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The treatment of dental crowding utilizing maxillary and mandibular arch expansion

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THE TREATMENT OF DENTAL CROWDING UTILIZING MAXILLARY AND MANDIBULAR ARCH EXPANSION: LONGTERM DENTAL AND CEPHLOMETRIC FINDINGS

by

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THESIS

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ABSTRACT

Dental crowding is a chief concern of most patients seeking orthodontic care. While there are several techniques for the treatment of dental crowding, one common one is the transverse expansion of the dental arches. While many researchers have shown this type of expansion to be unstable in the permanent dentition, transverse expansion in the mixed dentition has not been thoroughly studied. The purpose of this retrospective study was to investigate whether transverse expansion in the mixed dentition created dental arches significantly different than those of untreated persons. Twenty-three orthodontic patients (17 female, 6 male) from a single group practice had transverse expansion done in the mixed dentition with a combination of maxillary Schwartz appliance and a mandibular Crozat appliance. Arch width, arch length, and irregularity index were measured with digital calipers in the mixed and permanent dentition. Anteroposterior movements of the incisors were quantified by using lateral cephalograms taken in the mixed and permanent dentitions. The same type of records were obtained from an untreated sample of individuals (n=23; 17 female, 6 male) from the University of Michigan Growth Study. Between the mixed and permanent dentitions, the control group had a significant ($p<0.05$) widening of the lower molar width, a decrease in the lower arch width, a widening of the upper molar and canine width, and a decrease in upper arch length. During that same period, the treated group had a significant ($p<0.05$) lower canine width increase, lower arch length decrease, lower irregularity index decrease, upper molar and canine width increase, and upper irregularity index decrease. When comparing the changes between the treated and control groups, the only significant difference ($p<0.05$) was in upper irregularity index. The treated group had a significantly decreased change in the maxillary irregularity index. This study did not show a major treatment effect on changes in the arch width but use of these appliances did have some beneficial impact on the anterior teeth alignment.

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I. BACKGROUND, SIGNIFICANCE, AND SPECIFIC AIMS

A. INTRODUCTION

Dental crowding is a chief concern of most patients seeking orthodontic treatment because of the poor esthetics of misaligned teeth. In addition to problems with esthetics, crowded teeth have more problems with plaque accumulation,[1] gingival and periodontal problems,[1-6] and abnormal wear. For these reasons the treatment of dental crowding is a critical part of orthodontic care.

The question arises as to when is the best time to treat dental crowding. Should treatment begin in the primary dentition since crowding is occasionally seen at this stage and when it does, it normally results in crowding in the permanent dentition?[7] Or should treatment wait until the mixed dentition? In the mixed dentition, some dental transient crowding is a usual occurrence even in arches that will be well aligned later in the future.[7] Most orthodontic literature advocates starting treatment at the end of the late mixed dentition, claiming that almost 85% of cases can be treated at this stage without extractions.[8] The enlargement of the dental arches by transverse expansion in the mixed dentition is commonly done by orthodontists even though there is no research showing the results to be stable.

B. ETIOLOGY OF CROWDING

Dental crowding is the result of a mismatch between the amount of tooth structure and the amount of room in the dental arch. In the simplest sense, the possible etiology of crowding is that the teeth are too large, the dental arch is too small, or there is a combination of the two factors. Many studies have been done to determine which of these factors is of most importance, but the results are not conclusive. Research has shown that crowding is related to mesiodistal size of the lower incisors,[9-11] total mesiodistal size of the teeth in the entire arch,[12-16] arch width,[15-20] and arch depth.[19] However, there are an equal number of papers showing that tooth size,[17-19] arch width,[10, 16] and arch depth[15, 18] are not important at all to crowding. It appears that crowding is a multi-factorial phenomenon and tooth size, tooth angulation, and arch width can all contribute.

Many secondary variables have been examined to determine their influence on dental crowding. Factors such as gender and molar classification have been demonstrated to not be factors in dental crowding.[21] Other factors that may contribute to crowding include the angulation of the mandibular permanent incisors and molars,[22] premature loss of primary teeth(second molars),[16, 23] and mandibular length.[16, 24] The direction of facial growth (e.g., growth pattern) of the individual has been shown to affect dental crowding by many researchers[24-31] while a few have concluded growth is not a factor.[32, 33]

C. NORMAL DENTAL ARCH DEVELOPMENT

The size of the permanent incisors is normally larger than that of the primary incisors; the difference in size between the primary and permanent incisors is defined as "incisor liability." The incisor liability is an average 7.6 mm for the maxillary incisor and 6.0 mm for the mandibular incisors.[34] However, the transition from the primary to permanent dentition normally does not result in this much crowding because of several factors. There is often interdental spacing between the primary incisors, the amount ranging from 0 to 10 mm in the maxilla and 0 to 6 mm in the mandible.[35] This spacing provides extra arch perimeter in the anterior region to allow for proper alignment of the larger permanent incisors. Also, in the mandibular arch, as the incisors erupt the intercanine arch width increases.[36-38] It is believed to be a result of the eruptive force of the incisors moving the canines in a transverse direction. Even with these factors, there is an approximately 1.6-mm deficiency in space for the proper alignment of the mandibular incisors.[38, 39] By the time the permanent canines have erupted, the crowding has decreased.[20, 38-42] This could possibly be due to the lower incisors moving forward; it has been shown that they procline an average of 13° between the ages of five and eleven.[43] After the eruption of the canines, the amount of crowding does not improve. Therefore, leeway space does not contribute to the correction of crowding.[36-38, 42, 44]

D. ALTERNATIVE TREATMENT APPROACHES

The optimum treatment approach for any individual depends on many factors including dental stage, amount of crowding, and amount of protrusion and skeletal relationship. Several treatment options for crowding are possible.

1. *Extraction*

In the past, many prominent orthodontists believed that the teeth and jaw size were genetically determined and could not be altered.[45-47] They believed that crowding could only be corrected by extraction of teeth. While the strict convictions of unchangeable arch forms are not as widely held at this time, there are certain cases that still require extraction.

2. *Interproximal reduction*

Interproximal reduction reduces the size of individual teeth in a mesiodistal dimension and results in a net reduction of the total tooth structure in the arch. While this technique has been shown to not cause an increase in caries or periodontal problems, no long-term stability studies have been done.

3. *Proclination of Incisors (Sagittal Expansion)*

Proclination of the incisors will allow space for the alignment of the incisors. By proclining the incisors by one millimeter, approximately one millimeter of arch perimeter is gained to alleviate crowding.[48] Flaring of the incisors to alleviate crowding can be accomplished with passive movement such as with a lip bumper, or can be actively achieved by using fixed appliances with buccal or lingual wires.

While proclination of the incisors is an efficient method of gaining space to align teeth, this type of movement may result in a treatment result that has compromised stability, esthetics, and periodontal health. Excessive movement in the sagittal direction can move the incisors out of the alveolar bone, especially if inflammation is present which is common with some orthodontic appliances.[49] Animal studies have shown that excessive incisor proclination can result in apical migration of the gingival margin,[50] loss of marginal bone,[51] and bony dehisenses.[52] While research has shown that excessive proclination of mandibular incisors in adults causes increased clinical crown height and gingival recession,[53] this has not been shown conclusively in adolescents.[54]. Due to these various considerations, only about 2 mm of advancement of the incisors is recommended to ensure the incisors stay within the alveolar bone and remain stable after treatment.[49]

4. *Holding of Leeway Space*

The mesiodistal dimension of the deciduous second molar is larger by 2.2 to 2.7 mm[55] than the underlying second premolar. As the deciduous second molar is lost, this difference in size, termed leeway space, can be utilized to align anterior crowding. While the use of a lower lingual arch has been shown to be effective in the correction of crowding and the results appear to remain stable,[56] there is some question if the leeway space is actually being maintained. Research has shown that while the lingual arch reduces the amount of mesial molar migration after loss of the deciduous second molar, there is still some mesial movement of the permanent molar and a slight proclination of the lower incisors. [57]

5. *Transverse Expansion*

Buccal expansion is another way of increasing the amount of room in the arch by making the arch larger. Theoretically, each millimeter of expansion of the canine and molars together can result in a millimeter increase in arch perimeter.[48] This theoretical relationship between the amount of expansion and the amount of increased arch perimeter is shown to be true in clinical studies.[58] Berlocher et al., [58] expanded maxillary arches in the primary dentition and gained approximately 4 millimeters of arch width for both the canines and molars (Canine: 3.8mm $\pm$ 1.4 mm; Molar: 4.2 mm $\pm$ 1.5 mm) which resulted in a 4.1 millimeter (SD $\pm$ 1.7mm) increase in arch perimeter.

Expansion of the upper and lower arches must be evaluated separately. Expansion of the upper arch can be considered to be both dental and orthopedic since in younger individuals, the midpalatal suture is patent allowing the two halves of the maxilla to be moved apart. On the other hand, the suture between the two halves of the mandible fuses at approximately one year of age,[59] much earlier than any orthodontic treatment would start. This eliminates the possibility of orthopedic expansion and results entirely in dental movement of the teeth.

Arch expansion has been used primarily for the upper arch because of the high incidence of narrow upper arches that result in posterior lingual crossbite. Maxillary expansion treatment allows orthopedic changes in adolescents by separating the midpalatal suture and allowing bone to fill in.[60] Previous research has shown that rapid maxillary expansion produces dramatic short term changes in arch width[61] that are relatively stable over many years. For these reasons, maxillary expansion is a well-accepted part of orthodontic clinical practice.

Mandibular expansion, on the other hand, is discounted by most research. Expansion of intercanine width in the permanent dentition using fixed appliances has been shown to be unstable.[49, 62-68]

Research is now focusing on mandibular expansion during the mixed dentition. The theory of why expansion works in the mixed dentition in the mandibular arch suggests that the buccal movement of the deciduous teeth will develop the width of the alveolar bone. When the permanent canines and premolars erupt, they will erupt into wider alveolar bone. By developing the bony support before the permanent teeth erupt, their buccal positions will be more stable and will result is less periodontal problems.

Expansion of the arches in the mixed dentition and its resultant arch width changes have been well documented for several different treatment modalities in the upper and lower arches. While many studies[69-71] have described the changes in lower arch form via passive expansion, very few have looked at active expansion.

Much of the early literature on active mixed dentition expansion has come in the form of testimonials that show cases that help prove their belief in the benefits of mixed dentition expansion.[72, 73] More recently, research has shown that it is possible to get significant changes in arch width in the canine and premolar region with active expansion in the mixed dentition.[74, 75] However the question remains, does this change in arch form remain and is it greater than what would be seen in untreated individuals. Lutz and Poulton[75] found that while the expanded arches were wider than the controls in the early mixed dentition, the widths of the expanded groups were very similar to the control group in the later mixed dentition. Only one group of investigators has looked to see if the enlargement of the dental arch in the mixed dentition remained in the permanent dentition.[76] While the authors showed that after treatment, most cases had a decrease in intercanine width and arch length and an increase in crowding, there were some problems in their study design. Their subjects were taken from several different practices that used different expansion techniques resulting in different amounts of sagittal versus buccal expansion. There was no mention of selection criteria except for patients being treated with expansion. Their initial treatment group had an average age of ten years and 1 month old (range: 8 years, 0 month to 14 years, 7 months) which is generally in the range of late mixed dentition where most of the succedaneous teeth have erupted. Finally, the treatment group had a minimum of one-millimeter increase in arch length. This is a very small increase and any relapse would result in an arch length close to the original.

F. HYPOTHESIS, SPECIFIC AIMS AND SIGNIFICANCE

The width of the dental arches is likely a factor contributing to dental crowding. Therefore, it makes sense to directly treat the problem by increasing arch width. **The hypothesis to be tested was arch expansion in the mixed dentition is maintained in the permanent dentition, resulting in less crowding of the incisors.**

The specific aims of this study were to examine whether there are wider arches and less crowding at the permanent dentition stage in those individuals who had early expansion versus those chosen as untreated controls. Answering the question of whether expansion in the mixed dentition results in wider arches and less crowding in permanent dentition can help refine orthodontic procedures. Several valuable pieces of clinical information can be provided by this study. By describing the changes in arch width and incisor alignment using active expansion devices in the mixed dentition, clinicians can better understand and predict the arch form changes in their patients using a similar treatment regiment. Knowledge of the stability of the changes between the mixed dentition and the permanent dentition is critical for any clinician using a similar procedure. Finally, if changes in the arch form with treatment can be correlated with successful reduction of crowding in the permanent dentition, the clinician can understand what to expect at the beginning of phase II therapy. If this treatment is found to be effective, it will result in well aligned dental arches that are potentially more stable, with patients who have retained all their permanent teeth and maintained optimum facial esthetics. If this treatment approach is found to be ineffective, this information can advise clinicians to not use this treatment and save patients the time and cost.

II. MATERIALS AND METHODS

A. RECRUITMENT AND CRITERIA FOR INCLUSION OF SUBJECTS

1. *Treated group*

The treated group was gathered from one group practice located in the San Francisco Bay Area. This practice is typical of many around the country by providing interceptive treatment for children in the mixed dentition and finalizing treatment in a second phase of treatment during the permanent dentition. This practice was selected because it had records of a large number of patients who underwent bimaxillary arch expansion in the mixed dentition with a uniform technique and took standard records at the start of both phases of treatment. In order to be included in the treated sample, the subject had to meet all the following inclusion criteria:

1. Diagnosed clinically with a mild to moderate anterior crowding by all three of the orthodontists in the practice. Subjects with severe crowding were excluded if they were treated with serial extraction therapy in the mixed dentition.
2. Mixed dentition stage with the permanent first molars and permanent incisors erupted fully in the lower arch. In the upper arch, the permanent first molars and permanent central incisors had to be fully erupted.
3. No congenitally missing teeth (excluding third molars)
4. No premature loss or extraction of primary or permanent teeth
5. No previous orthodontic treatment or any orthodontic treatment after expansion therapy

6. No orthopedic appliances used to change the growth in the anterior-posterior direction (e.g., headgear, functional appliance)

7. No medical history of disease, trauma, or other condition which would affect the eruption of teeth or growth and development of the orofacial complex

8. Beginning records consisting of upper and lower models and a lateral cephalogram of diagnostic quality.

9. Treated with maxillary and mandibular expansion in the mixed dentition

10. Final records taken in early permanent dentition (all permanent teeth erupted except the third molars). The records must be of diagnostic quality and include upper and lower models and a lateral cephalogram.

There were 23 subjects (17 female, 6 male) which fit the inclusion criteria from a pool of 140 subjects that had undergone early expansion in this orthodontic office.

The children underwent transverse expansion in both the upper and lower arches. The mandibular expansion was always done with a Crozat appliance[77] while the maxillary expansion was accomplished with either a Crozat or Schwartz appliance. The Schwartz appliance was designed with Adams clasps on the primary second molars and acrylic covering of the palate and occlusal surfaces of the teeth. The subjects were instructed to turn the midline screw twice a week. The Crozat was designed with soldered clasps on the primary second molars. On the lingual surface of each clasp, an auxiliary wire was soldered as well as a heavy lingual wire that connected the two clasps. Holding the midline of the main lingual wire and bending the clasps away from each other several millimeters activated the Crozat appliance. Next, the lingual wire was held near its attachment to the clasp, and then the clasp was bent to rotate it in a distal direction. Finally, the auxiliary arms were made passive on the lingual surfaces of the teeth. While this appliance is removable, the patient was instructed not to remove it. The Crozat was reactivated every six weeks by the clinician. For a small subgroup of individuals, fixed appliances (e.g., braces) were placed on the upper incisors, primarily to close spaces after expansion. All three of the orthodontists working in this practice were familiar with the appliance delivery, activation, as well as the diagnostic criteria to judge the progress of treatment. Maxillary expansion was continued until the buccal incline of the lingual cusps of the upper molars was contacting the lingual incline of the buccal cusps of the lower molars. Mandibular expansion was continued until there was enough room between the canines to allow proper alignment of the four incisors. Because the mandibular expansion was a slow expansion, the maxillary expansion was always completed prior to the mandibular expansion. The upper and lower expansion appliances were worn until the expansion was complete in both arches (Upper: 0.61 ± 0.29 year; Lower: 0.86 ± 0.32 year) and then the wear was discontinued.

2. *Control Group*

The control sample was taken from the University of Michigan Elementary and Secondary School Growth Study.[78] The Michigan Growth Study is a mixed longitudinal study that has 99 male and 92 female subjects with records taken within the age range of 5 to 18 years old. The subjects chosen had to conform to the following inclusion criteria:

1. Diagnosed as having mild to moderate crowding in both maxillary and mandibular arches
2. No medical history of disease, trauma, or other condition that would affect the eruption of teeth or growth and development of the orofacial complex
3. No congenitally missing teeth (excluding third molars)
4. No premature loss or extraction of primary or permanent teeth

5. No orthodontic treatment prior to the records taken in the permanent dentition.
6. One set of records taken in the early mixed dentition. In the lower arch, the permanent first molars and permanent incisors had to be erupted fully. In the upper arch, the permanent first molars and permanent central incisors fully erupted. The records must be of diagnostic quality and include upper and lower models and a lateral cephalogram.
7. The second set of records taken in early permanent dentition (e.g., all permanent teeth erupted except the third molars). The records must be of diagnostic quality and include upper and lower models and a lateral cephalogram.

The first 17 females and 6 males who met the criteria were included in the study.

B. PATIENT EVALUATION AND DATA COLLECTION

Data were derived from: (1) medical history questionnaire, (2) treatment card, (3) dental cast measurements, and (4) lateral cephalometric measurements. The questionnaire was used to assess the history of disease or trauma to the orofacial complex or previous orthodontic treatment. The dental cast measurements were used to quantitatively describe the changes in arch width, arch length, and amount of crowding. The cephalometric measurements were used to analyze changes in the incisor proclination and dentoalveolar protrusion.

1. *Questionnaire*

Both control and treated individuals had completed a standard medical and dental history. This health history questionnaire was used to exclude previous orthodontics, trauma or diseases affecting the orofacial complex.

2. *Treatment Card*

The treatment card from the first phase of orthodontic treatment was examined for the treated group. The treatment card included the treatment plan for the patient as well as an account of each patient visit. This data source was used to confirm that only expansion treatment was performed and no sagittal correction was attempted.

3. *Dental Casts*

All dental casts were taken with an irreversible hydrocolloid impression material (Alginate). All impressions were poured in orthodontic stone in a timely manner. The initial set of dental casts were taken in the early mixed dentition just prior to initiation of expansion and the final set taken in the permanent dentition (all permanent teeth erupted except the third molars) just prior to fixed orthodontic treatment. The dental casts were examined to ensure they met all the dental criteria for inclusion in the study.

4. *Lateral cephalogram*

The cephalograms were taken on a combination panrorex/cephalogram machine. The initial lateral cephalogram was taken in the early mixed dentition just prior to initiation of expansion and the second one taken in the permanent dentition (all permanent teeth erupted except the third molars) just prior to fixed orthodontic treatment. All lateral cephalograms were taken at the same time as the dental models.

C. DATA ANALYSIS

1. *Dental Models*

Past literature has described four ways of obtaining data for analyzing cast dimensions: direct measurements from the dental casts are made with calipers, [17, 20, 33, 69-71, 74, 79-81] direct recording of points into a computer,[82], indirect measurements from photocopies of models,[83] or indirect measurements from photographs of the models.[44, 61] The first step was to evaluate which dental cast measurement technique would be most appropriate for this study. Direct digitization of the models into a computer would not be possible because this equipment was not available. Taking photographs of the models was also not an option because of the difficulty transporting photography equipment to the University of Michigan. This left either direct measurements from dental casts or indirect measurements from a photocopy.

The most commonly used technique in past research has been the direct measurement from dental casts. This would be considered the standard to which the other techniques should be compared. Therefore this would be the primary method of recording dental cast measurements. However, it was also desired to have a physical representation of the control models at the University of Michigan so the photocopy technique needed to be compared to the direct measurement technique to see if it was accurate.

a. *Direct Measurement Technique*

The direct cast measurements were made with a Mitutoyo (No. 573) electronic digital caliper and then recorded into a data book. The following is a list of the dental cast measurements made along with a description of how they were identified:

Table 1 - Definition of Lower Dental Measurements

Measurements	Definition
Intercanine Width (Buccal)	Distance between the right and left canines, where the central developmental ridge meets the gingival margin.
Intercanine Width (Lingual)	Distance between the right and left canines, measured from the most lingual points on the gingival margin.[58, 61]
Intercanine Width (Cusp Tip)	Distance between the cusp tips of the canines. If there was wear on cusp tip, its point was estimated to where it would have been.[84]
Intermolar Width (Buccal)	The distance between the intersection of the buccal groove and the gingival margin of the left and right permanent first molars.
Intermolar Width (Lingual)	Distance between the intersection of the lingual groove and the gingival margin of the left and right permanent first molars.[58, 61]
Intermolar Width (Cusp Tip)	Distance between the mesiobuccal cusps of the permanent first molars. If there was wear on the cusp tip, its position was estimated to where it would have been.
Arch Length	A line was made between the contact points of the permanent first molar and the tooth mesial to it (primary second molar or second premolar). That line was bisected and the perpendicular distance to the contact of the central incisors measured.[40, 61, 69]
Irregularity Index	The sum of the linear distance between anatomic contact points from the mesial of one canine to the other.[84]

Table 2 - Definition of Upper Dental Measurements

Measurements	Definition
Intercanine Width (Buccal)	Distance between the right and left canines, where the central developmental ridge meets the gingival margin.
Intercanine Width (Lingual)	Distance between the right and left canines, measured at the most lingual points on the gingival margin.[58, 61]
Intercanine Width (Cusp Tip)	Distance between the cusp tips of the canines. If there was wear on cusp tip, its point was estimated to where it would have been.[84]
Intermolar Width (Buccal)	The distance between the intersection of the buccal groove and the gingival margin of the left and right permanent first molars.
Intermolar Width (Lingual Groove)	Distance between the intersection of the lingual groove and the gingival margin of the left and right permanent first molars.
Intermolar Width (Lingual)	Distance between the intersection of the lingual groove and the gingival margin of the left and right permanent first molars.[58, 61]
Intermolar Width (MB Cusp Tip)	Distance between the mesiobuccal cusps of the permanent first molars. If there was wear on the cusp tip, its position was estimated to where it would have been.
Intermolar Width (L Cusp Tip)	Distance between the mesiolingual cusps of the permanent first molars. If there was wear on the cusp tip, its position was estimated to where it would have been.
Arch Length	A line was made between the contact points of the permanent first molar and the tooth mesial to it (deciduous second molar or second premolar). That line was bisected and the perpendicular distance to the contact of the central incisors measured.[40, 61, 69]
Irregularity Index	The sum of the linear distance between anatomic contact points from the mesial of one canine to the other.[84]

b. Photocopy measurement technique

The first step was preparing a photocopying template in which the models could be placed in a standard position on the glass of the photocopier. The template would have standard incremental markings that could be used for the determination of photocopy magnification. An 8.5 by 11 inch white piece of cardboard was obtained and a 57 by 140 millimeter rectangular piece was removed from the center of the paper. Two millimetric rulers were placed, one vertically and one horizontally, directly abutting against the window in the cardboard.

The next step was to determine if there was any magnification or reduction of the photocopied image. The cardboard template was placed in the location where a standard piece of paper would be placed for a photocopy, and the side with the rulers affixed facing the glass screen. The photocopier magnification factor was set at 100% (meaning a 1:1 reproduction). A third ruler was positioned in several positions in the cardboard window, and a photocopy was made at each position. Four photocopies were produced with the 2 rulers on the template a third ruler at a position in the cardboard window. With a sliding caliper, 10 cm on the third ruler was measured. The same 10-cm distance on the third ruler was made on the photocopies with the third ruler at different positions. By comparing the direct measurements of the ruler to the photocopied image of the ruler, the magnification or reduction of the photocopy could be determined. By evaluating the magnification/reduction amounts at different locations in the field to be used to photocopy the models, it could be determined if there was a distortion of the photocopied image.

The procedure to photocopy the models started by placing the ruler side of the template face down on the glass face of the copier (Xerox™ Model 5312) and then T1 and T2 models of one arch in the template window. The models were placed so the occlusal surface of the teeth was touching the glass screen. The midsagittal planes of the models were parallel to each other and the anterior teeth were on the same side of the window. Test copies were made to adjust the copier darkness to maximize the contrast between different areas of the model. In general the darkness setting close to maximum was selected to obtain the best contrast. A photocopy was made of the models with the magnification setting of 100%. The photocopy produced had the image of two models and the vertical and horizontal rulers.

The copy was taped to a rigid surface and 49 points on the model were digitized into a computer (IBM™ PS 2 Model 70) containing a program (TIOPS™) designed for arch measurements*. After the digitization of a model was complete, the program automatically determined the arch measurements. The measurements derived from the photocopied image digitized into the computer were compared to the direct measurements from the dental cast. The same models that were photocopied and digitized into the computer were then compared to direct measurements from the photocopy. This second time, however, the dental landmarks were marked with a lead pencil before digitizing and the direct measurement from the photocopy. This comparison was to ensure that any errors that occurred were not due to the differences identifying landmarks directly from the cast and from a photocopy.

2. ***Lateral cephalogram***

For each cephalogram, the mandible along with the incisors and first molars were traced on acetate paper with a 0.05-mm lead pencil. Any double contours along the borders of the mandible were bisected and the most anterior incisor in both the maxillary and mandibular arches was traced.

* TIOPS™ Developed by Dr. Jens Bjorn-Jorgensen, Roskilde, Denmark

Table 3- Definition of Cephalometric measurements

Measurements	Definitions
Lower incisor to mandibular plane (1-MP)	Angle in degrees between a line connecting the lower incisor tip and the lower incisor apex and a line tangent to the lower border of the mandible connecting menton (the lowest point of the mandibular symphysis) and the most inferior point on the mandibular angle.
CL-ML	Angle in degrees between a line connecting the a line tangent to the lower border of the mandible connecting menton and the most inferior point on the antegonial notch and the line connecting pogonion (the most prominent point of the chin) and infradentale (highest and most prominent point on the lower alveolar arch).
Lower incisor to Nasion-B point Line (mm) [1-NB(mm)]	Perpendicular millimetric distance from the line connecting nasion (the most anterior point of the fronto-nasal suture) and B point (the deepest point on the anterior contour of the lower alveolar arch) to the most anterior point on the lower incisor.
Lower incisor to Nasion-B point Line (^{O}) [1-NB(^{O})]	Angle in degrees between the line connection nasion and B point and the line connecting the lower incisor tip and lower incisor apex.

Measurements	Definitions
Upper incisor to palatal plane (1-NL)	Angle in degrees between the line connecting the anterior nasal spine and posterior nasal spine (nasal plane) and the line connecting the upper incisor tip and the upper incisor apex.
pr-n-ss	Angle in degrees between the line connecting A point (the deepest point on the anterior contour of the upper alveolar arch) and nasion and the line connecting nasion and prosthion (the lowest and most prominent point on the upper alveolar arch).
Upper incisor to Nasion-A point Line (mm) [1-NA(mm)]	Perpendicular millimetric distance from the line connecting nasion and A point to the most anterior point on the upper incisor.
Upper incisor to Nasion-A point Line ($^{\circ}$) [1-NA($^{\circ}$)]	Angle in degrees between the line connecting nasion and A point and the line connecting the upper incisor tip and upper incisor apex.

D. STATISTICAL METHODS

1. *Direct Measurement Intraexaminer Reliability*

The dental casts of ten randomly selected treated subjects were measured by the same person at three different times at least one day apart. The lateral cephalograms of ten randomly selected treated subjects were also traced and measured three times by the same person. The data was analyzed by a single factorial ANOVA with the $p<0.05$.

2. *Dental Measurements*

The mean and standard deviation of the intercanine width, intermolar width, arch length and crowding were determined for the initial and final models. Determination of statistically significant differences between the two sets were analyzed by a paired, two-tailed t-test (significance set at $p<0.05$). The arch dimension changes between the treated and control groups were compared statistically using an unpaired, two-tailed t-test (significance set at $p<0.05$).

3. *Lateral cephalograms*

The mean and standard deviation of the cephalometric measurements were determined for the initial and final radiographs. The radiographic dental changes between the two time points within each of the groups was determined using paired, two-tailed t-tests (significance set at $p<0.05$). The cephalometric dental changes between the treated and control groups were compared statistically by unpaired, two-tailed t-tests (significance set at $p<0.05$).

III. RESULTS

A. Evaluation of Photocopy Technique

The first step was to determine whether the photocopy of a ruler at several different positions on the glass screen was magnified when compared to the original ruler. Table 4 outlines the results of caliper measurements of photocopies at four different ruler positions and the caliper measurements of the original ruler. The H1 position is the closest to the horizontal ruler on the cardboard overlay. At each position in the cardboard window there was a magnification factor of 3% (0.3mm/9.8mm x 100).

Table 4. Photocopy Magnification at Different Positions on Photocopy Screen

Position	Ruler Measurement (mm)	Xerox Measurement (mm)
H1	10.1	9.8
H2	10.1	9.8
H3	10.1	9.8
H4	10.1	9.8

Next, photocopies of 5 casts were digitized into the computer and the intercanine width, intermolar width, and arch length were compared to the same measurements taken directly off the model with calipers. These results are listed in Table 5 and show there is a significant difference between the digitized values and those directly from the model. To test whether the error was in the computer measurement of the digitized points or in the identification of points on the digitized model, the digitized points were marked on the photocopy. The points were digitized and measured, and also measured on the photocopy with calipers. These results are summarized in Table 6 and show that the interarch measurements become more accurate, but there were still large differences in the arch length measurements.

Table 5. Digitized Photocopy vs. Direct Model Measurement

Cast Number	Intercanine Width (mm)		Intermolar Width (mm)		Arch Length (mm)	
	Digitized	Caliper	Digitized	Caliper	Digitized	Caliper
1	21.7	23.1	33.2	29.0	30.8	27.0
2	22.9	24.0	26.6	27.2	26.6	24.0
3	23.2	23.6	32.0	32.9	26.6	25.5
4	25.4	26.4	31.0	32.3	26.6	24.3
5	22.1	23.0	30.3	31.6	23.3	22.0

Results of Paired t-test analysis: Intercanine Width $p<0.01$, Intermolar Width NS, and Arch Length $p<0.05$

Table 6. Photocopy with Points Marked, Digitized vs. Caliper Measurement

Cast Number	Intercanine Width (mm)		Intermolar Width (mm)		Arch Length (mm)	
	Digitized	Caliper	Digitized	Caliper	Digitized	Caliper
1	24.3	24.5	31.2	31.4	27.0	24.9
2	26.0	26.5	30.6	31.1	25.8	23.9
3	24.7	25.2	30.0	30.6	28.2	25.2
4	28.1	28.6	29.6	29.7	27.6	25.3
5	23.4	23.8	31.8	32.3	26.7	24.1

Results of Paired t-test analysis: Intercanine Width $p<0.005$, Intermolar Width $p<0.05$, and Arch Length $p<0.0005$

B. Reliability Data with Repeated Measures

Ten of the treated dental casts were randomly selected and then measured on different days for a total of three measurements on each cast. Also, ten randomly selected treated cephalograms were retraced and remeasured a total of three times. The results of the single factorial ANOVA analysis with $p<0.05$ for the dental casts are shown in Table 7 and for the cephalograms in Table 8. All cast and cephalometric measurements were shown to be reliable.

Table 7. Cast Repeated Measurement

Mandibular Measurement	P-value	Maxillary Measurement	P-Value
Buccal Intermolar Width	NS	Buccal Intermolar Width	NS
Lingual Intermolar Width	NS	Lingual (Groove) Intermolar Width	NS
Cusp Intermolar Width	NS	Lingual Intermolar Width	NS
Buccal Intercanine Width	NS	MB Cusp Intermolar Width	NS
Lingual Intercanine Width	NS	L Cusp Intermolar Width	NS
Cusp Intercanine Width	NS	Buccal Intercanine Width	NS
Arch Length	NS	Lingual Intercanine Width	NS
Irregularity Index	NS	Cusp Intercanine Width	NS
		Arch Length	NS
		Irregularity Index	NS

Table 8. Cephalometric Repeated Measurements

Cephalometric Measurement	P-value	Cephalometric Measurement	P-value
Mandibular Measurements		**Maxillary Measurements**	
ML-1	NS	NL-1	NS
CL-ML	NS	pr-n-ss	NS
NB-1 (°)	NS	NA-1 (°)	NS
NB-1 (mm)	NS	NA-1 (mm)	NS

C. Description of Treated and Control Groups

Both the treated group and the control group had 23 subjects, and both groups had the same ratio of females to males (17 females and 6 males). Both the treated and control groups had 15 subjects with all the permanent incisors erupted at the time of mixed dentition models, and 8 subjects with one or both of the permanent lateral incisors not completely erupted. The mean ages of the treated group were 8.38 years in the mixed dentition and 12.81 years in the permanent dentition compared with the control group which had mean ages of 8.60 years in the mixed dentition and 13.25 years in the permanent dentition (Table 9).

Table 9. Mean Ages of the Treated and Control Groups at T1 and T2

	Treated Group		Control Group		p-value
	Mean	SD	Mean	SD	
Age at T1 (years)	8.38	0.91	8.60	0.80	NS
Age at T2 (years)	12.81	1.58	13.25	1.46	NS

D. Means and Standard Deviations of the Treated and Control Groups

The mean values and standard deviations for the treated group at both the mixed dentition and the permanent dentition time periods are outlined for the dental measurements in Table 10 and the cephalometric measurements in Table 11. The mean values and standard deviations for the control group at both the mixed dentition and the permanent dentition time periods are outlined for the dental measurements in Table 12 and the cephalometric measurements in Table 13. The mixed dentition values for the treated group were slightly smaller in arch width and arch length, and slightly larger in irregularity index, but still very comparable. The cephalometric values at the mixed dentition time point were also similar between the treated and control groups, however the treated group had slightly more protrusive lower incisors and more retrusive and retroclined upper incisors.

Table 10. Treated mean dental values

Measurements	Mixed Dentition (T1)		Permanent Dentition (T2)	
	Mean (mm)	S.D. (mm)	Mean (mm)	S.D. (mm)
Mandibular Measurements				
Buccal Intermolar Width	50.30	2.08	50.76	2.82
Lingual Intermolar Width	31.28	2.08	31.50	2.33
MB Cusp Intermolar Width	42.52	2.09	42.78	2.50
Buccal Intercanine Width	27.22	1.05	28.27	1.74
Lingual Intercanine Width	19.27	1.21	19.12	1.93
Cusp Intercanine Width	24.05	1.24	24.92	1.95
Arch Length	23.45	1.22	22.04	1.72
Irregularity Index	6.92	1.75	4.51	2.14
Maxillary Measurements				
Buccal Intermolar Width	51.29	2.61	53.12	2.44
Lingual (Groove) Intermolar Width	32.68	2.06	33.89	1.85
Lingual Intermolar Width	30.73	1.90	32.20	2.07
MB Cusp Intermolar Width	47.36	2.65	49.15	2.40
L Cusp Intermolar Width	37.59	2.25	38.80	2.16
Buccal Intercanine Width	32.88	1.97	34.94	2.39
Lingual Intercanine Width	23.88	2.24	24.92	2.81
Cusp Intercanine Width	29.63	2.25	32.89	2.05
Arch Length	27.24	1.68	26.97	2.11
Irregularity Index	7.94	3.09	4.32	2.02

Table 11. Treated mean cephalometric values

Measurements	Mixed Dentition (T1)		Permanent Dentition (T2)	
	Mean	S.D.	Mean	S.D.
ML-1 (degrees)	93.38	5.70	94.23	7.07
CL-ML (degrees)	73.31	6.23	71.97	6.34
NB-1 (degrees)	24.32	4.96	24.67	6.41
NB-1 (mm)	5.07	1.47	5.81	1.68
NL-1 (degrees)	108.62	5.22	109.35	4.46
pr-n-ss (degrees)	1.72	0.90	2.22	0.85
NA-1 (degrees)	20.38	5.16	19.59	4.94
NA-1 (mm)	4.77	1.42	5.67	1.31

Table 12. Control mean dental values

Measurements	Mixed Dentition (T1)		Permanent Dentition (T2)	
	Mean (mm)	S.D. (mm)	Mean (mm)	S.D. (mm)
Mandibular Measurements				
Buccal Intermolar Width	51.35	2.64	52.49	3.06
Lingual Intermolar Width	32.05	2.53	32.51	3.20
MB Cusp Intermolar Width	43.39	2.62	43.56	3.22
Buccal Intercanine Width	28.93	1.24	29.52	1.20
Lingual Intercanine Width	19.67	1.37	19.10	1.06
Cusp Intercanine Width	25.03	1.49	25.48	1.55
Arch Length	24.41	1.71	22.45	1.70
Irregularity Index	6.08	2.94	4.87	2.63
Maxillary Measurements				
Buccal Intermolar Width	53.01	2.50	54.70	3.01
Lingual (Groove) Intermolar Width	33.75	2.62	34.41	2.87
Lingual Intermolar Width	31.15	2.37	32.42	2.80
MB Cusp Intermolar Width	49.29	2.61	50.45	3.08
L Cusp Intermolar Width	39.16	2.70	39.83	3.21
Buccal Intercanine Width	34.87	1.39	36.36	1.76
Lingual Intercanine Width	24.50	1.62	24.78	1.77
Cusp Intercanine Width	30.99	1.75	33.74	1.69
Arch Length	28.57	1.62	27.68	1.81
Irregularity Index	5.41	2.29	5.02	1.68

Table 13. Control mean cephalometric values

Measurements	Mixed Dentition (T1)		Permanent Dentition (T2)	
	Mean	S.D.	Mean	S.D.
ML-1 (degrees)	93.77	5.53	92.96	6.80
CL-ML (degrees)	71.12	4.59	69.90	5.22
NB-1 (degrees)	23.66	6.12	22.74	6.92
NB-1 (mm)	4.67	1.58	5.19	1.98
NL-1 (degrees)	112.33	6.42	112.35	6.71
pr-n-ss (degrees)	1.80	0.98	2.71	1.13
NA-1 (degrees)	24.71	6.55	23.77	6.28
NA-1 (mm)	5.72	1.89	7.09	2.04

E. Comparison Between T1 and T2 Values

The mean change in the dental measurements between the mixed dentition and permanent dentition for the treated group are displayed in Table 14 along with the standard deviations and P-values. The mandibular intermolar width had a mean increase of 0.47 mm on the buccal, 0.22-mm on the lingual, and 0.25 mm at mesiobuccal cusp tip. None of these increases were statistically significant. The buccal and cusp tip mandibular intercanine widths increased by 1.06 mm and 0.88 mm, respectively: both of which were statistically significant. The mandibular arch length decreased by 1.41 mm and the mandibular irregularity index decreased by 2.41 mm, both changes were statistically significant. All the maxillary treated arch width changes were statistically significant. The maxillary mean intermolar width increased by 1.83 mm on the buccal, 1.20 mm at the lingual groove, 1.47 mm at the lingual, 1.79 mm at the mesiobuccal cusp tip, and 1.21 mm at the lingual cusp tip. The maxillary mean intercanine measurements increased by 2.06 mm, 1.04 mm, and 3.26 mm at the buccal, lingual, and cusp tip, respectively. The treated irregularity index decreased significantly by 3.62 mm and the arch length decreased by 0.27 mm.

Table 14. Treated mean dental changes between T1 and T2

Measurements	Mean (mm)	S.D. (mm)	P-value
Mandibular Measurements			
Buccal Intermolar Width	0.47	1.53	NS
Lingual Intermolar Width	0.22	1.56	NS
MB Cusp Intermolar Width	0.25	1.53	NS
Buccal Intercanine Width	1.06	1.26	<0.001
Lingual Intercanine Width	-0.15	1.31	NS
Cusp Intercanine Width	0.88	1.60	<0.05
Arch Length	-1.41	1.43	<0.0001
Irregularity Index	-2.41	2.20	<0.0001
Maxillary Measurements			
Buccal Intermolar Width	1.83	1.09	<0.0001
Lingual (Groove) Intermolar Width	1.20	0.91	<0.0001
Lingual Intermolar Width	1.47	1.21	<0.0001
MB Cusp Intermolar Width	1.79	1.35	<0.0001
L Cusp Intermolar Width	1.21	1.14	<0.0001
Buccal Intercanine Width	2.06	1.20	<0.0001
Lingual Intercanine Width	1.04	1.91	<0.05
Cusp Intercanine Width	3.26	1.37	<0.0001
Arch Length	-0.27	1.61	NS
Irregularity Index	-3.62	2.93	<0.0005

The mean changes in cephalometric measurements between the mixed dentition and the permanent dentition for the treated group are displayed in Table 15 along with the standard deviations and P-values. While the lower incisors became more proclined as evidenced by the increase in 1-MP and 1-NB (°) values of 0.85° and 0.74°, respectively, they were not statistically significant. However, there was statistically significant increase in pr-n-ss and NA-1 (mm) values of 0.50° and 0.36 mm, respectively, showing the increase in upper incisor protrusion.

Table 15. Treated mean cephalometric changes between T1 and T2

Measurements	Mean	S.D.	P-value
ML-1 (degrees)	0.85	4.30	NS
CL-ML (degrees)	-1.34	2.51	<0.05
NB-1 (degrees)	0.35	4.57	NS
NB-1 (mm)	0.74	0.93	<0.005
NL-1 (degrees)	0.72	4.57	NS
pr-n-ss (degrees)	0.50	0.89	<0.05
NA-1 (degrees)	-0.72	3.99	NS
NA-1 (mm)	0.36	1.31	<0.01

The mean change in the dental measurements between the mixed dentition and permanent dentition for the control group are displayed in Table 16 along with the standard deviations and P-values. The mandibular intermolar width increased at the buccal by 1.14 mm, at the lingual by 0.46 mm, and at the mesiobuccal cusp by 0.17 mm with the buccal intermolar width change being statistically significant. The mandibular intercanine width increased at the buccal (0.59 mm) and the cusp tip (0.45 mm) but decreased at the lingual (-0.57 mm). Both the mandibular arch length and the irregularity index measurements had statistically significant decreases between the mixed and permanent dentitions (-1.97 mm and -1.20 mm, respectively). All of the maxillary intermolar and intercanine width changes had statistically significant increases between the mixed and permanent dentition except the lingual intercanine width change. The maxillary molar intermolar width increased 1.69 mm at the buccal, 0.66 mm at the lingual groove, 1.27 mm at the lingual, 1.16 mm at the MB cusp, and 0.66 mm at the L cusp. The maxillary intercanine width increased 1.48 mm on the buccal, 0.27 mm on the lingual, and 2.75 mm on the buccal. The maxillary arch length decreased significantly by 0.88 mm, while the maxillary irregularity change of 0.39 mm was not statistically significant.

Table 16. Control mean dental changes between T1 and T2

Measurements	Mean (mm)	S.D. (mm)	P-value
Mandibular Measurements			
Buccal Intermolar Width	1.14	0.94	<0.0001
Lingual Intermolar Width	0.46	1.07	NS
MB Cusp Intermolar Width	0.17	1.20	NS
Buccal Intercanine Width	0.59	1.18	<0.05
Lingual Intercanine Width	-0.57	1.12	<0.05
Cusp Intercanine Width	0.45	1.64	NS
Arch Length	-1.97	1.03	<0.0001
Irregularity Index	-1.20	2.52	<0.05
Maxillary Measurements			
Buccal Intermolar Width	1.69	1.18	<0.0001
Lingual (Groove) Intermolar Width	0.66	1.30	<0.05
Lingual Intermolar Width	1.27	1.15	<0.0001
MB Cusp Intermolar Width	1.16	1.22	<0.0005
L Cusp Intermolar Width	0.66	1.22	<0.05
Buccal Intercanine Width	1.48	1.29	<0.0001
Lingual Intercanine Width	0.27	1.41	NS
Cusp Intercanine Width	2.75	1.47	<0.0001
Arch Length	-0.88	1.22	<0.005
Irregularity Index	-0.39	1.51	NS

The mean changes in cephalometric measurements between the mixed dentition and the permanent dentition for the control group are displayed in Table 17 along with the standard deviations and P-values. The lower incisors became more upright as evidenced by the change in 1-MP and 1-NB (^{o}) values of -0.81^{o} and -0.92^{o}, respectively. The changes were not statistically significant. While one measurement of lower dentoalveolar protrusion change had a statistically significant increase in protrusion [NB-1 change of 0.52 mm], the other had a nonstatistically significant decrease in protrusion (CL-ML change of -0.92^{o}). However, there was a statistically significant increase in pr-n-ss (°) and NA-1 (mm) values of 0.90^{o} and 1.37 mm, respectively, showing the increase in upper incisor protrusion. Finally, both measurements of upper incisor angulation changes were non-statistically significant: one showing almost no change (NL-1 increase of 0.02^{o}), and one showing an uprighting of the upper incisor [NA-1 change of -0.93^{o}].

Table 17. Control mean cephalometric values between T1 and T2

Measurements	Mean	S.D.	P-value
ML-1 (degrees)	-0.81	5.28	NS
CL-ML (degrees)	-1.21	2.79	NS
NB-1 (degrees)	-0.92	5.13	NS
NB-1 (mm)	0.52	1.16	<0.05
NL-1 (degrees)	0.02	4.67	NS
pr-n-ss (degrees)	0.90	1.15	<0.005
NA-1 (degrees)	-0.93	5.05	NS
NA-1 (mm)	1.37	2.17	<0.01

F. Comparison of Treated to Control Changes: Mean Values

The comparison of the treated group changes to the control group changes are outlined in Table 18 for the mandibular arch measurements, Table 19 for the maxillary arch measurements, and Table 20 for the cephalometric measurements.

In the mandibular arch, the control group tended to have a larger change in the intermolar width than the treated group. While not being statistically significant, the mean intermolar changes for the treated and control groups were, respectively, 0.47 mm and 1.14 mm on the buccal, 0.22 mm and 0.46 mm on the lingual, and 0.25 mm and 0.17 mm at the MB cusp tip. The intercanine width changes were also not statistically significant between the two groups. The intercanine width change tended to be larger for the treated group than the control group: buccal, 1.05 mm vs. 0.59 mm; lingual, -0.14 mm vs. -0.57 mm; and cusp 0.88 mm vs. 0.45 mm. While not being statistically significant, the arch length decreased less (-1.41 mm vs. -1.97 mm) in the treated group. The irregularity index decreased more (-2.41 mm vs. -1.20 mm) for the treated group when compared to the control group.

Table 18. Comparison of Treated and Control Mean Mandibular Changes

Measurements	Mean Changes		P-value
	Treated (mm)	Control (mm)	
Buccal Intermolar Width	0.47	1.14	NS
Lingual Intermolar Width	0.22	0.46	NS
MB Cusp Intermolar Width	0.25	0.17	NS
Buccal Intercanine Width	1.05	0.59	NS
Lingual Intercanine Width	-0.14	-0.57	NS
Cusp Intercanine Width	0.88	0.45	NS
Arch Length	-1.41	-1.97	NS
Irregularity Index	-2.41	-1.20	NS

In the maxillary arch (Table 19), the mean intermolar and intercanine widths increased more between the mixed dentition and the permanent dentition for the treated group than the control group, however, none of the changes were statistically significant. As in the mandibular arch, the maxillary arch length changed less in the treated group than the control group (-0.27 mm vs. -0.88 mm, respectively). The one statistically significant change was that the irregularity index decreased more in the treated group than the control group (-3.62 mm vs. -0.39 mm respectively, P 0<.001).

Table 19. Comparison of Treated and Control Mean Maxillary Changes

Measurements	Mean Changes		p-value
	Treated (mm)	Control (mm)	
Buccal Intermolar Width	1.83	1.69	NS
Lingual (Groove) Intermolar Width	1.20	0.66	NS
Lingual Intermolar Width	1.47	1.27	NS
MB Cusp Intermolar Width	1.79	1.16	NS
L Cusp Intermolar Width	1.21	0.66	NS
Buccal Intercanine Width	2.06	1.48	NS
Lingual Intercanine Width	1.04	0.27	NS
Cusp Intercanine Width	3.26	2.75	NS
Arch Length	-0.27	-0.88	NS
Irregularity Index	-3.62	-0.39	<0.001

Finally, while none of the cephalometric changes were statistically significant (Table 20) when comparing the two groups, there was a trend for the upper and lower incisors to have more proclination, and the upper incisors to have less change in protrusion in the treated group than the control group.

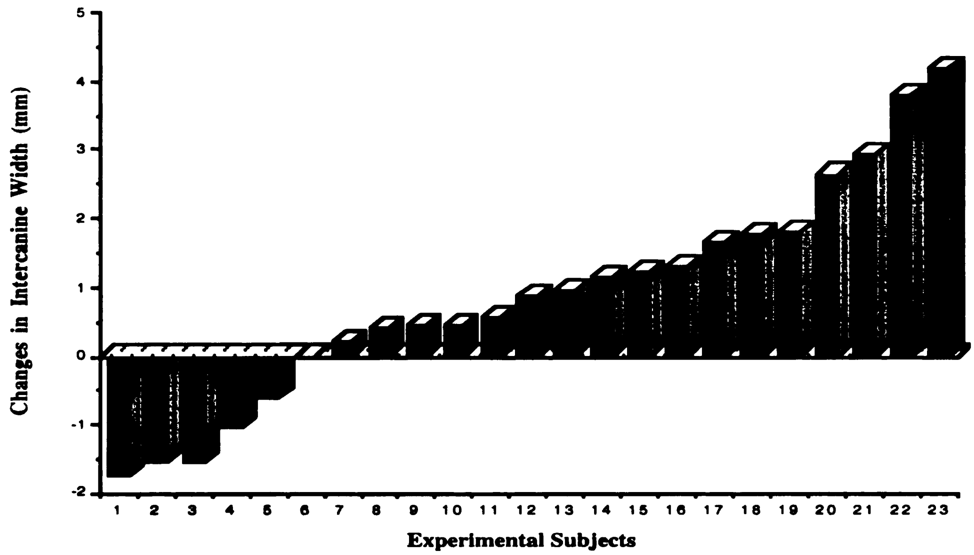
Table 20. Comparison of Treated and Control Mean Cephalometric Changes

Measurements	Mean Changes		p-value
	Treated	Control	
ML-1 (degrees)	0.85	-0.81	NS
CL-ML (degrees)	-1.34	-1.21	NS
NB-1 (degrees)	0.35	-0.92	NS
NB-1 (mm)	0.75	0.52	NS
NL-1 (degrees)	0.73	0.02	NS
pr-n-ss (degrees)	0.50	0.90	NS
NA-1 (degrees)	-0.72	-0.93	NS
NA-1 (mm)	0.36	1.37	NS

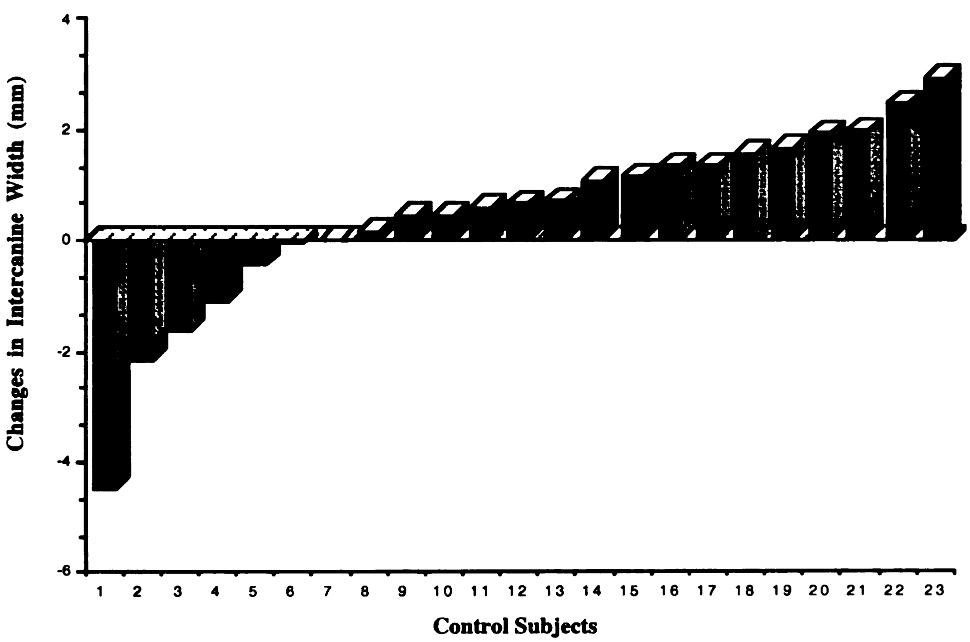
G. Comparison of Individual Treated and Untreated Control Subjects

While the mean changes between the treated and control groups were almost entirely statistically nonsignificant, general trends could be seen in the results. The treated group had a mean increase in arch width and a mean decrease in irregularity index that was greater than the control group. Graphs 1 and 2 show the individual changes in lower intercanine width at the cusp tip for all the 23 treated and 23 control subjects. Comparing these graphs, it is evident that, in the control group, there are no subjects that have arch width increases greater than 3 mm while in the treated group, there are four subjects with this amount of change. Graphs 3 and 4 show the individual changes in lower irregularity index for all the 23 treated and 23 control subjects. Comparison of these two graphs shows there are many more treated subjects that had a decrease in irregularity index, and there were many more treated subjects with large decreases in the irregularity index (>3 mm).

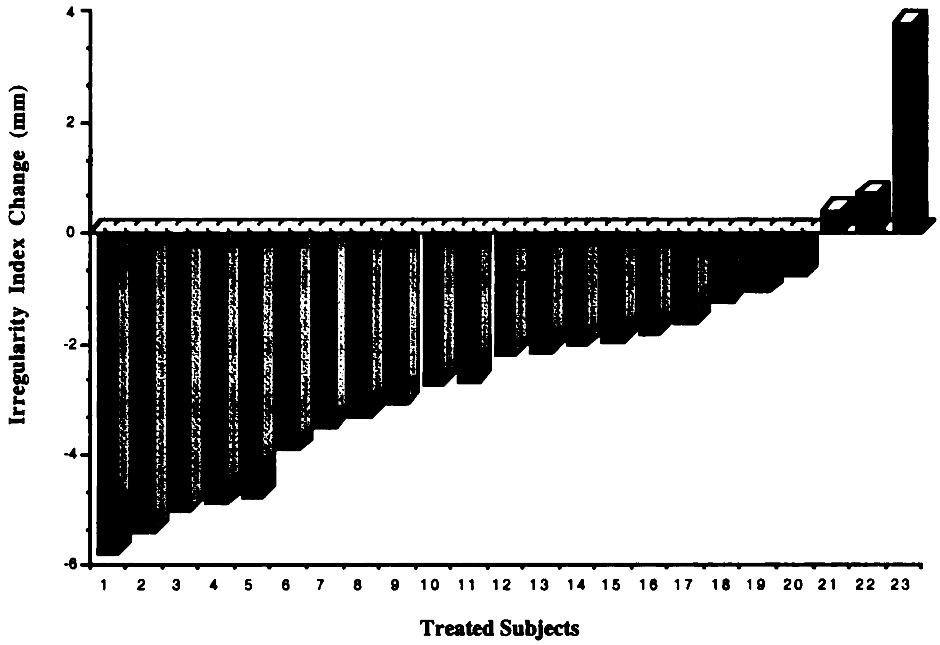
Graph 1. Lower Intercanine Width Changes Between T1 and T2 for Individual Treated Subjects



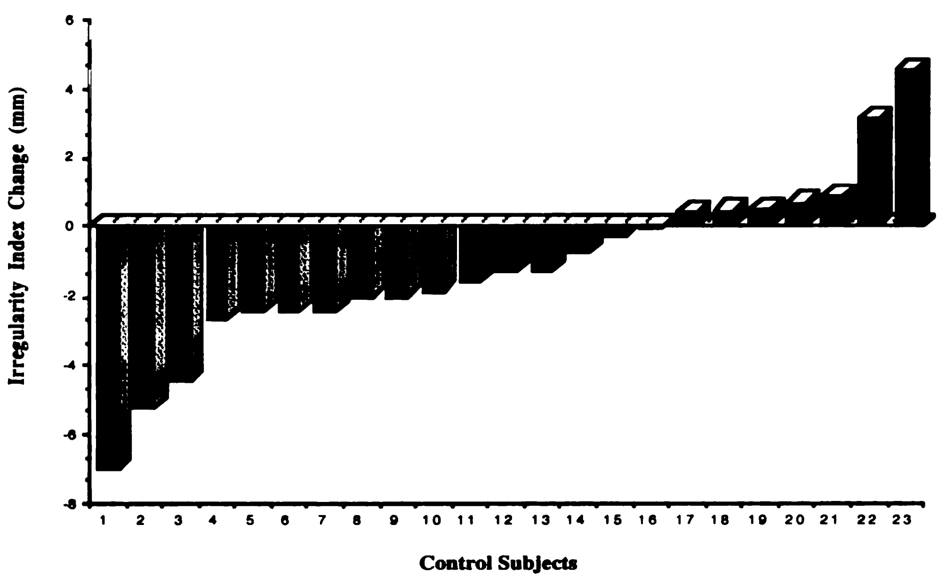
Graph 2. Lower Intercanine Width Changes Between T1 and T2 for Individual Control Subjects



Graph 3. Lower Irregularity Index Changes Between T1 and T2 for Individual Treated Subjects



Graph 4. Lower Irregularity Index Changes Between T1 and T2 for Individual Control Subjects



IV. DISCUSSION

A. METHODS OF MEASURING

The photocopying of the dental casts caused a reduction of the image by 3% compared to the true size of the dental cast. The measurements obtained by digitization of the photocopy image had a large variance in relation to the direct measurement technique. While most of the variance was due to differences in locating the measurement point on the photocopy and the actual model, the digitization still resulted in reduced values of arch width and increased values for arch length. In agreement with other researchers, methods of dental cast measurement other than that of direct caliper measurement may not be accurate.

B. COMPARING TREATED AND CONTROL GROUPS

The results of this study demonstrate that the early expansion group had mandibular arches with more width increase in the intercanine region, less decrease in arch length, and more decrease in irregularity index between the mixed and permanent dentitions than the untreated group. The maxillary arch had the same trend of change as the mandibular arch when comparing the treated and control group changes between the two time points. While there is a trend for wider arches and less crowding in the expansion group, these results were not statistically significant. By comparing the mean changes of some dental cast measurements of individual treated and control subjects, it can be seen there were more positive arch changes in the treated group.

With maturation, there is a change in arch dimensions as well as crowding. Therefore, when comparing the effects of expansion over time, it is critical to compare the changes to a similar aged untreated group. The present study does an effective job in closely matching the ages of the treated and control groups at both stages. At both stages, the mean age of the groups is within half a year. At both stages, the control group mean age is slightly greater than the treated group. This could be explained by the fact that one criteria for inclusion in the study is dental age. The Michigan Growth Study was mainly collected in the 1950's and 1960's, while the treated group was collected in the 1980's and 1990's. There has been a trend for present day children to mature earlier than those of the past, thus explaining the treated group being slightly younger.

Another strength of this project is that the treated individuals came from one practice and treated by a well calibrated group of practitioners. One of the major problems with the study by Little (1990) [33] was that the treated group came from several orthodontic offices that had different methods for expanding the arches. Another problem with the that study was that their definition of mixed dentition was not clearly defined. The treated subjects had a large age range and, obviously, had different dental ages. In the present study, there was strict selection criteria to ensure consistent dental age of the subjects. By doing this, it minimizes the confounding factor of the arch dimension changes that occur during different dental ages.

C. WEAKNESSES AND LIMITATIONS OF THE STUDY

One weakness of the study was that it was not a randomized clinical trial, therefore the possibility of selection bias was present. However, it was impossible to set up an experimental study where individuals who need treatment do not receive it. For this reason, a retrospective study was performed using an untreated sample from the University of Michigan Growth Study. While every attempt was made to closely match the treated and control groups, there was still that possibility that the two groups are different.

Another major problem in this study was that there were no records taken immediately after the expansion was complete. Therefore, it was impossible to tell how much of the dental and cephalometric changes were due to the orthodontic appliances, and then to observe how much relapse occurred after the completion of treatment and the full eruption of the permanent dentition. Also, it was impossible to determine whether the transverse expansion was orthopedic, bodily orthodontic tooth movement, or dental tipping. To answer these questions, anteroposterior cephalograms would had to have been taken at the same time as the other records in order to measure basal bone changes.

While 46 combined subjects for the treated and control groups was a fairly large sample size, the variation in the arch changes for each group was also quite large. Thus the power value for most of the measurements was under 0.2 and made the chances of getting a false negative result extremely high. In order to increase the power of the study, the number of subjects would have to be dramatically increased. For example, for the lower intercanine distance measurements to have a power value of 0.8, the sample size would have to increase to 346 subjects(assuming the standard deviation and mean change does not increase with the increased sample size.

Many additional treated individuals with records were available from this practice. The main criteria for excluding most of these records was the incomplete eruption of all the permanent incisors. It was important to exclude these records for two reasons. First, it is impossible to use Little's irregularity index without four incisors and the canines present. Second, the dental arch undergoes many changes in dimension during the eruption of the permanent incisors. The canines move buccally during incisor eruption causing an increase in intercanine width. The incisors erupt more labially than their primary predecessors, which will increase the arch length. However, the cases with incomplete eruption might have been expanded more.

Another inclusion criteria of this study was that the patients had to return to have a second phase of orthodontic treatment. Several patients met all the preliminary criteria to be in this study, but records were not available in the permanent dentition. It is impossible to say exactly how these individuals exclusion could have effected the results. Perhaps, some of them had such ideal alignment after this treatment that they never returned for a second phase of treatment. On the other hand, subjects may have had a poor result after treatment and sought further orthodontic treatment elsewhere. Therefore, in my judgement including these subjects would have a minimal result on the findings.

Another factor that must be considered are the changes in arch dimension with age. As the permanent teeth erupt, the intercanine width gets narrower, the arch length decreases, and the irregularity index increases.[33] These changes in arch form continue as individuals age. It would be interesting to investigate whether the early expansion treatment would alter the natural changes that occur in the dental arches over prolonged periods of time.

This type of mixed dentition expansion is very common in clinical orthodontic practice because orthodontists find positive arch changes. As the case of any clinical study, there were large variations among the responses of individual subjects. At this point, it is impossible to determine the reason why some subjects responded better to early expansion. There should be further study as to whether factors can be identified that explain why in certain subjects wider arches and less crowding were obtained with expansion in the mixed dentition than in others. Perhaps, clinical trials could be performed to examine if overexpansion past the criteria used in this project will cause sustained increase in arch width. There is also the belief that an equilibrium exists between tongue and cheek pressure and relapse is due to moving teeth to positions which creates a position of pressure on the teeth.[33] Perhaps the individuals who have stable results have adapted to make the tongue and cheek pressures balance in a new equilibrium (e.g., new tongue posture).

D. CONCLUSIONS

The goal of this study was to test if arch expansion in the mixed dentition resulted in changes in arch width and incisor position that were significantly different from untreated subjects. The data demonstrate the only statistically significant change in the dental arches which is maintained into the permanent dentition with early expansion is the reduction of crowding in the maxillary arch. By examining only the average change between the treated and control groups, it would be difficult to recommend this treatment to clinical orthodontists. A net gain of approximately 0.5 mm in lower intercanine width and 0.5 mm in lower arch length would only gain approximately 1 mm of space to correct the crowding[57] which is not significant clinically. However, when comparing Graphs 1 and 2, it is evident that the largest individual changes in lower intercanine width (over 2.5 mm) occur in the treated sample. In addition, Graph 3 and 4 demonstrate that the number of individuals who have a clinically significant change in crowding (more that 3 mm change) is substantially greater in the treatment group(9) than the untreated control group(3). The hypothesis that arch expansion in the mixed dentition is maintained in the permanent dentition and results is less crowding of the incisors cannot be conclusively rejected. Therefore, this treatment modality is recommended because it does provide meaningful clinical changes in many individuals. Additional research is needed to identify why certain individuals responded more positively to treatment.

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