandibular changes (Enlow and Harris, 1964). The duration of expansion was longer in non-growing subjects (Appendix B). It is possible that the non-growing subjects with longer duration of expansion had less resorptive change in the mandibular canine eminence region than did the growing subjects. This decrease in AMID in growing subjects—that the non-growing subjects did not have—could have resulted in a correlation for the observed decrease from T3 to T4. In general, the results of the AMID measurement in this study were inconclusive. The repeatability, significance, and usefulness of this measurement was not supported by the data in this study, and therefore its use is not recommended in further studies on mandibular intercanine distance.

5.7 Strengths

One of the greatest strengths of this study is the long time-span over which the patient data were recorded. Each subject was accounted for at each time point with no holes in the data. The duration of long-term follow-up was substantial (mean 8y2m). However, the study was retrospective, so there were a number of limitations which will be discussed in the next section.

The expander design and consistency of the expansion protocol was a major strength of the study. All patients had a substantial expansion ranging from 7.4mm to 11.9mm. In comparison, the Gryson (1977) study was well designed to examine the relationship of crossbite to lower arch response, but only averaged less than 6mm expansion. In the present study, the indirect effects on the mandible were only able to be examined clearly because of this substantial expansion along with strict selection criteria. The criteria were optimized to isolate these effects from other treatment effects. Subjects were excluded who had confounding treatments such as protraction chin-cup therapy or lower headgear at the time of expansion.

Other strengths of the study include the heterogeneity of the sample which included a wide range of ages, a good distribution of crossbite and non-crossbite subjects, and the inclusion of a range of short-term and long-term records.

5.7 Limitations

5.7.1 Sample Size

A major limitation of the study is a small sample size. This is a consequence of having many selection criteria, especially requiring the permanent mandibular canines in the initial casts, no active treatment on the lower arch at T2, and long-term post-retention models available. Long-term post-retention is a common factor which causes sample size attrition due to a change in contact information or moving out of the area. Although many patients had undergone expansion treatment at this private practice, few patients remained once all the selection criteria were applied.

5.7.2 Sample Heterogeneity

Since one of the main objectives of the study was to assess correlations between age at initiation of expansion treatment and the amount of spontaneous expansion and its stability, it was necessary to include a large age range of subjects. This is also a limitation of the study due to the possibility that age is a confounding variable. Some of older subjects also had the expander in place longer than others, so it is impossible to determine if the subjects' age or duration of expansion played a larger role.

Some subjects' T2 records were taken sooner and some later, allowing a wide range of times to test against for a correlation of spontaneous expansion; however, this was a confounding variable when attempting to correlate amount of spontaneous expansion to amount of relapse. It is theorized that those cases where records were taken sooner would have expanded more if allowed more time (Wertz, 1970), dooming this correlation to show irregularity where there might have been significance.

One area where the sample was too homogeneous was the close grouping of the amount of maxillary expansion. The range was 7.4mm to 11.9mm (mean 9.4mm, SD 1.2mm) which is acceptable, but possibly insufficiently wide to show significance in correlation to amount of spontaneous expansion or relapse.

There was a large range of the post-retention duration. This is evident in the large standard deviation in Table IV (mean 99mo, SD 49mo). Though the inclusion criteria stated that patients needed to have no retainers for at least 24 months, all patients had been out of retainers for significantly longer. This is also a strength of the study.

5.7.3 Model Limitations

While stone models are the gold standard from which to measure dental changes, they are not without problems. In one of the T2 models some bubbles were encountered in the incisal edges, which did not obstruct the visualization of the contact points for MIII measurement. One model had chipped mandibular lateral incisors which hindered but did not prevent MIII measurement of the contact points. One model had a void at T2 approximating the AMID landmark, so a measurement was obtained from the closest measurement to the landmark. The T2 models did not have stone bases added while the other timepoints did have bases, which likely made the AMID measurement less consistent at T2 as compared to the other timepoints.

Where there was a worn cusp tip, the CMID measurement was obtained from the center of the wear facet facio-lingually on a line through the mesio-distal axis of the tooth. Cusp tip wear was more prevalent in the T3 and T4 models. While this slightly compromises the CMID accuracy at T3 and T4, the precision of the LMID measurement, and the exceptionally high correlation results between the two measurements, corroborates the CMID accuracy. The LMID measurement could have been compromised to some degree from passive eruption or gingival recession throughout treatment. As the gingiva recedes, it causes more of the cingulum to be exposed and a decreased LMID measurement even though the teeth may have stayed in the same position relative to one another. Another cause for error in the LMID measurement was the presence of a banded lingual retainer at T3. The thickness of the band material at the lingual surface could have caused an erroneously small measurement, causing an underestimation of relapse.

There is a possible bias in that maybe only patients who liked the treating doctor or had good outcomes wanted to come back for late records to be obtained. Likewise, it is possible that good patients might be more likely to comply with the doctor's request to return to the office for a check-up.

Chronological age was used for simplicity in this study; however, including dental or skeletal age might have yielded more significant correlations.

5.8 Future Studies

A controlled prospective maxillary expansion study should be done in which no lower arch treatment is done for at least six months in a non-crossbite sample. A clinical example which might allow for such a study is bi-dental arch constriction. This might help to elucidate some of the ancillary effects of maxillary expansion which is more applicable to non-crossbite expansion scenarios. This would eliminate the confounding aspect of crossbite in the sample. Also, a study which includes estimation of skeletal and dental age at the initiation of expansion would be helpful in determining an age related response to maxillary expansion. As always, a larger sample size would also give more power to a future study.

6. CONCLUSIONS

1. Significant spontaneous expansion at lingual gingival margin, cusp tip, and mandibular canine eminence were found. Significant spontaneous mandibular incisor alignment was also found.

2. The correlation tests of age, duration of expansion, and amount of expansion failed to show a significant relationship to the resultant spontaneous expansion or relapse.

3. Relapse was not beyond spontaneous expansion values.

4. Mandibular Incisor irregularity did not relapse to an unacceptable level at 8 years post-treatment (not > 3.5mm).

While the clinical significance of a long-term intercanine distance increase of under one millimeter is debatable, the observation of relative stability observed in the mandibular incisors is significant. The inherent variability in each individual's potential to respond to this treatment in the short-term and remain stable with time is still quite unpredictable and needs further study.

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APPENDIX A

UNIVERSITY OF ILLINOIS
AT CHICAGO

Office for the Protection of Research Subjects (OPRS)
Office of the Vice Chancellor for Research (MC 672)
203 Administrative Office Building
1737 West Polk Street
Chicago, Illinois 60612-7227

Exemption Granted

June 8, 2011

Dale Benjamin, BS
Orthodontics
801 S Paulina
M/C 841
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Phone: (773) 888-2365 / Fax: (312) 996-0863

RE: Research Protocol # 2011-0403
"Subsequent Expansion in the Mandibular Arch with Rapid Maxillary Expansion"

Protocol Approval Period: June 2, 2011 to June 1, 2014

Dear Dr. Benjamin:

Your Claim of Exemption was reviewed on June 2, 2011 and it was determined that your research protocol meets the criteria for exemption as defined in the U. S. Department of Health and Human Services Regulations for the Protection of Human Subjects [(45 CFR 46.101(b)]. You may now begin your research

Your research may be conducted at UIC.

The specific exemption category under 45 CFR 46.101(b) is:

(4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

You are reminded that investigators whose research involving human subjects is determined to be exempt from the federal regulations for the protection of human subjects still have responsibilities for the ethical conduct of the research under state law and UIC policy. Please be aware of the following UIC policies and responsibilities for investigators:

1. Amendments You are responsible for reporting any amendments to your research protocol that may affect the determination of the exemption and may result in your research no longer being eligible for the exemption that has been granted.

Phone: 312-996-1711 http://www.uic.edu/depts/ovcr/oprs/ Fax: 312-413-2929

2. Record Keeping You are responsible for maintaining a copy all research related records in a secure location in the event future verification is necessary, at a minimum these documents include: the research protocol, the claim of exemption application, all questionnaires, survey instruments, interview questions and/or data collection instruments associated with this research protocol, recruiting or advertising materials, any consent forms or information sheets given to subjects, or any other pertinent documents.

3. Final Report When you have completed work on your research protocol, you should submit a final report to the Office for Protection of Research Subjects (OPRS).

Please be sure to:

→Use your research protocol number (listed above) on any documents or correspondence with the IRB concerning your research protocol.

We wish you the best as you conduct your research. If you have any questions or need further help, please contact me at (312) 355-4006 or the OPRS office at (312) 996-1711. Please send any correspondence about this protocol to OPRS at 203 AOB, M/C 672.

Sincerely,

Cynthia C. Tom-Klebba

Cynthia C. Tom-Klebba, M.A., C.I.P.
Associate Director
Office for the Protection of Research Subjects

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

APPENDIX B

	Sex[a]	*L3sXBt*[b]	*Age*	*T(exp)*	*T(1-2)*	*OffLing*	*MxIDT1*	*MxT2-1*	*LMID1*	*LMID2*	*LMID3*	*LMID4*
1	2	1	177	5.8	5.8	49	36.16	9.83	18.22	19.74	20.11	19.90
2	1	1	129	4.5	4.5	40	32.41	10.73	19.21	18.93	20.52	16.77
3	1	2	146	7.1	1.0	96	31.51	10.77	18.55	18.14	19.00	18.73
4	1	1	176	7.5	7.5	174	33.73	8.17	18.20	18.53	20.22	18.75
5	2	1	180	4.1	0.7	172	32.62	8.00	20.05	19.93	19.11	18.48
6	2	2	136	4.7	4.7	79	31.89	8.69	19.56	20.29	21.21	21.26
7	1	2	167	3.8	3.8	106	29.76	9.82	17.30	17.98	18.58	17.80
8	1	2	130	9.1	0.8	119	37.60	10.25	19.85	20.10	21.81	21.85
9	1	2	144	6.3	0.8	29	32.96	9.54	19.77	21.25	21.73	21.57
10	1	1	170	3.8	3.8	102	35.28	8.73	18.30	18.22	19.68	19.28
11	2	1	138	5.2	0.5	57	26.88	7.42	18.87	19.48	19.46	18.86
12	2	1	264	7.3	4.1	68	36.60	9.10	18.26	18.71	21.40	21.69
13	1	2	433	8.2	2.3	120	33.77	8.57	19.30	19.16	20.35	19.82
14	1	2	173	5.6	5.6	70	33.87	11.89	19.67	20.22	21.38	20.71
15	1	1	175	9.3	1.9	139	31.69	10.54	18.93	19.68	19.73	19.57
16	2	2	169	3.7	0.6	92	31.36	7.36	19.04	18.76	20.70	20.20
17	1	1	169	5.5	0.5	152	30.79	10.49	19.56	20.17	19.70	18.44
18	1	2	131	7.6	7.6	30	33.31	9.70	20.32	20.20	20.59	20.21
19	1	1	273	3.0	2.0	180	30.42	9.13	15.81	16.05	17.60	17.36

[a] Sex: 1 = Female, 2 = Male

[b] Mandibular Canine Crossbite: 1 = Non-Crossbite, 2 = Crossbite

	CMID1	*CMID2*	*CMID3*	*CMID4*	*AMID1*	*AMID2*	*AMID3*	*AMID4*	*MIII1*	*MIII2*	*MIII3*	*MIII4*
1	23.72	25.87	29.16	29.08	33.37	32.79	34.53	33.64	13.3	9.53	1.70	2.65
2	25.42	26.52	27.98	25.51	30.41	30.07	29.50	28.43	8.09	7.12	1.68	2.75
3	25.41	25.13	25.85	25.30	32.72	33.18	29.73	29.51	4.84	4.88	1.61	1.50
4	24.30	25.13	26.30	25.05	30.56	31.00	29.85	29.66	8.85	7.78	0.53	1.32
5	25.88	26.17	26.35	25.27	29.12	32.16	32.54	30.91	9.32	8.77	3.13	3.17
6	24.95	25.91	28.19	25.89	32.34	32.83	32.49	32.15	3.60	3.14	0.42	2.67
7	23.68	24.01	24.33	23.94	28.75	28.41	27.16	26.45	4.23	3.19	1.15	1.03
8	26.81	26.74	28.87	28.50	31.51	31.95	32.45	31.47	1.66	1.38	0.26	0.82
9	27.13	27.92	27.65	26.26	31.21	33.29	31.12	30.62	6.65	5.05	1.28	1.11
10	26.03	25.96	26.31	26.02	29.72	30.04	29.63	29.44	5.05	4.05	2.34	2.89
11	25.65	26.29	26.06	25.70	36.4	37.29	35.99	35.65	6.52	6.01	1.11	2.59
12	24.84	25.19	26.76	26.95	28.35	30.97	28.53	29.91	5.54	4.93	0.84	0.87
13	24.68	25.24	26.57	25.62	29.18	29.51	31.12	31.10	4.28	3.26	0.50	1.13
14	24.77	25.36	26.39	25.77	30.32	30.51	30.06	29.24	3.27	1.94	2.05	1.41
15	24.71	25.77	26.57	26.21	29.81	29.62	30.54	30.17	9.92	8.29	2.14	1.44
16	26.16	26.75	29.13	28.57	31.45	31.51	32.77	32.27	9.01	7.12	1.52	2.25
17	26.13	26.66	26.93	25.31	28.57	29.47	27.89	27.37	8.85	6.51	0.65	1.95
18	25.62	25.41	25.01	25.39	32.13	32.32	31.38	31.22	2.27	1.14	0.84	1.91
19	22.04	22.76	25.63	24.86	29.43	31.12	30.43	28.23	6.48	3.24	2.26	3.89

	LMID2-1	*CMID2-1*	*AMID2-1*	*MIII2-1*	*LMID3-1*	*CMID3-1*	*AMID3-1*	*MIII3-1*	*LMID4-3*	*CMID4-3*	*AMID4-3*	*MIII4-3*
1	1.52	2.15	-0.58	-3.77	1.89	5.44	1.16	-11.6	-0.21	-0.08	-0.89	0.95
2	-0.28	1.10	-0.34	-0.97	1.31	2.56	-0.91	-6.41	-3.75	-2.47	-1.07	1.07
3	-0.41	-0.28	0.46	0.04	0.45	0.44	-2.99	-3.23	-0.27	-0.55	-0.22	-0.11
4	0.33	0.83	0.44	-1.07	2.02	2.00	-0.71	-8.32	-1.47	-1.25	-0.19	0.79
5	-0.12	0.29	3.04	-0.55	-0.94	0.47	3.42	-6.19	-0.63	-1.08	-1.63	0.04
6	0.73	0.96	0.49	-0.46	1.65	3.24	0.15	-3.18	0.05	-2.30	-0.34	2.25
7	0.68	0.33	-0.34	-1.04	1.28	0.65	-1.59	-3.08	-0.78	-0.39	-0.71	-0.12
8	0.25	-0.07	0.44	-0.28	1.96	2.06	0.94	-1.40	0.04	-0.37	-0.98	0.56
9	1.48	0.79	2.08	-1.60	1.96	0.52	-0.09	-5.37	-0.16	-1.39	-0.50	-0.17
10	-0.08	-0.07	0.32	-1.00	1.38	0.28	-0.09	-2.71	-0.40	-0.29	-0.19	0.55
11	0.61	0.64	0.89	-0.51	0.59	0.41	-0.41	-5.41	-0.60	-0.36	-0.34	1.48
12	0.45	0.35	2.62	-0.61	3.14	1.92	0.18	-4.70	0.29	0.19	1.38	0.03
13	-0.14	0.56	0.33	-1.02	1.05	1.89	1.94	-3.78	-0.53	-0.95	-0.02	0.63
14	0.55	0.59	0.19	-1.33	1.71	1.62	-0.26	-1.22	-0.67	-0.62	-0.82	-0.64
15	0.75	1.06	-0.19	-1.63	0.80	1.86	0.73	-7.78	-0.16	-0.36	-0.37	-0.70
16	-0.28	0.59	0.06	-1.89	1.66	2.97	1.32	-7.49	-0.50	-0.56	-0.50	0.73
17	0.61	0.53	0.90	-2.34	0.14	0.80	-0.68	-8.20	-1.26	-1.62	-0.52	1.30
18	-0.12	-0.21	0.19	-1.13	0.27	-0.61	-0.75	-1.43	-0.38	0.38	-0.16	1.07
19	0.24	0.72	1.69	-3.24	1.79	3.59	1.00	-4.22	-0.24	-0.77	-2.20	1.63

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