2008

Long-term follow-up of patients treated with the edgewise crowned Herbst appliance in the mixed dentition

Timothy G. Wigal
West Virginia University

Follow this and additional works at: <https://researchrepository.wvu.edu/etd>

Recommended Citation

Wigal, Timothy G., "Long-term follow-up of patients treated with the edgewise crowned Herbst appliance in the mixed dentition" (2008). *Graduate Theses, Dissertations, and Problem Reports*. 2650.
<https://researchrepository.wvu.edu/etd/2650>

This Thesis is protected by copyright and/or related rights. It has been brought to you by the The Research Repository @ WVU with permission from the rights-holder(s). You are free to use this Thesis in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you must obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/ or on the work itself. This Thesis has been accepted for inclusion in WVU Graduate Theses, Dissertations, and Problem Reports collection by an authorized administrator of The Research Repository @ WVU. For more information, please contact researchrepository@mail.wvu.edu.

**LONG-TERM FOLLOW-UP OF PATIENTS
TREATED WITH THE EDGEWISE CROWNED
HERBST APPLIANCE IN THE MIXED DENTITION**

Timothy G. Wigal, D.D.S.

A THESIS

Submitted to:
The School of Dentistry
at West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science
In
Orthodontics

Peter Ngan, D.M.D., Chair
Chris Martin, D.D.S., M.S.
Thomas Razmus, D.D.S., M.S.

Department of Orthodontics

Morgantown, West Virginia
2008

ABSTRACT

LONG-TERM FOLLOW-UP OF PATIENTS TREATED WITH THE EDGEWISE CROWNED HERBST APPLIANCE IN THE MIXED DENTITION

Timothy G. Wigal, D.D.S.

Objectives: Research has indicated that the bite jumping technique employed by the crowned Herbst appliance can be effective in correcting Class II skeletal abnormalities by promoting growth of the mandible and remodeling of the glenoid fossa. This research investigated the skeletal and dental alterations of Class II patients treated at an early age with the edgewise crowned Herbst appliance and evaluated the long term stability of those effects. **Methods:** Cephalometric analysis was performed for a treatment group consisting of 22 radiographs taken before phase I treatment (T1), immediately after Herbst removal during phase I treatment (T2), at the completion of phase I treatment (T3), prior to beginning of phase II orthodontic treatment (T4), and immediately following phase II orthodontic treatment (T5). Measurements were compared to a matched control sample of untreated Class II patients from the Bolton-Brush study. The difference in each variable between the treatment and control groups across the five time periods was analyzed for pooled subjects, and separately for male and female subjects. The differences between certain time points were analyzed to investigate treatment changes and their stability over time. For all time periods, the change in the values of the variables for pooled subjects, male subjects, and female subjects in the treatment group were compared to the change in the values of the variables for pooled subjects, male subjects, and female subjects in the control group, respectively. In total, 37 variables were evaluated for each group including sagittal variables, vertical variables, angular variables, and condyle/glenoid fossa variables. In addition, an evaluation of the overjet correction and molar relationship correction for the treatment groups and an evaluation of the net overjet correction and net molar relationship correction for the treatment vs. control groups at each time period for pooled subjects were performed. **Results:** Treatment of Class II patients treated with the crowned Herbst appliance in the early mixed dentition resulted in the following changes relative to normal growth: The forward movement of the maxillary base (OLp-A pt) was initially restrained after treatment (T2-T1) and gradually became more restrained in the short-term (T3-T1) and long-term (T4-T1) post-treatment periods. An even greater restraint was seen after phase II orthodontics (T5-T1). The mandibular base (OLp-Pg) was initially moved forward after treatment (T2-T1), however, a gradual relapse was seen in the short-term (T3-T1) and long-term (T4-T1) post-treatment periods. Additional

relapse in a posterior direction was seen after phase II orthodontics (T5-T1). The maxillary molars (Ms-OLp) were initially distalized (T2-T1), relapsed slightly in the short-term post-retention period (T3-T1), and became distalized again in the long-term post-treatment period (T4-T1). The maxillary molars were mesialized during phase II orthodontic treatment (T5-T4) and most of the overall posterior molar movement was eliminated after this period (T5-T1). The mandibular molars (Mi-OLp) were initially mesialized after treatment (T2-T1), however gradual relapse occurred during the short-term post-treatment period (T3-T1) until they returned to their pre-treatment position after the long-term post-treatment period (T4-T1). They were mesialized again after phase II orthodontic treatment (T5-T1). The maxillary incisors (Is-OLp) moved backward and retroclined after treatment (T2-T1), then relapsed slightly during the short-term (T3-T1) and long-term (T4-T1) post-treatment period. A net posterior movement was maintained through the long-term post-treatment period (T4-T1). This posterior position of the maxillary incisor remained stable through phase II treatment (T5-T1). The mandibular incisors (Ii-OLp) moved forward and proclined after treatment (T2-T1), then relapsed to their pre-treatment position after the short-term post-treatment period (T3-T1). Forward movement and proclination occurred during the long-term retention period (T4-T3), giving a net forward movement and proclination after this period (T4-T1). The mandibular incisors returned to their pre-treatment position after phase II orthodontic treatment (T5-T1). A net overjet correction of 7.0 mm occurred after treatment (T2-T1), then relapsed in the short-term post-treatment period (T3-T1) until a relatively stable net overjet correction between 2.5-3.0mm was maintained over the long-term (T4-T1). The overjet correction remained stable through phase II treatment (T5-T1). A molar relationship correction of 6.6 mm occurred after treatment (T2-T1), then relapsed in the short-term post-treatment period (T3-T1) until a relatively stable net molar correction between 2.2-3.3mm was maintained over the long-term (T4-T1). The molar correction remained stable through phase II treatment (T5-T1). Relocation of the glenoid fossa occurred in an anterior and superior direction after treatment (T2-T1) and this relative change in position was stable over the long term (T4-T1). Restriction of the downward and backward movement of the fossa was observed and might additionally contribute to Class II correction. **Conclusions:** The results of this study suggest that early treatment with the edgewise crowned Herbst appliance can achieve overjet correction and molar relationship correction that remains stable over the long-term. However, the skeletal and dental contributions to this overjet and molar correction shift over time with decreasing skeletal contribution and increasing dental compensation. During phase II orthodontic treatment, an increased skeletal contribution to overjet and molar relationship correction occurs.

DEDICATION

To my beautiful wife, **Julie Wigal**, who is the love of my life and my best friend. The sacrifices you have made over the last seven years are unimaginable and the love and support you have given me through this process is beyond belief. Your knowledge of business is exceptional and your work ethic is second to none. I have leaned on you heavily throughout this journey and you have always delivered, without complaint. There is no one I trust more than you. Most importantly, you have been the most wonderful mother to our two daughters and I only hope they grow up to be just like you. We make a great team...we finally made it...I love you.

To my beautiful daughters, **Ella Wigal** and **Lydia Wigal**, whose smiles and personalities brightened my life and lifted me when I was down. The joy you have brought to my life keeps everything in perspective. I love you.

To my parents, **Gary Wigal** and **Debbie Wigal**, who have been with me from the start and have loved me and supported me in whatever it was I chose to do. I love you.

To my siblings, **James Wigal**, **Paige Windland**, and **Dustin Wigal**, who have provided a safety net of encouragement and support whenever I needed it. I wish you all the best in your lives. I love you.

To my grandparents, **James Goodwin** and **Gloria Goodwin**, who have sacrificed so much over the years to make sure I had every opportunity to succeed in life. Your constant encouragement and support gave me the confidence to excel despite the circumstances. Papaw, you are my best friend and greatest contributor to my success. Thanks for always being there, no matter what. I love you.

To my in-laws, **Dave Wagner** and **Nancy Wagner**, who have included me as one of their own. Thanks for all the support and guidance during the last seven years. We couldn't have made it without you. I love you.

To my in-laws, **Jeremy Wagner** and **Michelle Wagner**, who have offered constant support and kept me laughing through this process.

To **God**, who has provided me with an abundance of blessings more than I ever expected or deserved, and who continues to open doors for me. Thank you. I love you.

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank the following individuals who have contributed and assisted me throughout my specialty training.

Dr. Peter Ngan, for his lifelong commitment to education, encouragement, expertise in the clinic, and general wisdom offered on a daily basis. I consider you not only a mentor, but a true friend.

Dr. Chris Martin, for his everyday advice in the clinic, friendship, assistance with practice issues, support provided on the thesis, and full-time commitment to education.

Dr. Thomas Razmus, for his advice and encouragement throughout this thesis.

Dr. Terry Dischinger, for the use of records, for his enthusiasm for the Herbst appliance and his desire to constantly find new ways to better treat his patients.

Dr. Erdogan Gunel, for his statistical assistance and willingness to work overtime to deliver large amounts of statistics in a short period of time.

Dr. Mark Hans, Case Western Reserve University-Bolton Brush Study, for providing the records for the control group in this study.

Drs. Tim Tremont, Edward McFarland, Jeff Gilmore, Thomas Jarrett, Kerry Kirsch, Joe Bonello, John Dempsey, J.B. Wilfong, Mike Hazey, and Jennifer Hamilton, for the invaluable lessons in the classroom and the clinic. Thank you for the sacrifice of time away from your busy practices. Each of you has influenced my education in ways that will pay dividends for years to come.

Dustin Wigal, for his assistance in creating charts, graphs and tables for the thesis and his countless hours of data entry.

Pam, Charlotte, Vivian, and Karen, for their friendship and assistance in the clinic. You have all been a joy to work with.

Joyce and Carrie, for all their hard work that often goes unappreciated. You are both invaluable to this program.

Dr. Nikia Burns and Dr. Lindsay Jackfert, my co-residents, for their constant support, encouragement, and motherly guidance throughout the program. Our friendship will last forever, and I wish you both the best in your futures.

Mike, Meredith, Todd, Glenn, Spencer, and Jennifer, my fellow residents, for their friendship and guidance through the program. Thanks for everything.

Mike, Rajia, Thuy, Mike, Dean, and Kolin, my fellow residents, for the good times, debates, friendship, and support throughout the program. Holler!

Dr. Mike Munn, for his computer expertise and willingness to help out a friend. Your computer gymnastics will never be forgotten. I appreciate all your hard work.

TABLE OF CONTENTS

DEDICATION	iv
ACKNOWLEDGEMENTS	v
TABLE OF CONTENTS	vii
LIST OF TABLES	x
LIST OF FIGURES	xi
CHAPTER I: INTRODUCTION	1
Background	1
Purpose of the Study	2
Statement of the Problem	3
Significance of the Problem	3
Null Hypotheses	4
Definition of Terms	5
Assumptions	8
Limitations	8
Delimitations	9
CHAPTER II: REVIEW OF THE LITERATURE	10
History and Classification of Malocclusion	10
Etiology of Malocclusion and the Need for Orthodontic Therapy	11
Prevalence of Class II Malocclusion	11
Class II Skeletal Growth	12
Analysis of the Dentofacial Complex	14
Treatment of Class II Malocclusion	15
Functional Appliances Used to Treat Class II Malocclusion	17
The Herbst Appliance	19
Indications for Treatment with the Herbst Appliance	21
Timing of Treatment with Functional Appliances	21
Treatment Effects of the Herbst Appliance on the Dentofacial Complex	24
Skeletal Components	24
Dental Components	27
Vertical changes associated with the Herbst Appliance	27
Post-treatment relapse following Herbst treatment	28
The Edgewise Herbst Appliance	30
The Dischinger Protocol for the Edgewise Herbst Appliance	35
Summary and Conclusions	37
CHAPTER III: MATERIALS AND METHODS	40
Sample Selection	40
Appliance Design	41
Treatment Protocol	43
IRB Approval	45
Cephalometric Analysis	45
Method Error	47
Cephalometric Landmarks and Reference Lines	50
Evaluation of Overjet and Molar Relationship Correction	57

Statistical Analysis.....	59
CHAPTER IV: RESULTS AND DISCUSSION	61
RESULTS	61
Sample Size.....	61
Sex Distribution	61
Age Distribution.....	61
Distribution of Variable Measurements.....	64
Pre-treatment Craniofacial Morphology of the Treatment vs. the Control Group	65
Comparison of the Treatment Group and the Control Group Across the Time Periods.....	70
Sagittal Variables	71
Vertical Variables	71
Angular Variables	71
Condyle/Glenoid Fossa Variables.....	72
Graph Analysis of Variables Across Time for the Treatment vs. Control Groups.....	74
Sagittal Variables	74
Vertical Variables	77
Angular Variables	77
Condyle/Glenoid Fossa Variables.....	79
Comparison of the Treated Group vs. the Control Group	80
Comparison of T2-T1 (Treatment Effects of the Herbst Appliance).....	81
Overjet and Molar Relationship Correction-Treatment Group (T2-T1).....	87
Net Overjet and Molar Relationship Correction-Tx vs. Control Group (T2-T1)	90
Comparison of T3-T1 (Phase I Treatment Effects)	93
Overjet and Molar Relationship Correction-Treatment Group (T3-T1).....	98
Net Overjet and Molar Relationship Correction-Tx vs. Control Group (T3-T1)	101
Comparison of T4-T1 (Residual Phase I Treatment Effects)	104
Overjet and Molar Relationship Correction-Treatment Group (T4-T1).....	108
Net Overjet and Molar Relationship Correction-Tx vs. Control Group (T4-T1)	111
Comparison of T5-T1 (Combined Phase I and Phase II Treatment Effects).....	114
Overjet and Molar Relationship Correction-Treatment Group (T5-T1).....	120
Net Overjet and Molar Relationship Correction-Tx vs. Control Group (T5-T1)	123
Comparison of T5-T4 (Phase II Treatment Effects)	125
Comparison of T5-T4 (Phase II Treatment Effects)	126
Overjet and Molar Relationship Change-Treatment Group (T5-T4).....	131
Net Overjet and Molar Relationship Change-Tx vs. Control Group (T5-T4)	134
Comparison of T4-T3 (Relapse after Phase I to before Phase II Treatment)	137
Overjet and Molar Relationship Change-Treatment Group (T4-T3).....	142
Net Overjet and Molar Relationship Change-Tx vs. Control Group (T4-T3)	145
DISCUSSION	148
Sagittal Changes (Skeletal)	149
Sagittal Changes (Dental)	155
Overjet Changes.....	160
Molar Relationship Changes.....	166
Vertical Changes (Skeletal)	171
Vertical Changes (Dental).....	173
Condyle/Glenoid Fossa Changes	175

CHAPTER V: SUMMARY, CONCLUSIONS, RECOMMENDATIONS	181
Summary	181
Conclusions	183
Recommendations	185
REFERENCES	186
APPENDICES	197
ABSTRACT.....	ii
CURRICULUM VITAE.....	290

LIST OF TABLES

Table 1. Description of Timepoints used in the Study.....	40
Table 2. Correlation Coefficients for all variables at T1,T2,T3,T4, and T5.....	49
Table 3. Skeletal and Dental Landmarks	50
Table 4. Definition of reference lines	50
Table 5. Sagittal Measurements	51
Table 6. Vertical Measurements	52
Table 7. Angular Measurements	53
Table 8. Skeletal Landmarks of the Condyle/Glenoid Fossa Analysis.....	55
Table 9. Sagittal Measurements of the Condyle/Glenoid Fossa Analysis	55
Table 10. Vertical Measurements of the Condyle/Glenoid Fossa Analysis	55
Table 11. Calculation of Overjet and Molar Relationship Changes	57
Table 12. Age Distribution	63
Table 13. Comparison of the pre-treatment craniofacial morphology in pooled subjects	67
Table 14. Comparison of the pre-treatment craniofacial morphology in males subjects	68
Table 15. Comparison of the pre-treatment craniofacial morphology in female subjects	69
Table 16. Comparison of the Treatment group vs the Control group across the time periods	73
Table 17. Comparison of treated vs. control in pooled subjects at T2-T1	84
Table 18. Comparison of treated vs. control in male subjects at T2-T1.....	85
Table 19. Comparison of treated vs. control in female subjects at T2-T1.....	86
Table 20. Comparison of treated vs. control in pooled subjects at T3-T1	95
Table 21. Comparison of treated vs. control in male subjects at T3-T1	96
Table 22. Comparison of treated vs. control in female subjects at T3-T1	97
Table 23. Comparison of treated vs. control in pooled subjects at T4-T1	105
Table 24. Comparison of treated vs. control in male subjects at T4-T1.....	106
Table 25. Comparison of treated vs. control group in female subjects at T4-T1.	107
Table 26. Comparison of treated vs. control in pooled subjects at T5-T1.....	117
Table 27. Comparison of treated vs. control in male subjects at T5-T1.....	118
Table 28. Comparison of treated vs. control in female subjects at T5-T1.....	119
Table 29. Comparison of treated vs. control group in pooled subjects at T5-T4	128
Table 30. Comparison of treated vs. control in males subjects at T5-T4	129
Table 31. Comparison of treated vs. control in female subjects at T5-T4)	130
Table 32. Comparison of treated vs. control in pooled subjects at T4-T3	139
Table 33. Comparison of treated vs. control in pooled subjects at T4-T3.....	140
Table 34. Comparison of treated vs. control in female subjects at T4-T3.....	141

LIST OF FIGURES

Figure 1. The Edgewise Crowned Herbst Appliance.....	30
Figure 2. Mixed Dentition Herbst Appliance	31
Figure 3. Herbst Appliance (Maxillary Unit)	32
Figure 4. Herbst Appliance (Mandibular Unit).....	33
Figure 5. Corrected Tomograms taken prior to Herbst removal.....	36
Figure 6. Corrected tomograms taken A) before, B) during, and C) after Herbst treatment	44
Figure 7. Cephalometric landmarks and reference lines for sagittal measurements.....	52
Figure 8. Cephalometric landmarks and reference lines for vertical measurements	53
Figure 9. Cephalometric landmarks and reference lines for angular measurements	54
Figure 10. Landmarks/reference lines for sagittal and vertical measurements of the Condyle/Glenoid Fossa Analysis	56
Figure 11. Components of overjet correction (T2-T1)	88
Figure 12. Components of molar relationship correction (T2-T1)	89
Figure 13. Pitchfork analysis of overjet and molar correction (T2-T1).....	89
Figure 14. Components of net overjet correction (T2-T1)	91
Figure 15. Components of net molar correction (T2-T1)	92
Figure 16. Pitchfork analysis of net overjet and molar correction (T2-T1).....	92
Figure 17. Components of overjet correction (T3-T1)	99
Figure 18. Components of molar relationship correction (T3-T1)	100
Figure 19. Pitchfork analysis of overjet and molar corrections (T3-T1)	100
Figure 20. Components of net overjet correction (T3-T1)	102
Figure 21. Components of net molar correction (T3-T1)	103
Figure 22. Pitchfork analysis of net overjet and molar correction (T2-T1).....	103
Figure 23. Components of overjet correction (T4-T1)	109
Figure 24. Components of molar relationship correction (T4-T1)	110
Figure 25. Pitchfork analysis of overjet and molar correction (T4-T1).....	110
Figure 26. Components of net overjet correction (T4-T1)	112
Figure 27. Components of net molar correction (T4-T1)	113
Figure 28. Pitchfork analysis of net overjet and molar correction (T4-T1).....	113
Figure 29. Components of overjet correction (T5-T1)	121
Figure 30. Components of molar relationship correction (T5-T1)	122
Figure 31. Pitchfork analysis of overjet and molar correction.....	122
Figure 32. Components of net overjet correction (T5-T1)	124
Figure 33. Components of net molar correction (T5-T1)	125
Figure 34. Pitchfork analysis of net overjet and molar correction (T5-T1).....	125
Figure 35. Components of overjet correction (T5-T4)	132
Figure 36. Components of molar relationship correction (T5-T4)	133
Figure 37. Pitchfork analysis of overjet and molar correction (T5-T4).....	133
Figure 38. Components of net overjet correction (T5-T4)	135
Figure 39. Components of net molar correction (T5-T4)	136
Figure 40. Pitchfork analysis of net overjet and molar correction (T5-T4).....	136

Figure 41. Components of overjet correction (T4-T3)	143
Figure 42. Components of molar relationship correction (T4-T3)	144
Figure 43. Pitchfork analysis of overjet and molar correction (T4-T3).....	144
Figure 44. Components of net overjet correction (T4-T3)	146
Figure 45. Components of net molar correction (T4-T3)	147
Figure 46. Pitchfork analysis of net overjet and molar correction (T4-T3).....	147
Figure 47. Skeletal contribution to net overjet correction	164
Figure 48. Contribution of the skeletal bases and incisors to net overjet correction	165
Figure 49. Skeletal contribution to net molar correction	169
Figure 50. Contribution of skeletal bases and incisors to net molar correction.....	170

CHAPTER I: INTRODUCTION

Background

Removable functional appliances such as the activator¹, bionator², and Frankel appliance³ are commonly used in the treatment of Class II malocclusion in an effort to stimulate sagittal mandibular growth in retrognathic mandibles. Unfortunately, the effectiveness of these appliances has been questioned and treatment results are inconsistent. In addition, patient compliance is often a problem with removable appliances and treatment time is usually long (2-4 years)⁴. Fixed functional appliances such as the Herbst appliance offer an alternative treatment method with several advantages: the appliance is fixed to the dentition; no patient cooperation is required; treatment is continually applied (24 hours a day); and the treatment time is short (6-8 months)⁴. Research has indicated that the bite jumping technique employed by the Herbst appliance can be effective in correcting Class II skeletal abnormalities by promoting growth of the mandible and remodeling of the glenoid fossa^{5,6,7,8}.

Since Pancherz⁹ re-introduced the Herbst appliance in 1979, an increasing body of research has been published evaluating its effects on occlusion, the dentofacial complex, and the masticatory system. Pancherz et al.^{10,11,12} have published short-term and long-term data on the treatment effects of the banded Herbst appliance and the effects of the acrylic splint Herbst appliance have been investigated^{13,14}. However, after improvements in its design and increased clinical use, there seems to be an overall lack of information on the treatment changes observed with the crowned Herbst appliance and the long term stability of these effects.

The timing of orthopedic intervention with functional appliances has also been the subject of intense controversy within the profession of orthodontics. When determining the optimal time to initiate Class II treatment, other factors must be considered such as the ability to utilize all potential growth, likelihood of incisor trauma, development of improper swallowing patterns, incomplete lip function, effects on the temporomandibular joint, and psychosocial concerns. The decision to treat either in the early, late mixed, or permanent dentition has been debated and many questions remain unresolved. Successful treatment of Class II malocclusion in the early mixed dentition have been reported^{15,16}, however other studies report similar success during the late mixed dentition^{17,18} and early permanent dentition¹⁹. Data from randomized controlled clinical trials have shown that effective skeletal changes could be achieved at either point in time and remain stable, although they suggest that treatment in the late transitional dentition is the most efficient in most cases^{20,21}. Cozza et al.²² suggest that supplementary mandibular growth with functional appliance therapy appears to be significantly larger if the functional treatment is performed at the pubertal peak in skeletal maturation.

Purpose of the Study

This study investigated the skeletal and dental alterations of Class II patients treated in the early mixed dentition with the crowned Herbst appliance and examined the long term stability of these changes. Cephalometric analysis was performed on radiographs taken before phase I treatment (T1), immediately after Herbst removal during phase I treatment (T2), at the completion of phase I treatment (T3), prior to beginning of phase II orthodontic treatment (T4), and immediately following phase II orthodontic treatment

(T5). Measurements were compared to a matched control sample of untreated Class II patients from the Bolton-Brush study. The results of this study provide important information on the effectiveness of early treatment with the crowned Herbst appliance and offer new information on the long term stability of these treatment effects. This information can ultimately be used by clinicians to evaluate the best time and most effective technique for treating skeletal Class II deformities.

Statement of the Problem

Are the skeletal and dental effects achieved in mixed dentition treatment with the edgewise crowned Herbst appliance stable in the long term?

Significance of the Problem

Research has indicated that the bite jumping technique employed by the Herbst appliance can be effective in correcting Class II skeletal abnormalities by promoting growth of the mandible and remodeling of the glenoid fossa. Since Pancherz re-introduced the Herbst appliance in 1979, an increasing body of research has been published evaluating its effects on occlusion, the dentofacial complex, and the masticatory system. However, after improvements in its design and increased clinical use, there seems to be an overall lack of information on the treatment effects of the edgewise crowned Herbst appliance. In addition, the long-term stability of the effects of early treatment with the Herbst appliance has been questioned. This research investigated the skeletal and dental alterations of Class II patients treated at an early age with the edgewise crowned Herbst

appliance and evaluated the long term stability of those effects. The results provide valuable information that should help clinicians determine whether early treatment with the edgewise crowned Herbst appliance is warranted and if the results are stable over the long term.

Null Hypotheses

- 1) There are no significant short-term skeletal or dental changes associated with edgewise crowned Herbst treatment in the mixed dentition when compared to an untreated control group.
- 2) There are no significant short-term skeletal or dental changes associated with Phase I treatment (edgewise crowned Herbst treatment followed by two by four appliance treatment) when compared to an untreated control group.
- 3) There are no significant long-term skeletal or dental changes associated with Phase I treatment (edgewise crowned Herbst treatment followed by two by four appliance treatment) prior to Phase II treatment when compared to an untreated control group.
- 4) There are no significant skeletal or dental changes associated with combined Phase I treatment (edgewise crowned Herbst treatment followed by two by four appliance treatment) and Phase II treatment when compared to an untreated control group.
- 5) There are no significant skeletal or dental changes associated with Phase II comprehensive orthodontic treatment when compared to an untreated control group.

- 6) There is no significant skeletal or dental relapse that occurred from after Phase I treatment (edgewise crowned Herbst treatment followed by two by four appliance treatment) to before Phase II comprehensive orthodontic treatment when compared to an untreated control group.

Definition of Terms

Bolton-Brush Study:

A longitudinal growth study performed at the Case Western University, which involved subjects with Class I, Class II, and Class III malocclusions who did not receive orthodontic treatment. These individuals were followed with orthodontic records for several years and their growth patterns were charted.

Cephalogram:

A term used as a synonym for a cephalometric radiograph.

Cephalometric analysis:

An analysis made on cephalometric radiographs comprised of a number of given landmarks and measurements used to describe positions and relationships of various skeletal components.

Cephalometric radiograph:

A radiograph of the head made with precise reproducible relationships between x-ray source, subject, and film. The generally accepted distances between x-ray source and the center of the subject are 5 feet or 150 cm. The distance between the subject and film is usually 15 cm, but may be standardized at a different value or varied with patient size

and recorded for each exposure. The two standard orientations for cephalometric radiographs are lateral and postero-anterior (P-A).

Cephalometric tracing:

A tracing of selected structures from a cephalometric radiograph, made on translucent drafting paper or digitized on computer software for purposes of measurement and evaluation.

Class II malocclusion:

A type of malocclusion in which the mesiobuccal cusp of the maxillary first molar is located mesial to the buccal groove of the mandibular first molar when the teeth are in centric occlusion.

Class II skeletal pattern:

A type of skeletal malocclusion in which the mandible is in a retrusive position relative to the maxilla.

Fixed functional appliance:

An appliance that is placed in the patient's mouth to allow some type of growth guidance treatment to be carried out and which cannot be removed from the mouth by the patient.

Herbst appliance:

A type of functional appliance that protrudes the mandible into a forward position in an effort to stimulate mandibular growth and inhibit forward maxillary growth in patients with skeletal class II malocclusions.

Mixed dentition:

A stage of dental development in which primary and permanent teeth make up the dentition.

Phase I treatment:

Limited treatment which occurs during the mixed dentition stage to correct or reduce the severity of developmental abnormalities in growing patients, with the intent of following up with phase II treatment.

Phase II treatment:

Comprehensive orthodontic treatment provided when all the permanent teeth are present and following phase I treatment to achieve optimal anatomic and functional harmony of the dentition.

Removable Functional Appliance:

An appliance that is placed in the patient's mouth to allow some type of growth guidance treatment to be carried out and which can be removed from the mouth by the patient.

Retrognathic:

A term used to define the position of a skeletal component that is located in a more posterior position or relation than normal.

Assumptions

1. The lateral cephalograms are taken with teeth in centric occlusion.
2. Without treatment, growth patterns would be similar in the experimental and control groups, which are matched in age, sex, and craniofacial morphology.

Limitations

1. This is a retrospective study of a group of patients selected from the office of Dr. Terry Dischinger.
2. The experimental and control groups are selected from two different geographical sources (Lake Oswego, Oregon and Case Western Reserve University/Bolton Brush Study Center in Cleveland, Ohio, respectively).
3. Growth patterns and growth periods (peak pubertal growth period) are not available for the individuals in the study.
4. Skeletal ages of the experimental and control groups cannot be determined.
5. The experimental group was limited to patients who proceeded with Phase II orthodontic treatment after Phase I treatment with the Herbst appliance.
6. The experimental group was limited to patients who had acceptable quality radiographs available for at least four of the five time points included in the study.
7. The mechanics used in the Phase II orthodontic treatment of the experimental group were not considered in this study.

Delimitations

1. The experimental group was composed of 22 patients (7 males and 15 females) treated consecutively by one clinician (Dr. Terry Dischinger).
2. Criteria of patient selection included no previous orthodontic treatment.
3. All patients in the experimental group were corrected with the crowned Herbst appliance to a position in which the maxillary cuspid was in an end-to-end relationship with the mandibular first premolar.

CHAPTER II: REVIEW OF THE LITERATURE

History and Classification of Malocclusion

Crowding and mal-alignment of the teeth have probably been around since the beginning of man, but the prevalence has significantly increased within the last 1000 years²³. Evidence indicates that this recent increase may be the result of the transition of modern man from a primitive foraging subsistence strategy to a modern agricultural society in which foods are softer and less jaw function is necessary for survival²⁴. The earliest orthodontic appliances have been found in Greek and Etruscan materials dating back to around 1000 BC²⁵, but it wasn't until the appearance of Norman Kingsley's *Treatise on oral deformities as a branch of mechanical surgery*²⁶ after 1850 that a systematic approach to the practice of orthodontics was established in America. The publication of Edward Angle's classification of malocclusion²⁷ in the 1890's further advanced American orthodontics and led to the first clear definition of normal occlusion. In addition, Angle described three malocclusions:

Class I—the mesiobuccal cusp of the maxillary first molar occludes with the buccal groove of the mandibular first molar, with there being a discrepancy in the line of occlusion.

Class II—the mesiobuccal cusp of the maxillary first molar is located mesial to the buccal groove of the mandibular first molar.

Class III—the mesiobuccal cusp of the maxillary first molar is located distal to the buccal groove of the mandibular first molar.

Etiology of Malocclusion and the Need for Orthodontic Therapy

In most cases, malocclusion and dentofacial deformity is the result of moderate distortions in the normal developmental process. The primary etiologic factors associated with orthodontic problems have been cited as hereditary influences, environmental influences, and specific causes such as embryologic developmental and skeletal growth disturbances, muscle dysfunction, acromegaly and hemimandibular hypertrophy. Without proper orthodontic treatment, these dentofacial irregularities can lead to adversity for the individuals involved including: (1) psychosocial problems associated with discrimination because of facial appearance; (2) problems with the stomatognathic system including decreased jaw function, temporomandibular joint dysfunction, and problems with mastication, swallowing, and speech; and (3) increased risk of periodontal disease, tooth decay, and trauma²⁸. The need for orthodontic therapy continues to grow and it has assumed an important role in improving self esteem and overall quality of life in our society.

Prevalence of Class II Malocclusion

Class II malocclusion is defined by the mandibular first molar being positioned in a distal relationship to the maxillary first molar with the line of occlusion not specified²⁸. This class of malocclusion affects one third of the population in the United States and its prevalence is greater in people of Northern European decent (30%-40%) than other ethnic populations. Eight to ten percent of the overall population have an overjet greater than six millimeters^{29,30,31,32}.

Class II Skeletal Growth

Genetics, function, deformities, size and position of bones are all factors that can lead to Class II skeletal growth³³. Ultimately, Class II malocclusions are the result of either deficient mandibular growth, excessive maxillary growth, or a combination of the two. In the United States, Class II patients usually present with a convex facial profile due to a retrognathic mandible. A prognathic maxilla can be present, but this is less common. There are two divisions of Class II malocclusion. Class II division 1 malocclusion includes maxillary incisors that are in extreme labioversion, and Class II division 2 malocclusion includes relatively normal or slightly lingually tipped incisors.

Enlow divided the facial bones that contribute to a Class II skeletal pattern into segments including: (1) the anterior and posterior cranial base; (2) nasomaxillary complex; and (3) the ramus and corpus of the mandible³³. The orientation of these segments to one another and their interactions during the growth process determine the final dentofacial form of an individual.

The primary growth of the cranial base occurs as a result of bone deposition on its outer cortex and endochondral growth at the spheno-occipital synchondrosis. A pressure adaptive growth mechanism provides a bi-directional growth direction causing displacement of facial bones³³.

The growth of the nasomaxillary complex is the result of two mechanisms. Passive displacement, resulting from growth in the cranial base pushing the maxilla downward and forward, is an important growth mechanism during the primary dentition years, but becomes less important as the growth in the synchondrosis slows around seven years of age. Active growth of the maxillary sutures and nose is responsible for the majority of forward movement of the maxilla from ages seven to fifteen²⁸. The normal

growth of the maxilla is usually 1 to 2 mm a year^{28,34}, and there is a linear relationship between the effective maxillary length and mandibular length. Cephalometric analysis has shown that in the majority of Class II malocclusions, the position of the maxilla was normal. In cases that were not normal, the maxilla tended to be in a retrusive position more frequently than in a protrusive position indicating that the maxilla was not the major contributing factor to a Class II malocclusion³⁵.

Growth in the mandible is important in the establishment of a Class II malocclusion. Deposition and resorption of bone are responsible for directing growth in a posterior and superior direction. As the condyle grows directly towards its articular contact within the glenoid fossa, the entire mandible is displaced in the opposite direction to a more forward and downward position³⁶. The growth of the mandible occurs at a relatively stable rate before puberty with an average ramus height increase of 1 to 2 mm per year and an average body length increase of 2 to 3 mm per year²⁸. Growth changes in the region of the glenoid fossa have a significant effect of the prominence of the chin. Any mandibular length increase to improve the prominence of the chin is usually negated by a posterior shift in the temporomandibular joint. To effectively increase the prominence of the chin, the temporomandibular joint must shift to the anterior or remain in the same antero-posterior position with an increase in mandibular length. These properties of mandibular growth allow orthodontists to alter growth patterns to provide therapy for Class II malocclusions with a retrognathic mandible.

Analysis of the Dentofacial Complex

A Class II skeletal malocclusion can be defined as the mandible being positioned distally relative to the maxilla. This malposition of the jaws can result from a number of irregular positional relationships. Class II malocclusions are the result of either mandibular retrusion, maxillary protrusion, or a combination of both. Due to the hinging effect of the mandible, the vertical component of the dentofacial complex is also important in Class II malocclusions. A decrease in the vertical dimension of the anterior facial height causes the mandible to rotate upward and forward reducing the anteroposterior discrepancy, however an increase in vertical dimension will cause the opposite effect, making the anteroposterior relationship even worse. A Class II molar relationship usually accompanies a Class II skeletal malocclusion, however, a Class I molar relationship can be present. In addition, the incisors can be either extremely proclined, relatively normal, or even lingually inclined. Because many factors contribute to a Class II skeletal malocclusion, a thorough analysis of the dentofacial complex is important in describing the components of a particular malocclusion.

The evaluation of dentofacial form can be accomplished with cephalometric analysis. The anteroposterior position of the maxilla can be determined on a lateral cephalogram from the Sella-Nasion-Point A (SNA) angle^{37,38} and from Nasion perpendicular to Point A³⁹. The position of the upper incisors relative to the maxilla can be evaluated from the distance from the facial surface of the upper incisor to a vertical line drawn perpendicular to the Frankfort horizontal plane extending through the A Point³⁹. The relation of the lower incisors to the basal bone structures can be determined from the distance from the tip of the lower incisor to the A Point-Pogonion line^{40,41}.

Mandibular position relative to the cranial base can be assessed by measurements from the Pogonion to the nasion perpendicular³⁹ and from the Sella-Nasion-Point B (SNB) angle^{37,38}.

The vertical skeletal dimensions of a patient must also be evaluated since this dimension may either conceal or intensify the clinical parameters of the malocclusion^{41,42}. A decrease in vertical dimension of anterior facial height causes the mandible to rotate upward and forward. Patients with an increase in lower anterior facial height exhibit a retruded mandible, a poorly defined chin with a hyperactive mentalis muscle, and a tendency towards open bite. Vertical dimensions can be measured on a lateral cephalogram from the mandibular plane angle (MP-SN, MP-FH) and lower anterior facial height (the distance from the anterior nasal spine to the menton)³⁵.

The transverse relationship of the maxilla to the mandible is also important in the evaluation of dentofacial form. Tollaro et al.⁴³ have shown that in dental arches with Class II malocclusion and seemingly normal buccal relationships, an underlying transverse discrepancy of three to five millimeters exists. Studies by Bacetti et al.⁴⁴ Arya et al.⁴⁵, and Bishara et al.⁴⁶ indicate that maxillary transverse deficiency is associated with Class II malocclusions and tend to be self perpetuating. For this reason, Spillane⁴⁷ and McNamara⁴⁸ have recommended orthopedic rapid maxillary expansion during the early mixed dentition in mild to moderate Class II patients.

Treatment of Class II Malocclusion

The amount of growth remaining for an individual is an important consideration for the treatment of a Class II malocclusion. The treatment options for Class II

malocclusions in non-growing patients are somewhat limited. Because a significant amount of growth will no longer occur in these patients, clinicians must rely on treatment options other than growth modification to correct dentoalveolar disharmony.

Compromised/non-extraction, extraction/camouflage, distal movement of maxillary teeth, and surgery are the treatment options available for non-growing patients with a Class II condition. In cases where extraction and surgery are not options, a compromised/non-extraction approach is implemented in which the patient's teeth in each arch are straightened without correcting the intra-arch relationship. Because skeletal differences are not corrected between the maxilla and mandible, the patient may still have an overjet. Extractions are often indicated in patients with Class II malocclusions in order to provide space to align crowded incisors while avoiding excessive protrusion. Extractions are also recommended to camouflage a moderate skeletal discrepancy when modification by growth is not possible. In minor Class II malocclusions, the option of distalizing the maxillary molars exists. A maximum of 1-2 mm of distal movement is all that can be expected when using this approach¹⁶. In recent years, the Herbst appliance has been shown to be an effective treatment option for Class II malocclusions in non-growing adults⁴⁹. Adults have been shown to exhibit the same condylar growth and remodeling of the glenoid fossa that occurs in children and adolescents⁵⁰. Orthognathic surgery is by far the most invasive and expensive treatment for non-growing patients with Class II malocclusion. The surgical movement of the maxilla and/or mandible allows the upper and lower arches to be aligned into maximum intercuspation. This treatment option is often the most effective in obtaining an ideal occlusion.

More options for the treatment of Class II malocclusion are available when the patient is still growing. Treatment is often administered around an individual's peak pubertal growth period which occurs around age 13.9 ± 1.0 in males and age 11.7 ± 1.0 in females⁵¹. Non-extraction/compromise, extractions, and functional appliances are among the treatment options for these individuals.

Although more options exist for the orthodontist when treating growing individuals, ideal occlusion cannot always be achieved. Many parents dislike the alternatives of surgery or extraction for their children, and choose only to have the teeth aligned. In these cases, the patient will almost certainly still have an overjet due to size discrepancies between the maxilla and mandible. In growing patients, extraction is an option only when space is needed due to severe crowding of the anterior teeth. Extractions with the intent of camouflaging skeletal disharmony are contraindicated in growing patients because of the unpredictable growth of the maxilla and mandible. When teeth are aligned and an acceptable result is unachievable, the skeletal discrepancies must be corrected. Surgery is an option, however most patients prefer an alternative method that is non-invasive and less expensive. Because of these concerns, functional appliances were introduced to correct problems of skeletal disharmony without surgery in patients with a retrognathic mandible.

Functional Appliances Used to Treat Class II Malocclusion

In 1877, Norman W. Kingsley was the first to introduce an appliance designed to stimulate sagittal mandibular growth⁵². The bite jumping appliance consisted of an upper plate with an inclined plane which caught the lower incisors and forced the mandible

anteriorly. The rationale behind “bite jumping” was that forcing the mandible forward during function would stimulate condylar growth, thereby correcting the Class II malocclusion. Carl Breitner, with his experiments on rhesus monkeys, was the first to show that bite jumping led to condylar growth by means of (1) bone apposition at the distal wall of the articular fossa and resorption at the mesial wall and (2) apposition of cartilage at the posterior margin of the condylar head and resorption at the anterior margin⁵³.

The principle of bite jumping encouraged the development of several removable functional appliances that are used today for stimulating mandibular growth in Class II patients with a deficient mandible. The activator¹ was designed as a block of plastic that covered the teeth of both arches and the palate and was made to fit loose to allow advancement of the mandible several millimeters and open the bite 3-4 mm. The Bionator² is described as a cut-down activator with palatal coverage eliminated. The Frankel appliance³ is a tissue-borne functional appliance that consists of a small pad against the lingual mucosa beneath the lower incisors to stimulate mandibular repositioning. The Herbst appliance⁴ is a fixed functional appliance that forces the mandible forward by means of a pin and tube apparatus that runs between the arches.

The effect of the functional appliances have been debated with some studies showing alteration of mandibular growth^{54,55,56} and other studies showing no effect^{57,58}. Evaluating the treatment results of removable functional appliances can be difficult because (1) the appliance is used only part of the day and in certain individuals the threshold for condylar growth adaptation to forward displacement may never be reached, (2) patient compliance is a problem and undetected insufficient appliance wear could

produce erratic results, and (3) treatment time is relatively long (2-4 years) and a suitable control group is often unattainable. The fixed Herbst appliance offers several advantages in that (1) it works 24 hours a day, (2) patient cooperation is not a factor, and (3) active treatment time is relatively short (6-9 months)⁴. A review of the literature by Aelbers and Dermaut found that the Herbst appliance was the only functional appliance that could effectively alter mandibular growth to a clinically significant extent⁵⁸. A randomized, controlled trial by O'Brien et al.⁵⁹ concluded that the Herbst appliance had several advantages over functional appliances such as the Twin Block including better patient cooperation and decreased phase I treatment times.

The Herbst Appliance

Emil Herbst introduced a fixed bite jumping appliance called the “Scharnier” at the International Dental Congress in Berlin in 1909. The appliance was designed to alter mandibular jaw and muscle function by keeping the mandible in a continuously protruded position on both jaw closure and eccentric movements⁶⁰. Its design included a bilateral telescope mechanism attached by orthodontic bands to the lower first premolars and upper first molars. In 1934, Herbst published a series of articles in which he described the appliance to be most useful in: (1) Class II malocclusions with a retrognathic mandible; (2) mandibular ramus fractures; (3) condylectomies (used as an artificial joint); and (4) TMJ problems including crepitus and bruxism⁶¹. After 1934, however, little was published about the Herbst appliance and the treatment method was more or less forgotten.

Hans Pancherz reintroduced the Herbst appliance as an experimental tool in clinical research in 1977, and in 1979, he published a paper calling attention to the possibilities of stimulating mandibular growth with the appliance⁹. The popularity of the appliance increased after this time and the effects of the Herbst appliance on the occlusion, dentofacial complex, and masticatory apparatus began to be evaluated.

The Herbst appliance employs a bilateral telescope mechanism consisting of a tube, a plunger, two pivots, and two locking screws, which function to keep the mandible in a continuously anterior jumped position. The pivot for the tube is usually located on the maxillary first molar and the pivot for the plunger is usually attached to the mandibular first premolar. The length of the tube determines the amount of anterior displacement of the mandible and usually achieves an incisal end-to-end relationship. The anchorage system of the Herbst appliance has evolved since its reintroduction by Pancherz in 1979. Originally, a partial anchorage system was used in which the maxillary first premolars and first molars were banded and connected to the other side with a lingual or buccal sectional arch wire and the mandibular first premolars were banded and interconnected with a lingual sectional arch wire. Later, a total anchorage system was used in which a labial arch wire was ligated to brackets on the maxillary first premolars, canines, and incisors and a lingual sectional arch wire was extended to the first permanent molars which were also banded. Bands were eventually replaced by cobalt chromium alloy casted splints that were cemented with glass ionomer cement ensuring a precise fit on the teeth. In 1988, McNamara and Howe presented the removable acrylic splint Herbst appliance, with occlusal coverage extending posteriorly from the canines to the first molars on the maxillary arch and full occlusal coverage on

the mandibular arch¹³. The crowned Herbst appliance consisting of stainless steel crowns cemented to the mandibular first premolars and maxillary first molars was introduced in the late 1980's and early 1990's to compensate for the inadequacies of the banded Herbst appliance^{62,63,64}. The crowned appliance offers several advantages over conventional anchorage including having no removable parts, eliminating the need for patient cooperation, having a streamlined design which facilitates hygienic procedures, and the ease of recementation in the event of a loosened crown^{63,64}.

Indications for Treatment with the Herbst Appliance

The Herbst appliance is most useful in the treatment of growing individuals with both Class II, Division 1 and Class II, Division 2 malocclusions. The treatment method should be used cautiously in non-growing individuals as minimal changes will occur in the facial skeleton and most of the alteration will occur in the dentoalveolar area. In addition, increased chance of developing a dual bite and TMJ problems accompany treatment in non-growing individuals^{65,66}.

The Herbst appliance has been shown to be used effectively in post-adolescent patients with minimal remaining residual growth, in mouth breathers who cannot use removable functional appliances, in uncooperative patients, and in patients who do not respond to treatment with removable functional appliances⁴.

Timing of Treatment with Functional Appliances

The timing of orthopedic intervention with functional appliances has been the subject of intense controversy within the profession of orthodontics. The decision to treat

in the early mixed, late mixed, or permanent dentition has been debated and many questions remain unresolved. Two phase treatment with functional appliances became justifiable with the emergence of the functional matrix theory proposed by Moss in the 1960s⁶⁷. A shift from Brodie's genomic hypothesis that suggested craniofacial growth was established by three months old and could not be altered⁶⁸, the functional matrix paradigm exposed the possibility of correcting skeletal problems in a growing child with dentofacial orthopedics. The decision of when to begin Class II orthopedic treatment is made more difficult by individual variability between patients and uncertainty about growth and treatment response.

Successful treatment of Class II malocclusions with functional appliances have been reported in both the early mixed dentition^{15,16} and the late mixed dentition^{17,18}. A systematic review of mandibular changes produced by functional appliances in Class II malocclusions reported that the amount of supplementary mandibular growth appears to be significantly larger if the functional treatment is performed at the pubertal peak in skeletal maturation²². The majority of the literature supports the idea that Class II correction can be successfully achieved in both the mixed dentition and the permanent dentition. The current debate seems to revolve around the effectiveness and the efficiency of the Class II correction. With respect to both duration and outcome, Pancherz found that late treatment of Class II Division I malocclusion (in the permanent dentition) was more efficient than earlier treatment (in the early or late mixed dentition)⁶⁹. In a review of the data from a randomized controlled clinical trial, Tulloch et al. concluded that for children with moderate to severe Class II problems, early treatment followed by later treatment does not produce major differences in jaw

relationship or dental occlusion, compared with later one-stage treatment⁷⁰. According to the same study, early treatment appeared to be less efficient, in that it did not reduce the amount of time a child was in fixed appliances in a second phase of treatment, and it did not decrease the proportion of complex treatments in phase II involving extractions or orthognathic surgery²⁰. Other clinical studies have shown that early treatment can lead to more relapse, reduced patient motivation in the second phase of orthodontic treatment, and other potential hazards⁷¹⁻⁷⁵.

Despite these arguments against early treatment, many practitioners have published their opinions based on clinical experience suggesting that early treatment has many advantages. The ability to utilize all potential growth, increased probability of incisor fracture in untreated Class II patients, the development of improper swallowing patterns, incomplete lip function, temporomandibular joint dysfunction, and psychosocial considerations are all factors that support the concept of early treatment. Psychological studies have shown that younger children are good candidates for phase I orthodontics and expect orthodontics to lead to improvements in their lives⁷⁶. Another study showed that early treatment with Twin-block appliances resulted in an increase in self-concept and a reduction of negative social experiences⁷⁷. Surveys have shown that practice characteristics tend to affect orthodontists' decisions regarding orthodontic treatment and a wide range of acceptable treatment timing exists⁷⁸. Ultimately, the decision to initiate early phase orthodontics or orthopedic treatment should include a conversation with the parents and the child and the individual circumstances for each patient should be considered.

Treatment Effects of the Herbst Appliance on the Dentofacial Complex

The treatment effects of the Herbst appliance on the dentofacial complex are difficult to describe. The Herbst appliance directly or indirectly applies force in all three planes of space to the maxilla, the mandible, the maxillary and mandibular dental units, and the temporomandibular region. Evaluating the changes in the individual anatomic components and understanding the interaction between them becomes very complicated. In addition, treatment is usually performed on growing patients with variable growth patterns and rates. Although the Herbst appliance is considered a functional orthopedic appliance, the effects of treatment are not limited to the skeletal components. Anchorage on the dental units produces both desirable and undesirable side effects on the dentition. Changes in the angular position of the palatal plane, occlusal plane, and mandibular plane are important and should be considered. The temporomandibular joint, a ginglymodiarthrodial joint that allows both hinging and translational movement, is directly affected by treatment with the Herbst appliance and changes within the joint are very difficult to identify and quantify. When describing the treatment effects of the Herbst appliance, it is useful to divide the discussion into skeletal and dental components. The skeletal components include the maxilla, the mandible, and the temporomandibular region and the dental components include the dental units of the maxilla and mandible.

Skeletal Components

Maxilla: The Herbst appliance has a restraining effect on maxillary growth similar to a headgear^{9,10,19}. Studies have shown that growth of the maxilla in patients treated with the Herbst is consistently less than in control groups without

treatment^{11,14,79,80,81,82}. The overall size of the maxilla is reported to be unaffected by treatment^{14,79,82}, however there is a slight clockwise rotation of the palatal plane^{11,79}.

Mandible: Many animal studies have shown that skeletal mandibular changes can be produced with functional appliances^{5,83,84}, however the effects on humans are more controversial. A systematic review of the literature limited to randomized controlled clinical trials from 1966 to 1999 on the efficiency of functional appliances on mandibular growth by Chen et al.⁸⁵ reported that there is no difference in overall mandibular change in the horizontal or vertical direction. Another systematic review by Cozza et al.²² analyzed 22 studies that met inclusion criteria in an attempt to assess the scientific evidence of functional appliances in enhancing mandibular growth in Class II subjects. Two-thirds of the samples in the 22 studies reported a clinically significant supplementary elongation in total mandibular length compared to controls (a change of greater than 2.0mm in the treated groups compared to the control groups) as a result of treatment with functional appliances. However, none of the four randomized clinical trials included in the study reported a clinically significant change in mandibular length with treatment. The results were attributed to treatment timing due to the fact that three of the four randomized clinical trials described outcomes of treatment at a pre-pubertal stage of skeletal maturity.

Pancherz^{86,87} has reported that sagittal condylar growth is increased while vertical condylar growth is unaffected by Herbst treatment. Ruf and Pancherz⁵⁰ analyzed temporomandibular joint remodeling with magnetic resonance imaging during Herbst treatment and reported signs of condylar remodeling at the posterosuperior border. Voudouris et al.⁸⁸ performed radiographic investigations superimposing on metallic

implants in nonhuman primates and showed increases in condylar length in response to treatment with functional appliances. In the same study, histological analysis using undecalcified sections and tetracycline vital staining with fluorescence microscopy also confirmed the increased condylar response. Another implant study by Araujo et al.⁸⁹ on twenty five patients treated with the bionator appliance showed significant changes in the direction (more posterior) but not in overall amount of condylar growth. Despite these findings, a systematic review of the literature by Popowich et al.⁹⁰ evaluating the effects of Herbst treatment on temporomandibular joint morphology did not provide conclusive evidence of osseous remodeling or condyle position change.

Temporomandibular region: The response of the temporomandibular joint to mandibular forward repositioning has been very controversial in both experimental and clinical studies. Some researchers believe that the main effect of functional appliance therapy is increased condylar growth, others feel that the main effect is due to remodeling of the glenoid fossa, and others contend that little to no structural changes occur in response to treatment. Remodeling of the temporomandibular joint has been described to occur both within the glenoid fossa and the condyles of the mandible, with new bone formation on the posterior aspect of the condylar head and the roof of the fossa^{7,8,50}. Ruf and Pancherz⁵⁰ have noted glenoid fossa remodeling 6 to 12 weeks after the initiation of Herbst treatment. In a study on rats, Rabie et al.⁹¹ reported that a forward positioning of the mandible leads to increased new bone formation in the glenoid fossa of the temporal bone with the highest levels of bone deposition occurring in the posterior region of the glenoid fossa. From a study on nonhuman primates treated with the Herbst appliance, Voudouris et al.⁸⁸ reported that the growth modification measured in the glenoid fossa

was in an inferior and anterior direction. In addition, he noted that restriction of the downward and backward growth of the fossa observed in the control subjects might additionally contribute to the Class II correction.

Dental Components

Maxilla: There are significant effects on the maxillary dentition in response to treatment with the Herbst appliance^{14,92}. The maxillary molars exhibit a “high-pull headgear effect” in which they are distalized and intruded^{9,16,80,93,95}. The maxillary molar movements are only temporary in nature as they move downward and forward in the post-treatment phase following the normal growth pattern⁹⁵.

Mandible: In general, the mandibular dentition moves in an anterior direction in response to Herbst treatment^{9,16,80,93,95}. The mandibular molars continue to erupt in an anterior and superior direction, however their eruption can be impeded during treatment. The lower incisors are proclined and intruded during treatment, however, they recline somewhat in the post-treatment phase⁷⁹.

Vertical changes associated with the Herbst Appliance

The Herbst appliance affects the vertical dimension of the dentofacial complex with a reduction in the overbite⁹⁶. The reduction in the overbite is mainly the result of the intrusion of the lower incisors and the eruption of the lower molars, however, changes in the vertical mandibular incisor position can be attributed to the facial proclination of these teeth. Due to the vertical changes in the dentition, the lower facial height increases. The maxillary and mandibular jaw position is relatively unaffected, as there are no

significant alterations in the palatal plane angle or the mandibular plane angle in the long term⁴.

Post-treatment relapse following Herbst treatment

At the conclusion of treatment with the Herbst appliance, the sagittal dental arch relationships are generally overcorrected and there is often incomplete cuspal interdigitation among the teeth. Because the active treatment time is short (usually 6-8 months), the occlusion is unstable and adaptive changes will occur⁹². The occlusion usually settles into a Class I relationship during the first year post-treatment, and for the most part, the adjustments are of dental origin. The maxillary teeth, especially the molars move anteriorly, and the mandibular teeth move posteriorly with the incisors becoming more upright⁴. Accelerated maxillary growth and a reduction in mandibular growth rates occur only minimally within the first year after treatment⁹².

When the long-term effects of the Herbst appliance treatment were compared with a standardized control group, it was found that the Herbst appliance improves the sagittal jaw base relationship, but does not normalize it^{12,97}. The sagittal dental arch relationship is normalized and can compensate for an unfavorable jaw base relationship. A Class I dental relationship can be maintained by a stable cuspal interdigitation of the upper and lower teeth⁴. When relapses in overjet and sagittal molar relationships occur in individuals who have undergone treatment with the Herbst appliance, it is a result of maxillary and mandibular dental changes⁹⁸. The long-term effects of Herbst treatment on mandibular growth is difficult to evaluate. Increases in sagittal condylar growth and changes in mandibular morphology apparent during treatment could not be verified seven

years later⁸⁷. Despite these findings, it is believed that the functional stability of the occlusion prevents occlusal relapses⁴.

Many reports on the long-term effects of the Herbst appliance have been reported^{12,94,95,99}. The results indicate that the Herbst treatment had only a temporary impact on the existing skeletofacial growth pattern. After the treatment period, maxillary and mandibular growth seem to return to their pre-treatment patterns⁹⁹. Voudouris et al.¹⁰⁰ proposed a growth relativity concept to explain this phenomenon. Their non-muscular hypothesis of condyle-fossa remodeling with Herbst treatment suggest that glenoid fossa modification is associated with decreased muscle activity of the postural masticatory muscles and is a result of the stretch forces of the retrodiskal tissues. They contend that the impact of the viscoelastic tissues may be highly significant and should be considered along with the standard skeletal, dental, neuromuscular, and age factors that influence condyle-glenoid fossa modification with orthopedic advancement. They express concerns that these biodynamic factors are also capable of reversing effects of treatment on mandibular growth direction, size, and morphology. Relapse could occur after the completion of active treatment as a result of the release of the condyle and the ensuing compression against the newly proliferated retrodiskal tissues together with reactivation of muscle activity.

Contrary to the previous mentioned studies, Croft et al.¹⁸ suggest that early treatment with the Herbst appliance, in combination with retention, results in significant long-term improvements in skeletal and dental relationships and consider it a viable treatment option. A study by Berger et al.¹⁰¹ compared the treatment outcome and stability of Class II patients treated with functional appliances to patients treated

surgically with bilateral sagittal split ramus osteotomies. They reported that in the functional appliance group, the mandible continued to grow in a favorable direction even after discontinuation of the functional appliance and that both the functional appliance group and the surgical group experienced significant skeletal and soft tissue changes. This study concluded that early correction of Class II dentoskeletal malocclusions with functional appliances yielded favorable results without the possible deleterious effects of surgery.

The Edgewise Herbst Appliance

The Edgewise Herbst Appliance differs from other versions of the Herbst appliance in the fact that it is designed to incorporate edgewise brackets and mechanics into the correction of Class II malocclusions and minimize certain limitations of the original appliance⁶⁴.

Figure 1. The Edgewise Crowned Herbst Appliance

In most permanent dentition cases, the maxillary six anterior teeth and the four mandibular incisors are bracketed (Figure 1). The mandibular incisor brackets incorporate a -10° inclination to minimize the anterior proclination that is a side effect of Herbst treatment. The maxillary bicuspid and mandibular bicuspid and canines usually are not bracketed. In the mixed dentition, brackets are usually placed on the maxillary and mandibular incisors; however, this sometimes varies depending on the individual circumstances of the case⁶⁴.

Figure 2. Mixed Dentition Herbst Appliance

Stainless steel crowns on the maxillary and mandibular permanent first molars anchor the Herbst appliance to the dentition (Figure 2). Double buccal tubes are placed on the molar crowns to permit the use of an auxiliary archwire to intrude the maxillary or mandibular incisors as necessary. The maxillary arch is tied back to hooks on the molar

tubes to prevent space from opening in the maxillary arch because the molars tend to be driven distally during treatment. In addition, consolidating the arch distributes the load applied to the dentition to more teeth. In the mandibular arch, a 2mm half-round cantilever is placed between the first molar and interproximal area between the first bicuspid and cuspid. The axle is placed at the mesial end of the cantilever, and a .022”X.028” archwire tube is placed above and below the axle⁶⁴.

Figure 3. Herbst Appliance (Maxillary Unit)

A transpalatal arch is not included in the appliance to allow the first molars to rotate as the Class II relationship is corrected (Figure 3). A lingual arch is not included to allow easier placement of the appliance and prevent possible tipping of the lower anterior incisors (Figure 4). Both arches are free to accommodate expansion during treatment, if

necessary. An occlusal stop off the cantilever arm or directly soldered to the stainless steel crowns extends into and rests on the distal central fossa of the first bicuspid or the mesial central fossa of the second primary molar to prevent tipping of the cantilever arm and impingement into the buccal mucosa and to minimize tipping of the mandibular first molar⁶⁴.

Figure 4. Herbst Appliance (Mandibular Unit)

According to Dishinger⁶⁴, the Edgewise Herbst has the following advantages over other Herbst designs and functional appliances:

- 1) It is a fixed functional appliance that requires no patient cooperation and has no removable parts.
- 2) Orthodontic tooth movements can be accomplished at the same time that orthopedic Class II correction is taking place.
- 3) The lower arch can expand along with the upper arch.
- 4) There is no lingual wire which allows easier placement of the appliance, eliminates interference with the tongue, and prevents possible tipping of the lower anterior incisors.
- 5) Leveling of the lower arch can be accomplished prior to Herbst removal eliminating anterior tooth contact and improving stability.
- 6) Appliance breakage or loosening is rare.
- 7) The streamlined design of the appliance allows for easy cleaning and improved oral hygiene.
- 8) Recementation is easy if a crown becomes loosened.
- 9) The appliance incorporates a built-in lip bumper effect.
- 10) Lower cuspids and first premolars are free to erupt.
- 11) The use of negative inclination brackets and the position of the archwire tube on the axle allow leveling of the lower arch with a straight wire.

The Dischinger Protocol for the Edgewise Herbst Appliance

The Dischinger protocol⁶⁴ for the clinical use of the edgewise Herbst appliance applies certain concepts and principles in an attempt to achieve maximum skeletal correction of Class II skeletal malocclusions while minimizing dentoalveolar side effects. VanLaecken et al.¹⁰² analyzed the treatment effects of the edgewise Herbst appliance on 32 patients with Class II skeletal malocclusion treated by Dr. Terry Dischinger. They found that the net effect of the edgewise Herbst treatment was primarily skeletal (85% of the overjet correction and 96% of the molar correction). This is an increased skeletal effect compared to the 70% skeletal contribution to overjet correction reported by Hagg et al.¹⁰³. These results suggest that it could be important to follow detailed procedures when treating with the Herbst appliance to achieve maximum skeletal correction with the appliance.

Dr. Dischinger developed and continues to modify his treatment protocol after 20 years of clinical practice in an attempt to achieve the greatest amount of skeletal correction possible when treating Class II malocclusions¹⁰⁴. Initially, the Herbst appliance is activated to an edge to edge incisor relationship with the skeletal midlines in alignment. Brackets are bonded to the maxillary six anterior teeth and the mandibular incisors and high tech archwires are used to control incisor inclination and mandibular molar movement. Archwire sequence begins with a .014 Damon CuNiTi. Then a .016X.025 Damon CuNiTi with the maxillary wire tied back to the hook on the maxillary molar and the lower wire annealed and cinched to prevent anterior movement of the wire. Next, a .019X.025 lower reverse curve NiTi archwire is placed if more leveling is necessary. Finally, a .019X.025 TMA is inserted if more leveling or torque is desired¹⁰⁴.

To achieve maximum orthopedic effect, it is important to tie back the maxillary archwire to prevent distalization of the maxillary molars. The appliance is activated in a step-by-step fashion a distance of 4 mm every 12 weeks until the maxillary cuspid achieves an end-to-end relationship with the mandibular first premolar. The over-corrected position is held for a period of 12 weeks¹⁰⁴. Several studies have reported a greater skeletal effect on the sagittal jaw relationship with an incremental step-by-step advancement of the Herbst appliance^{103,105}. Rabie et al.¹⁰⁶ has reported that a stepwise advancement leads to a significant increase in the number of replicating mesenchymal cells that is closely related to the increase in the level of bone formation, thus increasing the growth potential of the condyle.

A corrected tomogram is taken prior to Herbst placement and before Herbst removal to confirm condylar position (Figure 5). If the condyles are reasonably centered in the glenoid fossa, then a lateral cephalogram is taken and the patient is scheduled for Herbst removal as soon as possible. It is important to intrude the mandibular incisors so that the initial contact upon Herbst appliance removal is on the posterior teeth and not on the anterior teeth. This reduces the seating force of the condyle on the newly remodeled glenoid fossa¹⁰⁴.

Figure 5. Corrected Tomograms taken prior to Herbst removal.

In mixed dentition treatment after Herbst removal, the first permanent molars are banded and two by four appliance treatment continues until the anterior occlusion is correct. If more arch length is necessary, molar bands with .022X.028 extension tubes soldered in the archwire slots are placed and open coil springs are utilized to create more arch length. Deband occurs in two appointments. At the first appointment, upper and lower alginate impressions are taken, and sectional archwires are placed. At the second appointment, incisor brackets are removed and maxillary and mandibular lingual holding arches are placed. Patients are told that the holding arches will remain in place until all the permanent teeth have erupted. At that time they will receive comprehensive orthodontic treatment to finalize the occlusion¹⁰⁴.

Summary and Conclusions

Removable functional appliances such as the activator¹, bionator², and Frankel appliance³ are commonly used in the treatment of Class II malocclusion in an effort to stimulate sagittal mandibular growth in retrognathic mandibles. Unfortunately, the effectiveness of these appliances has been questioned and treatment results are inconsistent. In addition, patient compliance is often a problem with removable appliances and treatment time is usually long (2-4 years)⁴. Fixed functional appliances such as the Herbst appliance offer an alternative treatment method with several advantages: the appliance is fixed to the dentition; no patient cooperation is required; treatment is continually applied (24 hours a day); and the treatment time is short (6-8 months)⁴. Research has indicated that the bite jumping technique employed by the

Herbst appliance can be effective in correcting Class II skeletal abnormalities by promoting growth of the mandible and remodeling of the glenoid fossa^{5,6,7,8}. Since Pancherz⁹ re-introduced the Herbst appliance in 1979, an increasing body of research has been published evaluating its effects on occlusion, the dentofacial complex, and the masticatory system. However, after improvements in its design and increased clinical use, there seems to be an overall lack of information on the treatment changes observed with the edgewise crowned Herbst appliance and the long term stability of these effects.

The timing of orthopedic intervention with functional appliances has also been the subject of intense controversy within the profession of orthodontics. The decision to treat either in the early, late mixed, or permanent dentition has been debated and many questions remain unresolved. Successful treatment of Class II malocclusion in the early mixed dentition have been reported¹⁵, however other studies report similar success during the late mixed dentition¹⁷. Data from randomized controlled clinical trials have shown that effective skeletal changes could be achieved at either point in time and remain stable, although they suggest that treatment in the late transitional dentition is the most efficient in most cases^{20,21}. When determining the optimal time to initiate Class II treatment, other factors must be considered such as the ability to utilize all potential growth, likelihood of incisor trauma, development of improper swallowing patterns, incomplete lip function, effects on the temporomandibular joint, and psychosocial concerns.

This study investigated the skeletal and dental alterations of Class II patients treated at an early age with the edgewise crowned Herbst appliance and evaluated the long term stability of those effects. The results should provide valuable information to

help clinicians determine whether early treatment with the edgewise crowned Herbst appliance is warranted and if the results are stable over the long term.

CHAPTER III: MATERIALS AND METHODS

Sample Selection

Experimental Group: The experimental group was obtained from a collection of 56 patients treated consecutively by Dr. Terry Dischinger at his private office in Lake Oswego, OR with the edgewise crowned Herbst appliance in the mixed dentition. The treatment records consisted of lateral cephalometric radiographs taken at five time points throughout treatment (Table 1). All patients had no history of previous orthodontic treatment. Lateral cephalograms were taken before Phase I treatment (T1), immediately following Herbst appliance removal in Phase I treatment (T2), at the completion of Phase I treatment (T3), before Phase II treatment (comprehensive orthodontic treatment) (T4), and at the completion of Phase II treatment (T5). Treatment outcome was not considered and no other inclusion criteria were used other than the availability of good quality lateral cephalograms taken at each of the five time points.

Table 1. Description of Timepoints used in the Study

T1	Before Phase I Treatment
T2	Immediately Following Herbst Appliance Removal in Phase I Treatment
T3	At the Completion of Phase I Treatment
T3	Before Phase II Treatment (Comprehensive Orthodontic Treatment)
T5	At the Completion of Phase II Treatment

The number of subjects included in the study from the original collection of 56 consecutively treated patients were determined based on the following inclusion criteria: no history of previous orthodontic treatment before the initial radiograph, acceptable quality radiographs for at least four of the five time points included in the study, and completion of both Phase I and Phase II orthodontic treatment. Some subjects that completed Phase I treatment did not return for Phase II treatment or were determined by Dr. Terry Dischinger not to need Phase II treatment and were eliminated from the study. Additional exclusion criteria included poor quality radiographs and missing radiographs at any of the critical timepoints (T1, T3, T4, or T5).

Control Group: Serial cephalometric radiographs of subjects with Class II malocclusion and no history of orthodontic treatment were obtained from the Case Western University Bolton-Brush Study, Cleveland, Ohio, and were used as the control group. The control subjects were matched in sex, age, and craniofacial morphology with the experimental subjects. Each control subject was matched with a treatment subject and lateral cephalometric radiographs were obtained at each time point (T1, T2, T3, T4, and T5) corresponding with those available for the treatment subjects. The Bolton-Brush cephalograms were taken at either 6 or 12 month intervals and therefore matched up effectively with the experimental cephalograms.

Appliance Design

The Herbst appliance used by Dr. Terry Dischinger employs a bilateral telescope mechanism consisting of a tube, a plunger, two pivots, and two locking screws, which function to keep the mandible in a continuously anterior jumped position (See Figures 1-

4). The pivot for the tube is usually located on the maxillary first molar and the pivot for the plunger is usually attached to the mandibular first premolar. The length of the tube determines the amount of anterior displacement of the mandible. The appliance is designed to incorporate edgewise brackets and mechanics into the correction of Class II malocclusions.

The mandibular incisor brackets incorporate a -10° inclination to minimize the anterior proclination that is a side effect of Herbst treatment. In the mixed dentition, brackets are usually placed on the maxillary and mandibular incisors; however, this sometimes varies depending on the individual circumstances of the case (See Figure 2).

Stainless steel crowns on the maxillary and mandibular permanent first molars anchor the Herbst appliance to the dentition. Double buccal tubes are placed on the molar crowns to permit the use of an auxiliary archwire to intrude the maxillary or mandibular incisors as necessary. The maxillary arch is tied back to hooks on the molar tubes to prevent space from opening in the maxillary arch because the molars tend to be driven distally during treatment. In addition, consolidating the arch distributes the load applied to the dentition to more teeth. In the mandibular arch, a 2mm half-round cantilever is placed between the first molar and interproximal area between the first bicuspid and cuspid. The axle is placed at the mesial end of the cantilever, and a .022"X.028" archwire tube is placed above and below the axle⁶⁴.

A transpalatal arch is not included in the appliance to allow the first molars to rotate as the Class II relationship is corrected. A lingual arch is not included to allow easier placement of the appliance and prevent possible tipping of the lower anterior incisors. Both arches are free to accommodate expansion during treatment, if necessary.

An occlusal stop off the cantilever arm or directly soldered to the stainless steel crowns extends into and rests on the distal central fossa of the first bicuspid or the mesial central fossa of the second primary molar to prevent tipping of the cantilever arm and impingement into the buccal mucosa and to minimize tipping of the mandibular first molar⁶⁴.

Treatment Protocol

The Dischinger protocol¹⁰⁴ was followed during the treatment of the experimental subjects included in the study. Initially, the Herbst appliance was activated to an edge to edge incisor relationship with the skeletal midlines in alignment. Brackets were bonded to the maxillary and mandibular incisors and high tech archwires were used to control incisor inclination and mandibular molar movement. Archwire sequence began with a .014 Damon CuNiTi. Then a .016X.025 Damon CuNiTi was used with the maxillary wire tied back to the hook on the maxillary molar and the lower wire annealed and cinched to prevent anterior movement of the wire. Next, a .019X.025 lower reverse curve NiTi archwire was placed when more leveling was necessary. Finally, a .019X.025 TMA was inserted if more leveling or torque was desired.

To achieve maximum orthopedic effect, Dr. Dischinger tied back the maxillary archwire to prevent distalization of the maxillary molars. The appliance was activated in a step-by-step fashion a distance of 4 mm every 12 weeks until the maxillary cuspid achieved an end-to-end relationship with the mandibular first premolar or primary first molar. The over-corrected position was held for a period of 12 weeks. A corrected tomogram was taken prior to Herbst placement and before Herbst removal to confirm

condylar position. If the condyles were reasonably centered in the glenoid fossa, then a lateral cephalogram was taken and the patient was scheduled for Herbst removal as soon as possible (Figure 6).

Figure 6. Corrected tomograms taken A) before, B) during, and C) after Herbst treatment

Figure 6-A shows a corrected tomogram taken before Herbst placement identifying the condyle in the center of the glenoid fossa. Figure 6-B shows a corrected tomogram taken during Herbst treatment with the condyle translated in an anterior inferior position on the articular eminence of the glenoid fossa. Figure 6-C shows a corrected tomogram taken after Herbst removal with the condyle centered in the glenoid fossa.

In mixed dentition treatment after Herbst removal, the first permanent molars were banded and two by four appliance treatment continued until the anterior occlusion was correct. If more arch length was necessary, molar bands with .022X.028 extension tubes soldered in the archwire slots were placed and open coil springs were utilized to create more arch length. Deband occurred in two appointments. At the first appointment, upper and lower alginate impressions were taken, and sectional archwires were placed. At the second appointment, incisor brackets were removed and maxillary and mandibular lingual holding arches were placed. Patients were told that the holding arches would remain in place until all the permanent teeth had erupted. At that time the patients were re-evaluated and comprehensive orthodontic treatment to finalize the occlusion was initiated, if necessary.

IRB Approval

IRB exemption was obtained from West Virginia University prior to beginning the study (Appendix A). Approval was obtained from both Dr. Terry Dischinger and Dr. Mark Hans from Case Western University for the use of the orthodontic records and the Bolton-Brush Study lateral cephalograms, respectively (Appendix B and C).

Cephalometric Analysis

Lateral cephalograms were obtained from the office of Dr. Terry Dischinger for the experimental subjects before Phase I treatment (T1), immediately following Herbst appliance removal in Phase I treatment (T2), at the completion of Phase I treatment (T3), before Phase II treatment (Comprehensive orthodontic treatment) (T4), and at the

completion of Phase II treatment (T5). The radiographs were scanned into digital format with an Epson Expression 1680 scanner (Epson America, Long Beach, California) and printouts of the lateral cephalometric images were made on a Lexmark C510 Printer (Lexmark International, Lexington, KY) . Each printout was superimposed on the original radiograph to ensure a 1:1 conversion with no distortion.

Digital copies of the lateral cephalograms matched closely in age, sex, and craniofacial morphology with the treatment subjects were obtained from the Bolton-Brush Study at Case Western Reserve University in Cleveland, OH and were used as the control subjects. The images were scanned at 12 bit grayscale resolution with a spatial resolution of 0.1 mm per pixel and stored in uncompressed TIFF format. The images were converted to JPEG format with the IrfanView software (Version 4.0) and loaded into Adobe Photoshop 6.0 (Adobe Systems, San Jose, California) for size analysis. All original radiographs from the Bolton Study were indexed with 4 corner fiduciary points using a template according to the method described by Baumrind and Miller¹⁰⁷. Within Adobe Photoshop, the resolutions of the images were verified (600dpi), and the images were resized to the original dimensions of the unscanned radiographs. Printouts were then made on a Lexmark C510 Printer (Lexmark International, Lexington, KY) and the fiduciary points were measured with an electronic digital caliper to ensure a 1:1 conversion with no distortion from the original radiographs.

Tracings were performed on printouts obtained from the digitized cephalograms by one operator using a #2 HB mechanical lead pencil (Pentel 0.5 mm lead), an orthodontic protractor, and 0.003 inch matte cephalometric acetate tracing film (3M Unitek, Monrovia, CA). A custom cephalometric analysis was performed utilizing

landmarks correlating with the cephalometric systems described by Bjork¹⁰⁸, Pancherz⁹⁶, and Van Laecken¹⁰². The data was normalized to account for magnification differences between the cephalometric machine used for the Bolton Brush Study (5.6%) and the cephalometric machine used at the office of Dr. Terry Dischinger (10%).

The measurement for each angular variable was performed with the use of a cephalometric protractor and evaluated to the nearest 0.5 degree. The measurement for each sagittal and vertical measurement was performed with an electronic digital caliper and evaluated to the nearest 0.1 mm. The caliper was calibrated to 0.0 mm prior to each measurement. Because lateral cephalograms often present landmarks with right and left images, the midpoint bisecting the two images was used.

Method Error

The reliability of the cephalometric measurements was tested by investigating the error in locating, superimposing, and measuring the changes of all landmarks. Pre-treatment and post-treatment lateral cephalograms of ten randomly selected patients were retraced at least two weeks after the initial tracing and analyzed to evaluate error. For all cephalometric variables, differences between the measurements recorded at the first tracing and measurements recorded at the second tracing were compared for each individual at T1, T2, T3, T4, and T5. A matched pairs t-test was performed to compare the two registrations. P-values were found to be larger than 0.05 in most measurements, indicating that there were no statistically significant differences among the duplicate registrations. Significant differences were found in the following variables at the indicated time points: T1: Mi-OLp (p=0.0467), Ii-ML (p=0.0364), SNL-NL (p=0.0191);

T2: Mic-ML (p=0.0324), li/ML (p=0.0222); T3: Is-OLp (p=0.0474), li-OLp (p=0.0346), Ms-OLp (p=0.0176), SNL-NL (p=0.0227); T4: Mi-OLp (p=0.0387), SNL-NL (p=0.0422), Isa-Is/Iia-Ii (p=0.0014). A correlation coefficient was established for each variable at each time point to determine the degree of reliability (Table 2).

Overall, the method of cephalometric analysis used in this study including landmark identification, superimposition of radiographs, and measurements were determined to be reliable. The correlations ranged from 0.667 to 1.0, however, the overwhelming majority of the correlation coefficients were above 0.900.

Table 2. Correlation Coefficients for all variables at T1,T2,T3,T4, and T5.

Variables	T1			T2			T3			T4			T5		
	Mean (1st)	Mean (2nd)	Correlation	Mean (1st)	Mean (2nd)	Correlation	Mean (1st)	Mean (2nd)	Correlation	Mean (1st)	Mean (2nd)	Correlation	Mean (1st)	Mean (2nd)	Correlation
Sagittal:															
1. Oip-A pt.	75.5	75.8	0.992	77.1	77.2	1.000	77.4	77.8	0.987	79.5	79.7	0.985	81.4	81.4	0.987
2. Oip-Pg	77.8	78.1	0.993	80.5	80.8	0.982	81.7	82.2	0.966	85.2	85.4	0.983	88.3	88.3	0.978
3. Oip-Co	10.9	10.8	0.986	11.7	10.9	0.748	10.8	10.5	0.914	11.3	11.4	0.922	11.1	10.9	0.944
4. Co-A pt.	86.9	87.3	0.991	89.3	88.6	0.983	88.8	88.9	0.972	91.4	91.5	0.937	93.1	93.0	0.982
5. Co-Gn	105.7	105.8	0.979	109.6	109.2	0.978	110.6	110.9	0.983	114.8	115.1	0.980	118.6	118.6	0.971
6. Co-Gn minus Co-A pt.	18.7	18.6	0.943	20.3	20.6	0.988	21.8	22.0	0.990	23.4	23.6	0.987	25.5	25.2	0.977
7. Wits	1.7	1.7	0.891	-0.7	-0.9	0.886	0.1	0.4	0.967	1.3	1.2	0.959	0.6	0.8	0.968
8. Is-Oip	81.7	82.1	0.997	82.0	82.3	0.995	84.5	85.0	0.994	87.6	87.9	0.991	89.2	89.3	0.994
9. li-Oip	75.4	75.9	0.996	78.7	78.7	0.996	79.4	80.1	0.991	82.3	82.6	0.996	84.3	84.5	0.998
10. Overjet	6.2	6.2	0.994	3.3	3.6	0.994	5.1	4.9	0.967	5.3	5.2	0.925	4.9	4.9	0.979
11. Ms-Oip	51.2	51.7	0.983	50.9	51.0	0.992	53.1	53.9	0.984	57.1	56.9	0.991	60.0	59.7	0.991
12. Mi-Oip	50.7	51.3	0.992	54.0	54.3	0.991	55.4	55.9	0.988	58.4	58.5	0.987	62.0	61.5	0.976
13. Molar Relationship	0.5	0.4	0.955	-3.1	-3.3	0.996	-2.3	-2.0	0.981	-1.3	-1.6	0.988	-2.1	-1.8	0.969
Vertical:															
14. Ols-A pt.	27.1	26.9	0.934	27.6	27.1	0.946	28.8	28.4	0.944	29.9	29.8	0.950	31.1	31.2	0.958
15. ANS-Me	61.8	62.3	0.987	64.3	64.7	0.991	64.5	64.9	0.984	66.6	66.6	0.987	69.0	69.1	0.993
16. Is-NL	26.0	26.3	0.987	28.1	28.4	0.823	28.0	28.1	0.854	28.8	28.9	0.946	29.3	29.4	0.979
17. li-ML	36.1	36.5	0.990	37.3	37.3	0.992	37.9	37.9	0.998	39.7	39.5	0.994	41.1	40.9	0.993
18. Overbite	2.4	2.7	0.978	2.6	2.8	0.975	2.5	2.5	0.982	3.6	3.0	0.969	2.9	3.0	0.943
19. Msc-NL	19.5	19.3	0.810	18.6	18.4	0.915	20.5	19.9	0.825	22.1	21.8	0.929	22.9	23.0	0.977
20. Mic-ML	27.6	27.8	0.954	29.1	28.9	0.997	29.0	28.7	0.985	30.2	30.0	0.993	31.6	31.5	0.985
Angular:															
21. SNA	77.9	78.3	0.946	78.1	78.3	0.989	78.4	78.9	0.974	79.2	79.3	0.953	79.6	79.5	0.988
22. SNB	73.2	73.4	0.929	74.1	74.1	0.990	74.5	74.8	0.943	75.2	75.3	0.920	75.9	75.6	0.974
23. ANB	4.8	4.9	0.951	4.1	4.1	0.950	3.9	4.1	0.971	4.0	4.0	0.960	3.7	3.9	0.917
24. SNL-NL	10.1	9.1	0.929	8.7	8.4	0.953	8.6	7.0	0.875	8.4	7.4	0.929	7.6	7.1	0.970
25. SNL-ML	35.7	35.5	0.977	35.2	35.5	0.993	35.1	35.0	0.983	34.0	33.7	0.991	33.6	33.5	0.996
26. SNL-OL	21.9	21.7	0.943	24.1	24.6	0.967	21.5	20.7	0.907	18.8	18.3	0.940	18.8	18.7	0.978
27. Is/NL	111.6	111.3	0.929	104.8	104.4	0.939	110.4	109.9	0.890	110.5	110.8	0.949	110.0	110.2	0.909
28. li/ML	94.9	93.9	0.972	96.8	95.6	0.999	95.3	95.2	0.980	96.2	96.9	0.982	94.1	95.6	0.945
29. Interincisal Angle	128.0	128.4	0.958	131.8	132.6	0.980	127.7	127.0	0.965	127.4	125.5	0.990	130.1	128.0	0.952
Condyle/Glenoid Fossa:															
30. Oip-CoC	-7.0	-7.1	0.972	-7.6	-6.9	0.766	-6.7	-6.6	0.942	-7.4	-7.5	0.904	-7.1	-6.8	0.939
31. Oip-GFS	-7.0	-7.1	0.956	-8.3	-7.8	0.745	-7.0	-6.5	0.890	-7.2	-7.7	0.874	-6.7	7.2	0.940
32. Oip-GFA	-2.4	-2.0	0.914	-3.0	-2.7	0.666	-1.6	-1.4	0.761	-1.9	-2.5	0.821	-1.7	-1.4	0.965
33. Oip-GFP	-13.8	-13.2	0.953	-14.6	-14.1	0.795	-13.0	-11.2	0.871	-13.2	-13.8	0.860	-13.4	-12.8	0.892
34. Ols-CoC	23.0	23.8	0.802	23.8	24.2	0.968	24.3	24.8	0.919	25.9	25.9	0.958	26.5	26.7	0.863
35. Ols-GFS	16.9	17.6	0.892	17.0	17.5	0.948	17.7	18.0	0.906	19.0	19.0	0.945	19.5	19.7	0.905
36. Ols-GFA	18.8	19.3	0.873	19.0	19.1	0.971	19.5	19.5	0.948	20.5	20.6	0.944	21.4	21.2	0.920
37. Ols-GFP	21.2	21.6	0.939	21.3	21.2	0.961	21.6	21.4	0.963	22.5	22.5	0.941	23.5	23.2	0.950

Cephalometric Landmarks and Reference Lines

The cephalometric systems described by Bjork¹⁰⁸, Pancherz⁹⁶, and Van Laecken¹⁰² were used in this study. The landmarks are defined in Table 3. The reference lines that were used are defined in Table 4.

Table 3. Skeletal and Dental Landmarks

Symbol	Name	Definition
Ii	Incision inferious	The incisal point of the most prominent mandibular central incisor
Is	Incision superious	The incisal point of the most prominent maxillary central incisor
Iia	Mandibular incisor apex	The root apex of the most prominent mandibular central incisor
Isa	Maxillary incisor apex	The root apex of the most prominent maxillary central incisor
Mi	Molar inferious	The mesial contact point of the mandibular permanent first molar
Mic	Molar inferious mesial cusp	The mesio-buccal cusp tip of the mandibular first molar
Ms	Molar superious	The mesial contact point of the maxillary permanent first molar
Msc	Molar superious mesial cusp	The mesio-buccal cusp tip of the maxillary first molar
Co	Condylion	The most supero-posterior point on the curvature of the condylar head
Pg	Pogonion	The most prominent point of the chin
ANS	Anterior Nasal Spine	The apex of the spina nasalis anterior
A pt.	Subspinale	The deepest point in the concavity of the anterior maxilla between the Ans and alveolar crest
PNS	Posterior Nasal Spine	The most posterior point on the contour of the palate in the midsagittal plane
Me	Menton	The deepest point of the mandibular symphysis
Go	Gonion	The lowest point of the bony contour of the angle of the mandible
S	Sella	The center of Sella turcica
N	Nasion	The most anterior point of the nasofrontal suture
B pt.	Supramentale	The innermost point on the contour of the mandible between the incisor tooth and the bony chin
Gn	Gnathion	The center of the inferior point on the mandibular symphysis

Table 4. Definition of reference lines

Symbol	Name	Definition
NSL	Sella-Nasion Line	Reference line joining Nasion and Sella
OL	Occlusal Line	Reference line joining the maxillary incisal edge and the molar superious mesial cusp tip
OLp	Occlusal Line Perpendicular	Reference line produced by dropping a perpendicular line from sella to the occlusal plane
OLs	Occlusal Line Sella	Reference line parallel to OL passing through sella (perpendicular to OLp passing through sella)
NL	Maxillary Line	Reference line joining anterior nasal spine and posterior nasal spine
ML	Mandibular Line	Reference line joining menton and gonion

The measurements for this study were grouped into three categories: sagittal, vertical, and angular.

Sagittal Measurements: Analysis of the sagittal skeletal and dental changes were performed by forming a reference grid based on the occlusal line (OL) and occlusal line perpendicular (OLp), obtained from the T1 lateral cephalogram (Figure 7). This reference grid was used for all sagittal measurements between OLp and the cephalometric landmarks. The reference grid from T1 was transferred to T2, T3, T4, and T5 radiographs by superimposition on the anterior cranial base. Measurements were taken from OLp to designated landmarks as well as four other measurements: Condylion—A pt (Co-Apt); Condylion—Gnathion (Co-Gn); Condylion—Gnathion minus Condylion—A pt. (Co-Gn minus Co-Apt); and Wits analysis. In total, there were thirteen sagittal measurements recorded for each cephalogram (Table 4).

Table 5. Sagittal Measurements

Variables	Definition
Skeletal measuring points:	
OLp—A pt.	Position of maxillary base
OLp—Pg	Position of mandibular base
OLp—Co	Position of Condyle
Co—A pt.	Effective midface length
Co—Gn	Effective mandibular length
Co—Gn minus Co—A pt.	Maxillomandibular length differential
Wits analysis	Position of the maxillary base relative to the mandibular base
Dental measuring points:	
Is—OLp	Position of maxillary central incisor
Ii—OLp	Position of mandibular incisor
Is—OLp minus Ii—OLp	Overjet
Ms—OLp	Position of maxillary first permanent molar
Mi—OLp	Position of mandibular first molar
Ms—OLp minus Mi—OLp	Molar Relationship

Figure 7. Cephalometric landmarks and reference lines for sagittal measurements

Vertical Measurements: The reference lines that were used for vertical measurements included OLS, NL, and ML, and OL (Figure 8). OLS was obtained from the T1 radiograph and transferred by superimposition on the anterior cranial base to the T2, T3, T4, and T5 radiographs. A measurement from ANS to Me (ANS-Me) was also included. The seven variables are listed in Table 5.

Table 6. Vertical Measurements

<u>Variables</u>	<u>Definition</u>
Skeletal measuring points:	
OLS—A pt.	Maxillary vertical position
ANS—Me	Lower facial height
Dental measuring points:	
Is—NL	Position of maxillary central incisor
Li—ML	Position of mandibular central incisor
Distance from Li perpendicular To OL	Overbite
Msc—NL	Position of maxillary permanent first molar
Mic—ML	Position of mandibular permanent first molar

Figure 8. Cephalometric landmarks and reference lines for vertical measurements

Angular Measurements: Angular measurements were used to identify changes in the dentofacial complex (Table 7). Cephalometric landmarks and reference lines for angular measurements are illustrated in Figure 9.

Table 7. Angular Measurements

<u>Variables</u>	<u>Definition</u>
Skeletal measuring points:	
SNA	Maxillary base relative to SNL
SNB	Mandibular base relative to SNL
ANB	SNA minus SNB
SNL—NL	Palatal plane angle
SNL—ML	Mandibular plane angle
SNL—OLf	Occlusal plane angle (Functional occlusal plane)
Dental measuring points:	
Is/NL	Maxillary central incisor angle
Ii/ML	Mandibular central incisor angle
Isa—Is/Iia—Ii	Interincisal angle

Figure 9. Cephalometric landmarks and reference lines for angular measurements

Condyle/Glenoid Fossa Measurements: In addition to the preceding cephalometric evaluations, an additional analysis of the condyle and glenoid fossa was performed for each of the subjects. The reference lines used for this analysis included OLp and OLs, the same lines that were used in the previous analyses (Figure 10). A reference grid was formed from the OLp and OLs reference lines from the T1 radiograph and transferred to the T2, T3, T4, and T5 radiographs through superimposition on the anterior cranial base. The additional skeletal landmarks used in this analysis are defined in Table 8. The sagittal and vertical measurements used in this analysis are described in Table 9 and Table 10, respectively.

Table 8. Skeletal Landmarks of the Condyle/Glenoid Fossa Analysis

Symbol	Name	Definition
CoC	Center of Condyle	A point located at the center of the condylar head
GFS	Glenoid Fossa Superior	The most superior point of the Glenoid Fossa
GFA	Glenoid Fossa Anterior	The midpoint of the anterior aspect of the Glenoid Fossa between GFS and ATI
GFP	Glenoid Fossa Posterior	A point through which a line perpendicular to OLp passing through ATI intersects with the posterior aspect of the Glenoid Fossa
ATI	Articular Tubercle Inferior	The most inferior point of the articular tubercle

Table 9. Sagittal Measurements of the Condyle/Glenoid Fossa Analysis

Variables	Definition
OLp-CoC	Sagittal position of the center of the mandibular condylar head
OLp-GFS	Sagittal position of the most superior aspect of the glenoid fossa
OLP-GFA	Sagittal position of the most anterior aspect of the glenoid fossa
OLp-GFP	Sagittal position of the most posterior aspect of the glenoid fossa

Table 10. Vertical Measurements of the Condyle/Glenoid Fossa Analysis

Variables	Definition
OLs-CoC	Vertical position of the center of the mandibular condylar head
OLs-GFS	Vertical position of the most superior aspect of the glenoid fossa
OLs-GFA	Vertical position of the most anterior aspect of the glenoid fossa
OLs-GFP	Vertical position of the most posterior aspect of the glenoid fossa

Figure 10. Landmarks/reference lines for sagittal and vertical measurements of the Condyle/Glenoid Fossa Analysis

Evaluation of Overjet and Molar Relationship Correction

To determine the amount of skeletal and dental contribution to the overjet and molar relationship correction, the amount of dental change in the maxilla and mandible were calculated. The method of calculation is shown below (Table 11).

Table 11. Calculation of Overjet and Molar Relationship Changes

<u>Overjet</u>	<u>Molar Relationship</u>
Skeletal contributions: 1. OLp-Apt 2. OLP-Pg	Skeletal contributions: 1. OLp-Apt 2. OLP-Pg
Dental contributions: 3. Is-OLp minus OLp-Apt 4. Ii-OLp minus OLP-Pg	Dental contributions: 3. Ms-OLp minus OLp-Apt 4. Mi-OLp minus OLP-Pg
Overjet correction:	Molar relationship correction:
Sum of 1,2,3,and 4	Sum of 1,2,3,and 4

When adding figures from the above table, the following formula was used for overjet correction:

$$\text{Overjet Correction} = \text{Maxilla} + \text{Mx incisor} - \text{Mandible} - \text{Md incisor}$$

Maxilla = OLp-A pt.

Mx incisor = Is-OLp minus OLp-A pt.

Mandible = OLp-Pg

Mandibular incisor = Ii-OLp minus OLP-Pg

When adding figures from the above table, the following formula was used for molar relationship correction or increase;

$$\text{Molar Relationship Correction} = \text{Maxilla} + \text{Mx Molar} - \text{Mandible} - \text{Md Molar}$$

$$\text{Maxilla} = \text{OLp-A pt.}$$

$$\text{Maxillar molar} = \text{Ms-OLp minus OLp-A pt.}$$

$$\text{Mandible} = \text{OLp-Pg}$$

$$\text{Mandibular molar} = \text{Mi-OLp minus OLp-Pg}$$

Net Overjet/Molar Relationship Changes: When determining the net treatment effect of overjet and molar relationship correction, the control group figures were subtracted from the treated group. Calculations were made for the treatment group minus the control group at various time periods and the same formulas were used to calculate net overjet and net molar relationship correction or change:

$$\text{Net Overjet Correction} = \text{Maxilla} + \text{Mx incisor} - \text{Mandible} - \text{Md incisor}$$

$$\text{Maxilla} = \text{OLp-A pt. (treated) minus OLp-A pt. (control)}$$

$$\text{Mx incisor} = (\text{Is-OLp minus OLp-A pt.(treated)}) \text{ minus } (\text{Is-OLp minus OLp-A pt.(control)})$$

$$\text{Mandible} = \text{OLp-Pg (treated) minus OLp-Pg (control)}$$

$$\text{Mandibular incisor} = (\text{Ii-OLp minus OLp-Pg(treated)}) \text{ minus } (\text{Ii-OLp minus OLp-Pg(control)})$$

When comparing the treated and control subjects for net molar relationship correction the following formula was used:

$$\text{Net Molar Relationship Correction} = \text{Maxilla} + \text{Mx molar} - \text{Mandible} - \text{Md molar}$$

Maxilla = OLp-A pt. (treated) **minus** OLp-A pt. (control)

Mx molar = (Ms-OLp minus OLp-A pt.(treated)) **minus** (Ms-OLp minus OLp-A pt.(control))

Mandible = OLp-Pg (treated) **minus** OLp-Pg (control)

Mandibular incisor = (Mi-OLp minus OLp-Pg(treated)) **minus** (Mi-OLp minus OLp-Pg(control))

Statistical Analysis

A matched pairs t-test was used to compare the starting forms between the treatment and control subjects at T1. The difference between the treatment and control subjects for each variable across the five time periods (T1 through T5) was analyzed for pooled subjects (males and females combined), male subjects, and female subjects. A repeated measures analysis of variance (ANOVA) was performed to determine if the differences between the treatment and control subjects were the same across the five time periods. A matched pairs t-test was performed for each variable to identify treatment effects of the Herbst appliance (**Tx (T2-T1)) minus (Control (t2-t1))**), Phase I treatment effects (**Tx (T3-T1)) minus (Control (t3-t1))**), residual Phase I treatment effects (**Tx (T4-T1)) minus (Control (t4-t1))**), and combined Phase I and Phase II treatment effects (**Tx (T5-T1)) minus (Control (t5-t1))**). In addition, Phase II treatment effects were evaluated (**Tx (T5-T4)) minus (Control (t5-t4))**) as well as the relapse that occurred from after Phase I treatment to before Phase II treatment (**Tx (T4-T3)) minus (Control (t4-t3))**)

with a matched pairs t-test. A level of significance of $p < 0.05$ (95% confidence interval) was used in this study.

Reliability was tested with a matched pairs t-test to evaluate the correlation between measurements made at the initial tracing and measurements made on the same tracing at a later time. Correlation coefficients were reported to determine how strongly the first measurements were associated with the second measurements for each variable at every time period in ten individuals.

CHAPTER IV: RESULTS AND DISCUSSION

RESULTS

Sample Size

The control and treatment groups at T1, T3, T4, and T5 each consisted of 22 subjects (7 males and 15 females). Some of the radiographs were not available at T2 immediately after the Herbst appliance was removed and the control and treatment groups at T2 each consisted of 13 subjects (7 males and 6 females).

Sex Distribution

The sex of the treated and control groups were matched exactly. The control and treatment groups at T1, T3, T4, and T5 each consisted of 7 males and 15 females. The control and treatment groups at T2 each consisted of 7 males and 6 females.

Age Distribution

The age of the treatment and control groups were matched very closely (Table 12). The mean age of the treatment group at T1 for pooled subjects was 8.4 years. The mean age of the control group at T1 for pooled subjects was 8.4 years. The mean age of the treatment group at T1 for male subjects was 8.7 years. The mean age of the control group at T1 for male subjects was 8.7 years. The mean age of the treatment group at T1 for female subjects was 8.3 years. The mean age of the control group at T1 for female subjects was 8.3 years. Age distributions for both the treatment and control groups for pooled subjects, male subjects, and female subjects at each Time period (T1, T2, T3, T4,

and T5) are reported in Table 12. No significant differences were found between the treatment and control groups for any of the Time periods (T1, T2, T3, T4 or T5).

Table 12. Age Distribution

		MEAN	S.D.	MAX	MIN	DIFF	SIG
POOLED							
T1	Control	8.4	1.1	10.7	6.3	0.0	NS
	Treatment	8.4	1.0	11.0	6.5		
T2	Control	9.4	0.8	11.6	8.1	0.1	NS
	Treatment	9.3	0.9	11.5	7.9		
T3	Control	10.4	1.1	13.1	8.1	0.2	NS
	Treatment	10.2	1.0	12.8	8.4		
T4	Control	13.0	1.4	16.0	10.9	0.1	NS
	Treatment	12.9	1.4	15.7	11.1		
T5	Control	14.7	1.5	18.7	13.0	0.1	NS
	Treatment	14.6	1.4	17.9	12.8		
MALES							
T1	Control	8.7	1.1	10.7	7.0	0.0	NS
	Treatment	8.7	1.3	11.0	7.0		
T2	Control	9.6	1.1	11.6	8.1	0.0	NS
	Treatment	9.6	1.2	11.5	7.9		
T3	Control	10.5	1.4	13.1	8.5	0.2	NS
	Treatment	10.3	1.4	12.8	8.4		
T4	Control	13.4	1.3	15.0	10.9	0.1	NS
	Treatment	13.3	1.3	14.7	11.2		
T5	Control	15.2	1.9	18.7	13.0	0.0	NS
	Treatment	15.2	1.5	17.9	13.2		
FEMALES							
T1	Control	8.3	1.1	10.0	6.3	0.0	NS
	Treatment	8.3	0.9	9.9	6.5		
T2	Control	9.2	0.3	9.8	9.0	0.1	NS
	Treatment	9.1	0.4	9.6	8.6		
T3	Control	10.3	1.0	12.0	8.1	0.2	NS
	Treatment	10.1	0.9	11.8	8.9		
T4	Control	12.9	1.5	16.0	10.9	0.2	NS
	Treatment	12.7	1.4	15.7	11.1		
T5	Control	14.4	1.3	17.0	13.0	0.1	NS
	Treatment	14.3	1.3	16.8	12.8		

Distribution of Variable Measurements

The measurements for each of the 37 variables in both the treatment and control groups were analyzed. The mean, standard deviation, maximum, and minimum for each variable measurement were recorded for pooled subjects, male subjects, and female subjects at each Time period (T1, T2, T3, T4, and T5). In the treatment and control groups at T1, T3, T4, and T5, 22 measurements were made for each variable for pooled subjects, 7 measurements were made for each variable for male subjects, and 15 measurements were made for each variable for female subjects. In the treatment and control groups at T2, 13 measurements were made for each variable for pooled subjects, 7 measurements were made for each variable for male subjects, and 6 measurements were made for each variable for female subjects. Distributions of the variable measurements in both treatment and control groups for pooled subjects, male subjects, and female subjects at each Time period (T1, T2, T3, T4, and T5) are reported in Appendices D-AA.

Pre-treatment Craniofacial Morphology of the Treatment vs. the Control Group

The pre-treatment craniofacial morphology of the treatment group and the control group were compared to determine if there were statistically significant differences in any of the 37 variables used in this study. Differences were analyzed at T1 for pooled subjects, male subjects, and female subjects.

For pooled subjects, only 4 of the 37 variables were significantly different between the treatment group and control group at T1 (Table 13). OLp-A pt., Is-OLp, and ANB were significantly greater in the treatment group than in the control group. OLs-A pt. was significantly less in the treatment group than in the control group. All other variables showed no significant differences at T1 between the treatment and control groups.

For males, only 3 of the 37 variables were significantly different between the treatment group and control group at T1 (Table 14). Overjet and molar relationship were significantly greater in the treatment group than in the control group. ANS-Me was significantly less in the treatment group than in the control group. All other variables showed no significant differences at T1 between the treatment and control groups.

For females, 9 of the 37 variables were significantly different between the treatment group and control group at T1 (Table 15). OL-A pt., Is-OLp, Ii-OLp, Ms-OLp, Mi-OLp, ANB, and OLp-CoC were significantly greater in the treatment group than in the control group. OLp-Co and OLs-A pt. were significantly less in the treatment group than in the control group. All other variables showed no significant differences at T1 between the treatment and control groups.

The data suggest that the pre-treatment craniofacial morphology of the treatment group and the control group were similar. For pooled subjects, the maxilla and maxillary incisors were slightly more anterior in the treatment group than in the control group. In addition, the ANB angle was 1.8 ° greater in the treatment group than in the control group.

Table 13. Comparison of the pre-treatment craniofacial morphology in pooled subjects

POOLED (MALES AND FEMALES)							
Variable	Control		Treated		p value	Diff.	Sig
	Mean	S.D.	Mean	S.D.			
Sagittal:							
1. Olp-A pt.	68.3	4.2	70.6	3.3	0.0479	2.3	*
2. Olp-Pg	71.0	5.5	71.9	4.5	0.5437	0.9	NS
3. Olp-Co	9.6	2.1	8.2	2.9	0.0738	1.4	NS
4. Co-A pt.	78.3	4.3	79.7	4.9	0.3255	1.4	NS
5. Co-Gn	95.5	5.0	95.1	4.9	0.8154	0.4	NS
6. Co-Gn minus Co-A pt.	17.1	2.9	15.8	3.8	0.2072	1.3	NS
7. Wits	1.1	1.6	1.1	1.9	0.983	0.0	NS
8. Is-Olp	73.5	5.6	76.6	4.3	0.0403	3.1	*
9. li-Olp	68.8	4.4	71.0	3.5	0.0782	2.2	NS
10. Overjet	4.7	2.1	5.6	2.6	0.1694	0.9	NS
11. Ms-Olp	46.0	3.7	47.9	2.7	0.0524	1.9	NS
12. Mi-Olp	45.7	4.3	47.1	2.9	0.1894	1.4	NS
13. Molar Relationship	0.3	0.9	0.8	2.0	0.3244	0.5	NS
Vertical:							
14. OLs-A pt.	25.2	2.2	22.8	4.1	0.0215	2.4	*
15. ANS-Me	57.0	4.6	56.9	3.2	0.9324	0.1	NS
16. Is-NL	23.7	4.1	23.6	2.8	0.9635	0.1	NS
17. li-ML	34.1	3.2	33.2	2.4	0.3418	0.9	NS
18. Overbite	1.6	3.0	1.4	3.4	0.8021	0.2	NS
19. Msc-NL	16.7	3.0	17.0	1.9	0.7502	0.3	NS
20. Mic-ML	25.7	1.9	25.6	2.1	0.8807	0.1	NS
Angular:							
21. SNA	79.9	3.2	81.4	3.9	0.1633	1.5	NS
22. SNB	75.3	3.0	75.0	3.6	0.8058	0.3	NS
23. ANB	4.6	1.3	6.4	2.1	0.0018	1.8	*
24. SNL-NL	7.5	3.2	8.3	3.6	0.459	0.8	NS
25. SNL-ML	34.1	4.6	34.4	7.9	0.8803	0.3	NS
26. SNL-OL	20.3	3.5	22.3	4.2	0.1057	2.0	NS
27. Is/NL	111.0	5.9	109.6	6.0	0.4226	1.4	NS
28. li/ML	94.6	5.7	96.0	9.3	0.5413	1.4	NS
29. Interincisal Angle	127.6	7.9	126.7	10.3	0.7386	0.9	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	-5.9	2.0	-5.1	2.8	0.2822	0.8	NS
31. Olp-GFS	-6.1	2.4	-5.9	2.9	0.7938	0.2	NS
32. Olp-GFA	-1.8	2.1	-1.4	2.5	0.573	0.4	NS
33. Olp-GFP	-11.7	2.2	-11.8	3.4	0.9092	0.1	NS
34. Ols-CoC	21.7	2.3	20.9	2.6	0.2862	0.8	NS
35. Ols-GFS	15.8	2.4	14.8	2.8	0.1998	1.0	NS
36. Ols-GFA	17.3	2.3	16.6	2.6	0.3536	0.7	NS
37. Ols-GFP	19.2	2.2	19.0	2.5	0.8521	0.2	NS

Table 14. Comparison of the pre-treatment craniofacial morphology in males subjects

MALES							
Variable	Control		Treated		p value	Diff	Sig
	Mean	S.D.	Mean	S.D.			
Sagittal:							
1. Olp-A pt.	72.5	4.4	71.4	3.3	0.5976	1.1	NS
2. Olp-Pg	75.0	6.9	72.5	5.5	0.4822	2.5	NS
3. Olp-Co	9.2	2.5	9.2	4.3	0.9822	0	NS
4. Co-A pt.	82.0	3.2	82.4	4.0	0.8793	0.4	NS
5. Co-Gn	99.1	3.5	97.3	4.6	0.4244	1.8	NS
6. Co-Gn minus Co-A pt.	17.0	3.4	16.2	2.9	0.6313	0.8	NS
7. Wits	2.2	1.5	1.9	2.1	0.7745	0.3	NS
8. Is-Olp	78.1	6.4	78.4	4.6	0.9224	0.3	NS
9. li-Olp	72.7	4.5	70.7	5.0	0.4367	2	NS
10. Overjet	5.4	2.5	7.7	1.2	0.0462	2.3	*
11. Ms-Olp	48.5	4.1	48.6	3.8	0.9757	0.1	NS
12. Mi-Olp	48.5	5.0	46.4	3.4	0.3764	2.1	NS
13. Molar Relationship	0.1	1.2	2.2	1.3	0.0065	2.1	*
Vertical:							
14. OLs-A pt.	25.0	2.3	24.5	3.2	0.6971	0.5	NS
15. ANS-Me	60.9	3.7	57.0	2.3	0.0361	3.9	*
16. Is-NL	25.5	3.8	24.7	2.1	0.6326	0.8	NS
17. li-ML	36.5	2.8	34.7	1.1	0.143	1.8	NS
18. Overbite	1.8	2.8	3.3	1.4	0.2465	1.5	NS
19. Msc-NL	17.4	3.2	17.3	2.3	0.9725	0.1	NS
20. Mic-ML	27.2	2.0	25.1	2.4	0.1012	2.1	NS
Angular:							
21. SNA	79.7	1.8	80.6	3.9	0.5772	0.9	NS
22. SNB	74.4	1.8	74.9	3.6	0.7481	0.5	NS
23. ANB	5.4	0.4	5.8	2.2	0.6229	0.4	NS
24. SNL-NL	7.9	2.6	7.6	3.7	0.8394	0.3	NS
25. SNL-ML	35.9	3.4	33.2	6.1	0.3366	2.7	NS
26. SNL-OL	20.4	3.3	20.6	3.7	0.9112	0.2	NS
27. Is/NL	108.7	3.6	112.3	7.4	0.2716	3.6	NS
28. li/ML	93.2	4.6	94.3	10.6	0.8102	1.1	NS
29. Interincisal Angle	130.1	5.5	127.3	12.7	0.5947	2.8	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	-5.3	2.4	-6.1	4.1	0.6427	0.8	NS
31. Olp-GFS	-5.7	2.2	-6.9	3.9	0.5115	1.2	NS
32. Olp-GFA	-1.3	2.4	-2.0	3.3	0.6349	0.7	NS
33. Olp-GFP	-11.2	2.3	-12.9	4.9	0.4241	1.7	NS
34. Ols-CoC	22.2	3.2	21.3	3.3	0.6254	0.9	NS
35. Ols-GFS	16.0	3.4	15.8	3.3	0.8817	0.2	NS
36. Ols-GFA	17.5	3.4	17.9	2.7	0.8014	0.4	NS
37. Ols-GFP	19.3	3.4	20.6	2.2	0.4028	1.3	NS

Table 15. Comparison of the pre-treatment craniofacial morphology in female subjects

FEMALES							
Variable	Control		Treated		p value	Diff	Sig
	Mean	S.D.	Mean	S.D.			
Sagittal:							
1. Olp-A pt.	66.4	2.3	70.3	3.3	0.0008	3.9	*
2. Olp-Pg	69.1	3.7	71.6	4.1	0.0914	2.5	NS
3. Olp-Co	9.8	2.0	7.8	2.0	0.009	2	*
4. Co-A pt.	76.6	3.5	78.5	4.9	0.2392	1.9	NS
5. Co-Gn	93.8	4.8	94.1	4.9	0.8519	0.3	NS
6. Co-Gn minus Co-A pt.	17.2	2.8	15.6	4.3	0.2527	1.6	NS
7. Wits	0.6	1.4	0.7	1.8	0.8446	0.1	NS
8. Is-Olp	71.3	3.7	75.8	4.1	0.0035	4.5	*
9. li-Olp	67.0	3.1	71.1	2.8	0.0006	4.1	*
10. Overjet	4.3	1.8	4.7	2.6	0.6545	0.4	NS
11. Ms-Olp	44.9	2.9	47.7	2.0	0.0047	2.8	*
12. Mi-Olp	44.4	3.3	47.5	2.7	0.0082	3.1	*
13. Molar Relationship	0.5	0.7	0.1	1.9	0.5213	0.4	NS
Vertical:							
14. OLs-A pt.	25.2	2.2	22.1	4.3	0.017	3.1	*
15. ANS-Me	55.1	3.9	56.8	3.7	0.2407	1.7	NS
16. Is-NL	22.9	4.2	23.2	3.0	0.8208	0.3	NS
17. li-ML	32.9	2.8	32.6	2.5	0.711	0.3	NS
18. Overbite	1.5	3.2	0.5	3.7	0.4157	1	NS
19. Msc-NL	16.4	2.9	16.8	1.8	0.6721	0.4	NS
20. Mic-ML	25.0	1.5	25.8	2.0	0.2038	0.8	NS
Angular:							
21. SNA	79.9	3.8	81.7	3.9	0.2114	1.8	NS
22. SNB	75.7	3.4	75.1	3.8	0.6531	0.6	NS
23. ANB	4.3	1.4	6.7	2.1	0.0011	2.4	*
24. SNL-NL	7.3	3.5	8.6	3.7	0.3306	1.3	NS
25. SNL-ML	33.2	4.9	34.9	8.8	0.5263	1.7	NS
26. SNL-OL	20.3	3.7	23.0	4.3	0.0733	2.7	NS
27. Is/NL	112.1	6.5	108.3	5.1	0.0858	3.8	NS
28. li/ML	95.2	6.1	96.8	9.0	0.5724	1.6	NS
29. Interincisal Angle	126.4	8.8	126.4	9.5	0.9921	0	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	-6.2	1.9	-4.6	2.0	0.0322	1.6	*
31. Olp-GFS	-6.3	2.5	-5.4	2.3	0.3495	0.9	NS
32. Olp-GFA	-2.1	2.1	-1.2	2.1	0.2315	0.9	NS
33. Olp-GFP	-11.9	2.2	-11.3	2.5	0.4641	0.6	NS
34. Ols-CoC	21.5	1.8	20.7	2.4	0.3255	0.8	NS
35. Ols-GFS	15.7	2.0	14.4	2.5	0.107	1.3	NS
36. Ols-GFA	17.2	1.7	16.0	2.4	0.1231	1.2	NS
37. Ols-GFP	19.1	1.5	18.3	2.3	0.2605	0.8	NS

Comparison of the Treatment Group and the Control Group Across the Time Periods

The difference in each variable between the treatment and control groups across the five time periods (T1 through T5) was analyzed for pooled subjects, and separately for male and female subjects. A repeated measures ANOVA was performed to determine if the differences between the treatment and control groups were the same across the five time periods. Graphs plotting the values of the 37 variables across time for the treatment and control groups for pooled subjects, male subjects, and female subjects are provided in Appendix AB. If there were no differences between the variables in the treatment and control groups across the five time periods at a $p < .05$ confidence level, plots of the variables across time for the treatment and control groups would be close to parallel and the effects of treatment on the variable were considered insignificant. If there were significant differences between the variables in the treatment group and the control group across the five time periods, plots of the variables across time for the treatment and control groups would deviate from parallel, and the effects of the treatment on the variable were considered significant.

Statistical analysis comparing the differences between the treatment and control groups across the time periods for all 37 variables for pooled subjects, male subjects, and female subjects is reported in Table 16. For pooled subjects, significant differences were found between the treatment and control groups across the five time periods for sagittal, angular, vertical, and condyle/glenoid fossa variables. For male subjects, significant differences were found between the treatment and control groups across the five time

periods for sagittal, angular, and vertical variables. For female subjects, significant differences were found between the treatment and control groups across the five time periods for sagittal, angular, vertical, and condyle/glenoid fossa variables.

Sagittal Variables

For pooled subjects, significant differences between the treatment and control groups across the time periods were found for all sagittal variables ($p < .05$) except for the variable OLp-Co ($p = 0.0898$). For male subjects, significant differences were found between the treatment and control groups for the variables Wits ($p = 0.0001$), Is-OLp ($p = 0.0034$), Ii-OLP ($p = 0.0491$), Overjet ($p = 0.0001$), and molar relationship ($p = 0.0001$). For female subjects, significant differences were found between the treatment and control groups for all sagittal variables except for the variable Co-Gn minus Co-A pt. ($p = 0.4056$).

Vertical Variables

For pooled subjects, significant differences between the treatment and control groups across the time periods ($p < .05$) were found for the vertical variables ANS-Me ($p = 0.0431$) and Msc-NL ($p = 0.0061$). For male subjects, significant differences were found between the treatment and control groups for the vertical variables Ii-ML ($p = 0.0246$) and Overbite ($p = 0.0126$). For female subjects, significant differences were found between the treatment and control groups for the vertical variable Msc-NL ($p = 0.0387$).

Angular Variables

For pooled subjects, significant differences between the treatment and control groups across the time periods were found for all angular variables ($p < .05$) except for

the variables SNL-NL ($p = 0.4629$), SNL-ML ($p = 0.6299$), and Interincisal angle ($p = 0.4484$). For male subjects, significant differences were found between the treatment and control groups for the variables ANB ($p = 0.0111$), SNL-OL ($p = 0.0054$), and Is/NL ($p = 0.0012$). For female subjects, significant differences were found between the treatment and control groups for the angular variables SNA ($p = 0.0024$), SNB ($p = 0.0323$), ANB ($p = 0.0061$), and Ii/ML ($p = 0.0130$).

Condyle/Glenoid Fossa Variables

For pooled subjects, significant differences between the treatment and control groups across the time periods were found ($p < .05$) for the condyle/glenoid fossa variable OLp-CoC ($p = 0.0264$). For male subjects, no significant differences were found between the treatment and control groups for any of the condyle/glenoid fossa variables. For female subjects, significant differences were found between the treatment and control groups for the condyle/glenoid fossa variables OLp-CoC ($p = 0.0108$), OLp-GFA ($p = 0.0462$), OLp-GFP ($p = 0.0451$).

Table 16. Comparison of the Treatment group vs the Control group across the time periods

Variables	Pooled Subjects		Male Subjects		Female Subjects	
	p value	Significant	p value	Significant	p value	Significant
Sagittal:						
1. Olp-A pt.	0.0002	*	0.2888	NS	0.0001	*
2. Olp-Pg	0.0211	*	0.4693	NS	0.0003	*
3. Olp-Co	0.0898	NS	0.6754	NS	0.0123	*
4. Co-A pt.	0.0009	*	0.5267	NS	0.0002	*
5. Co-Gn	0.0154	*	0.7683	NS	0.0013	*
6. Co-Gn minus Co-A pt.	0.0235	*	0.1226	NS	0.4056	NS
7. Wits	0.0001	*	0.0001	*	0.0251	*
8. Is-Olp	0.0001	*	0.0034	*	0.0079	*
9. Ii-Olp	0.0005	*	0.0491	*	0.0041	*
10. Overjet	0.0001	*	0.0001	*	0.0002	*
11. Ms-Olp	0.0001	*	0.1642	NS	0.0001	*
12. Mi-Olp	0.0002	*	0.1355	NS	0.0002	*
13. Molar Relationship	0.0001	*	0.0001	*	0.0001	*
Vertical:						
14. OLs-A pt.	0.7155	NS	0.4930	NS	0.7704	NS
15. ANS-Me	0.0431	*	0.1691	NS	0.2974	NS
16. Is-NL	0.5956	NS	0.2595	NS	0.8916	NS
17. Ii-ML	0.2252	NS	0.0246	*	0.8711	NS
18. Overbite	0.0600	NS	0.0126	*	0.5826	NS
19. Msc-NL	0.0061	*	0.2760	NS	0.0387	*
20. Mic-ML	0.7173	NS	0.5470	NS	0.7433	NS
Angular:						
21. SNA	0.0027	*	0.0775	NS	0.0024	*
22. SNB	0.0329	*	0.2159	NS	0.0323	*
23. ANB	0.0001	*	0.0111	*	0.0061	*
24. SNL-NL	0.4629	NS	0.1407	NS	0.4422	NS
25. SNL-ML	0.6299	NS	0.1267	NS	0.7682	NS
26. SNL-OL	0.0031	*	0.0054	*	0.0895	NS
27. Is/NL	0.0033	*	0.0012	*	0.2680	NS
28. Ii/ML	0.0011	*	0.0840	NS	0.0130	*
29. Interincisal Angle	0.4484	NS	0.0966	NS	0.7365	NS
Condyle/Glenoid Fossa:						
30. Olp-CoC	0.0264	*	0.5061	NS	0.0108	*
31. Olp-GFS	0.1113	NS	0.7518	NS	0.0696	NS
32. Olp-GFA	0.1677	NS	0.7404	NS	0.0462	*
33. Olp-GFP	0.1221	NS	0.8220	NS	0.0451	*
34. Ols-CoC	0.2181	NS	0.2043	NS	0.6226	NS
35. Ols-GFS	0.6034	NS	0.6719	NS	0.8038	NS
36. Ols-GFA	0.6553	NS	0.5985	NS	0.8383	NS
37. Ols-GFP	0.2059	NS	0.4149	NS	0.3598	NS

Graph Analysis of Variables Across Time for the Treatment vs. Control Groups

A visual inspection of the graphs plotting the values of the 37 variables across time for the treatment and control groups can indicate the time points at which differences between the treatment and control groups became apparent. An abrupt change in the value of the reported variable can suggest an important effect of treatment and the distance between the treatment and control variables over time indicate whether any change was temporary in nature or stable over the long term. A description of the graphs of the treatment and control group for the pooled subjects variables that were determined to be significantly different across the five time periods follow. Graphs plotting the values of the 37 variables across time of the treatment and control groups for pooled subjects, male subjects, and female subjects are shown in Appendix AB.

Sagittal Variables

OLp-A pt. Initially, the value of OLp-A pt. was greater in the treatment group than in the control group. Although this difference became smaller at T2 indicating a possible restriction of maxillary growth with treatment, the treatment group value remained greater than the control group value throughout the time periods until T5 when the control group value of OLp-A pt. became greater than the treatment group value.

OLp-Pg Initially, the value of OLp-Pg was greater in the treatment group than in the control group. This difference became larger at T2 indicating an initial enhanced forward positioning of the lower jaw, and then progressively declined. The control group value became greater than the treatment group value at T5 indicating the loss of any initial enhanced forward positioning of the lower jaw after treatment at T2.

Co-A pt. Initially, the value of Co-A pt. was greater in the treatment group than in the control group. At T2, the treatment group value dropped below the value of the control group indicating a restriction of maxillary growth during treatment. The treatment group value remained lower than the control group value through T5 indicating a possible sustained treatment effect.

Co-Gn The values of Co-Gn for the treatment group and the control group were very similar through T3. At T4 the control group value became greater than the treatment group and remained this way through T5.

Co-Gn minus Co-A pt. Initially, the value of Co-Gn minus Co-A pt. was lower in the treatment group than in the control group. At T2, the value of the treatment group became greater than the value of the control group indicating an initial reduction in jaw discrepancy with treatment. However, the values of the treatment group and control group became similar at T3, returned to treatment value lower than control value at T4, and finished with similar values at T5.

Wits Analysis Initially, the values of the Wits analysis were very similar for the treatment and control groups. An abrupt decline to negative values occurred in the treatment group at T2, however a gradual reduction in the difference in values occurred until they became very similar again at T4. At T5, the Wits analysis values for the treatment group once again dropped below the control group values.

Is-OLp Initially, the value of Is-OLp in the treatment group was greater than the value in the control group. The value of the treatment group dropped to become very similar to the control group value at T2, indicating retroclination of the maxillary incisor

during treatment. The values of the treatment and control groups remained similar through T5.

Ii-OLp Initially, the value of Ii-OLp of the treatment group was greater than the value of the control group. At T2, this difference became even larger indicating proclination of the mandibular incisors during treatment. The difference between the treatment and control group values gradually became smaller through T5 where they ended up very similar.

Overjet Initially, the value of Overjet for the treatment group was slightly greater than the value for the control group. At T2, an abrupt decline in the treatment group brought the value well below the control group, indicating a major reduction in overjet with treatment. Although this difference gradually became smaller until T4, the value of the treatment group remained well below the value of the control group. At T5, the difference became larger as the treatment group value was decreased again.

Ms-OLp Initially, the value of Ms-OLp was greater in the treatment group than in the control group. At T2, the treatment group value dropped below the control group value indicating a posterior movement of the maxillary molar with treatment. The values of the treatment group and control group became very similar at T3, however the treatment group value remained slightly below the control group value through T5.

Mi-OLp Initially, the value of Mi-OLp was greater in the treatment group than in the control group. At T2, the difference became even larger as the treatment group value increased more than the control value, indicating a mesial movement of the mandibular first molar during treatment. The difference in values gradually decreased to very similar

levels at T5, although the treatment group value remained slightly larger than the control group value.

Molar relationship Initially, the value of Molar relationship for the treatment group was slightly greater than the value for the control group. At T2, an abrupt decline in the treatment group brought the value well below the control group, indicating over-correction of molar relationship with treatment. Although this difference gradually became smaller through T5, the value of the treatment group remained well below the value of the control group indicating a sustained molar relationship correction over the long term.

Vertical Variables

ANS-Me The values of ANS-Me for the treatment group and the control group were very similar through T3. At T4 the control group value became greater than the treatment group and remained this way through T5.

Msc-NL Initially, the values of Msc-NL for the treatment group and the control group were very similar. At T2, the value for the treatment group became smaller than the control group indicating intrusion of the maxillary molar during treatment. The values of the treatment group rebounded slightly, but remained lower than the control group through T5.

Angular Variables

SNA Initially, the value of SNA in the treatment group was larger than in the control group. At T2, the difference was smaller although the value in the treatment group remained larger than in the control group. The treatment group values remained

slightly larger than the control group values through T4, however at T5 the treatment group value became less than the control group value.

SNB Initially, the values of SNB in the treatment group and the control group were very similar. At T2, the treatment group value became slightly larger than the control group value, however this difference gradually became smaller through T4. At T5, the treatment group value dropped below the control group value.

ANB Initially, the value of ANB in the treatment group was greater than the value in the control group. At T2, the value in the treatment group was reduced to a value very similar to the control group value. The treatment value gradually became slightly larger than the control value through T4. At T5, the treatment value was once again reduced to a very similar level as the control value.

SNL-OL Initially, the value of SNL-OL in the treatment group was greater than the value of the control group. At T2, the treatment group value increased and the difference between the values became larger. This difference gradually became smaller through T4 until the treatment group value was only slightly greater than the control group value. At T5, the treatment group value once again became greater than the control group value.

Is/NL Initially, the value of Is/NL in the treatment group was slightly lower than the value of the control group. At T2, the treatment group value decreased and the difference between the values became larger. This difference gradually became smaller through T4 until the treatment group value was very similar to the control group value. The values remained similar through T5.

Ii/ML Initially, the values of Ii/ML in the treatment group and the control group were very similar. At T2, the value of the treatment group became larger than the value of the control group. At T3, the value of the treatment group decreased to a level only slightly higher than the value of the control group. At T4, the treatment group value increased again and remained at this level through T5.

Condyle/Glenoid Fossa Variables

OLp-CoC Initially, the value of OLp-CoC in the treatment group was slightly larger than the value in the control group. At T2, the treatment group value increased and the difference between the values became larger. This difference remained fairly consistent through T5.

Comparison of the Treated Group vs. the Control Group

Treatment effects of the edgewise crowned Herbst appliance in the mixed dentition and the long term stability of these effects in the treatment group were compared with an untreated control sample. The differences between certain time points were analyzed to investigate: **T2-T1**: treatment effects of the Herbst appliance (Tx (T2-T1)) minus (Control (t2-t1)), **T3-T1**: Phase I treatment effects (Tx (T3-T1)) minus (Control (t3-t1)), **T4-T1**: residual Phase I treatment effects (Tx (T4-T1)) minus (Control (t4-t1)), and **T5-T1** combined Phase I and Phase II treatment effects (Tx (T5-T1)) minus (Control (t5-t1)). In addition, **T5-T4**: phase II treatment effects (Tx (T5-T4)) minus (Control (t5-t4)) were evaluated as well as **T4-T3**: the relapse that occurred from after Phase I treatment to before Phase II treatment (Tx (T4-T3)) minus (Control (t4-t3)).

For all time periods, the change in the values of the variables for pooled subjects, male subjects, and female subjects in the treatment group were compared to the change in the values of the variables for pooled subjects, male subjects, and female subjects in the control group, respectively. In total, 37 variables were evaluated for each group including sagittal variables, vertical variables, angular variables, and condyle/glenoid fossa variables. In addition, an evaluation of the overjet correction and molar relationship correction for the treatment groups and an evaluation of the net overjet correction and net molar relationship correction for the treatment vs. control groups at each time period for pooled subjects were performed.

Comparison of T2-T1 (Treatment Effects of the Herbst Appliance)

Of the 37 variables investigated, 19 showed statistically significant differences between the treatment group and control group in pooled subjects in the time period T2-T1 (Table 17). The majority of the sagittal and angular variables showed significant differences, however, only two of the vertical variables showed significant differences. Only two of the condyle/glenoid fossa variables showed significant differences. Significance differences in variables are apparent for male subjects only and female subjects only and are reported in Tables 18 and 19, respectively. Only data from pooled subjects is reported here.

Sagittal differences: All sagittal variables showed a significant difference between the treatment and control groups except for OLp-A pt., OLp-Pg, and Co-Gn. The position of the maxillary base (OLp-A pt.) in the treatment group moved forward 1.0 mm from its original position and although it was not significant, the maxillary base was restricted 0.4 mm in the treatment group relative to the control group. The position of the mandibular base (OLp-Pg) moved forward 2.8 mm from its original position and although it was not significant, the mandibular base in the treatment group moved forward 2.0 mm relative to the control group. The position of the condyle (OLp-Co) moved anteriorly 1.5 mm in the treatment group relative to the control group. Effective maxillary length (Co-A pt.) and mandibular length (Co-Gn) showed a -2.6 mm and a 0.7 mm difference from the control group, respectively. The difference in effective mandibular length was not significant. The difference between the effective maxillary and mandibular length (Co-Gn minus Co-A pt.) between the treatment and control groups was significant with a 2.6 mm difference. The position of the maxilla relative to the

mandible along the functional occlusal plane (Wits) showed a difference of -3.7 mm for the treatment group. The position of the maxillary incisor (Is-OLp) in the treatment group moved backwards 1.6 mm while the control group moved forwards 2.5 mm, a net difference of 4.1 mm in a posterior direction. The mandibular incisors (Ii-OLp) moved forward 4.8 mm in the treatment group and only 1.9 mm in the control group, a net difference of 2.9 mm in an anterior direction. The maxillary molars (Ms-OLp) moved posteriorly 1.9 mm in the treatment group and 1.6 mm anteriorly in the control group, a net difference of -3.5 mm in the treatment group. The mandibular molars (Mi-OLp) moved forward 4.8 mm in the treatment group and 1.7 mm forward in the control group, a net difference of 3.1 mm in an anterior direction.

Vertical differences: All vertical variables showed no significant difference between the treatment and control groups at T2-T1 except for Ii-ML and Msc-NL. The lower incisor (Ii-ML) was intruded significantly showing 0.8 mm of downward movement in the treatment group compared to 1.0 mm of upward movement in the control group, a net intrusion of 1.8 mm. The maxillary molar was also intruded significantly showing 1.3 mm of upward movement in the treatment group compared to 1.3 mm of downward movement in the control group, a net intrusion of 2.6 mm.

Angular differences: Significant differences in the angular variables between the control and treatment groups were found in ANB, SNL-NL, SNL-OL, Is/NL, and Ii/ML. A net decrease in ANB of 2.0 ° was found in the treatment group relative to the control groups. A net increase of 1.7 ° and 2.8 ° in the treatment group was found in the palatal plane angle (SNL-NL) and the functional occlusal plane angle (SNL-OL), respectively. The maxillary incisor proclination (Is/NL) had a net decrease of 7.0 ° in the treatment

group compared to the control group, however the mandibular incisor angle (Ii/ML) experienced a net increase of 7.6 ° in the treatment group.

Condyle/Glenoid Fossa differences: Only two condyle/glenoid fossa variables showed significant differences between the treatment and control groups; OLp-CoC and OLp-GFA. Although not all significant, every sagittal condyle/glenoid fossa variable (OLp-CoC, OLp-GFS, OLp-GFA, and OLp-GFP) showed a forward movement in the treatment group and a backward movement in the control group. Net anterior movements of 1.7 mm, 1.0 mm, 2.1 mm, and 1.6 mm were found in the treatment group relative to the control group for the condylar position (OLp-CoC), the superior aspect of the glenoid fossa (OLp-GFS), the anterior aspect of the glenoid fossa (OLp-GFA), and the posterior aspect of the glenoid fossa (OLp-GFP). No significant differences were found in the vertical condyle/glenoid fossa variables between the treatment and control groups.

Table 17. Comparison of treated vs. control in pooled subjects at T2-T1

POOLED (MALES AND FEMALES)							
Variable	Control (t2-t1)		Treated (T2-T1)		Diff.	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	13.5	6.9	12.2	6.8	-1.3	0.6304	NS
Sagittal:							
1. Olp-A pt.	1.4	0.6	1.0	1.9	-0.5	0.4206	NS
2. Olp-Pg	0.8	2.8	2.8	3.5	2.0	0.1221	NS
3. Olp-Co	0.7	1.6	-0.8	1.9	-1.5	0.0396	*
4. Co-A pt.	2.1	1.7	-0.5	3.4	-2.6	0.0205	*
5. Co-Gn	2.7	2.5	3.4	2.3	0.7	0.4778	NS
6. Co-Gn minus Co-A pt.	0.6	2.1	3.2	2.9	2.6	0.0159	*
7. Wits	-0.7	1.6	-4.4	3.0	-3.7	0.0009	*
8. Is-Olp	2.5	1.9	-1.6	4.5	-4.0	0.0065	*
9. li-Olp	1.9	1.5	4.8	3.0	3.0	0.0041	*
10. Overjet	0.6	1.6	-6.4	3.9	-6.9	0.0001	*
11. Ms-Olp	1.6	1.3	-1.9	2.2	-3.4	0.0001	*
12. Mi-Olp	1.7	1.4	4.8	1.9	3.1	0.0001	*
13. Molar Relationship	-0.2	0.9	-6.6	2.8	-6.4	0.0001	*
Vertical:							
14. OLs-A pt.	1.4	1.2	2.0	1.6	0.6	0.3174	NS
15. ANS-Me	1.7	1.4	1.3	1.7	-0.4	0.5006	NS
16. Is-NL	1.8	3.1	0.9	3.0	-0.9	0.4766	NS
17. li-ML	1.0	0.8	-0.8	2.5	-1.8	0.0175	*
18. Overbite	1.3	2.9	-1.1	3.6	-2.4	0.0821	NS
19. Msc-NL	1.3	2.0	-1.3	1.2	-2.7	0.0005	*
20. Mic-ML	0.6	1.0	1.2	1.3	0.7	0.1517	NS
Angular:							
21. SNA	0.6	1.4	-0.3	2.4	-1.0	0.2269	NS
22. SNB	0.6	1.6	1.6	2.1	1.0	0.1745	NS
23. ANB	0.0	1.2	-2.0	2.4	-2.0	0.0141	*
24. SNL-NL	-0.7	2.0	1.0	1.8	1.7	0.0283	*
25. SNL-ML	-0.1	1.8	0.1	1.6	0.2	0.7347	NS
26. SNL-OL	0.6	2.1	3.4	3.8	2.8	0.0306	*
27. Is/NL	-0.3	3.4	-7.3	7.3	-7.0	0.0043	*
28. li/ML	-0.5	2.8	7.1	6.9	7.6	0.0012	*
29. Interincisal Angle	-0.8	6.0	1.4	9.4	2.2	0.4922	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	-0.5	1.6	1.2	1.7	1.6	0.0206	*
31. Olp-GFS	-0.1	1.7	0.9	1.8	1.0	0.1583	NS
32. Olp-GFA	-0.5	1.7	1.6	1.8	2.1	0.0118	*
33. Olp-GFP	-0.3	2.0	1.3	2.5	1.6	0.0841	NS
34. Ols-CoC	1.1	1.3	0.5	1.6	-0.6	0.2832	NS
35. Ols-GFS	0.5	1.2	0.5	1.5	0.0	0.9293	NS
36. Ols-GFA	0.5	1.0	0.2	1.3	-0.2	0.5962	NS
37. Ols-GFP	0.2	1.2	0.0	1.7	-0.1	0.8123	NS

Table 18. Comparison of treated vs. control in male subjects at T2-T1.

MALE SUBJECTS							
Variable	Control (t2-t1)		Treated (T2-T1)		Diff	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	11.0	2.0	10.1	3.4	-0.9	0.5000	NS
Sagittal:							
1. Olp-A pt.	1.2	0.7	0.4	1.0	-0.8	0.1274	NS
2. Olp-Pg	-0.4	3.1	2.8	4.0	3.2	0.1186	NS
3. Olp-Co	0.1	1.5	-0.6	2.2	-0.7	0.4585	NS
4. Co-A pt.	1.3	1.4	-1.5	3.9	-2.8	0.1008	NS
5. Co-Gn	1.4	2.0	3.6	2.2	2.2	0.0841	NS
6. Co-Gn minus Co-A pt.	0.1	2.4	3.8	2.7	3.7	0.0213	*
7. Wits	-0.3	1.9	-5.4	2.9	-5.1	0.0042	*
8. Is-Olp	2.2	0.9	-3.0	2.8	-5.2	0.0006	*
9. li-Olp	1.3	1.3	5.0	1.8	3.7	0.0012	*
10. Overjet	0.8	1.3	-8.1	3.2	-8.9	0.0001	*
11. Ms-Olp	0.9	0.9	-2.4	1.4	-3.3	0.0003	*
12. Mi-Olp	1.1	1.2	5.1	1.7	4.0	0.0004	*
13. Molar Relationship	-0.3	1.1	-7.5	2.1	-7.2	0.0001	*
Vertical:							
14. OLs-A pt.	0.9	0.6	2.2	1.1	1.3	0.0316	*
15. ANS-Me	1.9	1.7	2.0	1.8	0.1	0.9706	NS
16. Is-NL	1.4	2.9	1.0	2.2	-0.4	0.8006	NS
17. li-ML	0.8	0.6	-1.8	2.1	-2.6	0.0088	*
18. Overbite	0.7	2.4	-2.6	1.6	-3.3	0.0115	*
19. Msc-NL	0.8	1.7	-1.3	1.2	-2.1	0.0171	*
20. Mic-ML	0.5	0.9	1.5	1.3	1.0	0.1294	NS
Angular:							
21. SNA	0.0	0.7	-1.4	1.4	-1.4	0.0336	*
22. SNB	0.0	0.9	1.2	1.8	1.2	0.1244	NS
23. ANB	0.0	1.2	-2.7	2.2	-2.7	0.0132	*
24. SNL-NL	-0.9	1.9	1.0	2.0	1.9	0.0939	NS
25. SNL-ML	0.5	1.6	0.2	1.7	-0.3	0.8169	NS
26. SNL-OL	0.5	2.3	4.4	3.6	3.9	0.0340	*
27. Is/NL	0.5	3.6	-10.5	7.5	-11.0	0.0045	*
28. li/ML	-0.3	2.1	7.3	7.9	7.6	0.0300	*
29. Interincisal Angle	-1.7	5.4	4.0	9.4	5.7	0.1856	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	0.0	1.5	1.1	2.0	1.1	0.2742	NS
31. Olp-GFS	0.5	1.6	0.7	1.8	0.2	0.7930	NS
32. Olp-GFA	0.1	1.4	0.8	1.1	0.7	0.3964	NS
33. Olp-GFP	0.2	1.8	1.5	2.6	1.3	0.3186	NS
34. Ols-CoC	0.8	1.0	0.9	1.3	0.1	0.9402	NS
35. Ols-GFS	0.4	1.4	0.5	1.4	0.1	0.9975	NS
36. Ols-GFA	0.5	1.1	-0.1	1.0	-0.6	0.2870	NS
37. Ols-GFP	0.3	1.1	-0.7	1.1	-1.0	0.1023	NS

Table 19. Comparison of treated vs. control in female subjects at T2-T1.

FEMALE SUBJECTS							
Variable	Control (t2-t1)		Treated (T2-T1)		Diff.	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	16.3	9.5	14.5	9.2	-1.8	0.7413	NS
Sagittal:							
1. Olp-A pt.	1.6	0.4	1.5	2.5	-0.1	0.9555	NS
2. Olp-Pg	2.3	1.4	2.8	3.0	0.5	0.7242	NS
3. Olp-Co	1.2	1.6	-1.0	1.6	-2.2	0.0314	*
4. Co-A pt.	3.0	1.5	0.6	2.3	-2.4	0.0708	NS
5. Co-Gn	4.1	2.4	3.1	2.4	-1.0	0.4847	NS
6. Co-Gn minus Co-A pt.	1.1	1.7	2.4	3.1	1.3	0.3941	NS
7. Wits	-1.0	1.1	-3.1	2.6	-2.1	0.1091	NS
8. Is-Olp	2.7	2.6	0.1	5.7	-2.6	0.3401	NS
9. li-Olp	2.4	1.5	4.5	4.2	2.1	0.2666	NS
10. Overjet	0.2	1.8	-3.2	3.3	-3.4	0.0575	NS
11. Ms-Olp	2.3	1.3	-1.2	2.9	-3.5	0.0230	*
12. Mi-Olp	2.3	1.3	4.3	2.1	2.0	0.0809	NS
13. Molar Relationship	0.0	0.5	-5.6	3.3	-5.6	0.0025	*
Vertical:							
14. OLs-A pt.	1.8	1.5	1.6	2.0	-0.2	0.8362	NS
15. ANS-Me	1.3	0.9	0.3	0.9	-1.0	0.1241	NS
16. Is-NL	2.1	3.4	0.7	3.8	-1.4	0.5135	NS
17. li-ML	1.2	0.9	0.3	2.3	-0.9	0.4368	NS
18. Overbite	2.0	3.3	1.5	4.9	-0.5	0.8634	NS
19. Msc-NL	1.8	2.3	-1.3	1.3	-3.1	0.0176	*
20. Mic-ML	0.6	1.1	0.8	1.1	0.2	0.7321	NS
Angular:							
21. SNA	1.2	1.6	0.9	2.8	-0.3	0.8107	NS
22. SNB	1.3	1.8	2.0	2.4	0.7	0.6053	NS
23. ANB	0.0	1.2	-1.0	2.4	-1.0	0.3976	NS
24. SNL-NL	-0.5	2.3	1.0	1.5	1.5	0.2122	NS
25. SNL-ML	-0.8	1.9	0.0	1.5	0.8	0.4708	NS
26. SNL-OL	0.7	2.0	2.1	3.8	1.4	0.4484	NS
27. Is/NL	-1.3	3.0	-3.6	5.2	-2.3	0.3747	NS
28. li/ML	-0.5	3.6	6.8	6.0	7.3	0.0287	*
29. Interincisal Angle	0.3	7.0	-1.7	8.9	-2.0	0.6644	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	-1.0	1.6	1.2	1.4	2.2	0.0330	*
31. Olp-GFS	-0.7	1.7	1.1	1.8	1.8	0.1022	NS
32. Olp-GFA	-1.0	1.8	2.6	2.0	3.6	0.0156	*
33. Olp-GFP	-0.9	2.0	0.9	2.4	1.8	0.1670	NS
34. Ols-CoC	1.3	1.6	0.0	1.7	-1.3	0.1819	NS
35. Ols-GFS	0.5	0.9	0.5	1.5	0.0	0.8981	NS
36. Ols-GFA	0.3	0.9	0.5	1.4	0.2	0.7481	NS
37. Ols-GFP	0.0	1.4	0.9	1.8	0.9	0.3500	NS

Overjet and Molar Relationship Correction-Treatment Group (T2-T1)

The amount of skeletal and dental contribution to the overjet and molar relationship correction in the treatment group at T2-T1 was calculated using the formulas in Table 11. The amount of overjet correction in the treatment group was 6.4 mm. 1.8 mm (28.1%) of the correction was due to skeletal correction. 4.6 mm (71.9%) of the correction was due to dental correction. The amount of molar relationship correction was 6.7 mm. 1.8 mm (26.9%) of the correction was skeletal in nature and 4.9 mm (73.1%) of the correction was dental in nature. Calculations are shown for the overjet and molar relationship correction on the following pages. In addition, diagrams are provided to illustrate the anterior or posterior movement of the maxillary base, mandibular base, maxillary incisors, mandibular incisors, maxillary molars, and mandibular molars (Figures 11 and 12). A pitchfork analysis describing the skeletal and dental contributions to overjet and molar relationship correction is shown in Figure 13.

<u>Overjet Correction:</u>		<u>Molar relationship:</u>	
Skeletal Contribution:		Skeletal Contribution:	
1) Maxilla	1.0	1) Maxilla	1.0
2) Mandible	2.8	2) Mandible	2.8
Dental Contribution:		Dental Contribution:	
3) Mx incisor	-2.6	3) Mx molar	-2.9
4) Md incisor	2.0	4) Md molar	2.0

$$\text{Overjet Correction} = \text{Maxilla} + \text{Mx incisor} - \text{Mandible} - \text{Md incisor}$$

$$\text{Overjet Correction} = 1.0 + (-2.6) - 2.8 - 2.0 = -6.4 \text{ mm}$$

Figure 11. Components of overjet correction (T2-T1)

$$\text{Molar Relationship Correction} = \text{Maxilla} + \text{Mx molar} - \text{Mandible} - \text{Md molar}$$

$$\text{Molar Relationship Correction} = 1.0 + (-2.9) - 2.8 - 2.0 = -6.7 \text{ mm}$$

Molar correction
of 6.7 mm
Skeletal contribution
= 1.8 mm
Dental contribution
= 4.9 mm

Figure 12. Components of molar relationship correction (T2-T1)

Figure 13. Pitchfork analysis of overjet and molar correction (T2-T1)

Net Overjet and Molar Relationship Correction-Tx vs. Control Group (T2-T1)

The amount of skeletal and dental contribution to the net overjet and net molar relationship correction in the treatment group vs. the control group at T2-T1 was calculated using the formulas in Table 11. The amount of net overjet correction in the treatment group relative to the control group was 7.0 mm. 2.4 mm (34.3%) of the correction was due to skeletal movement. 4.6 mm (65.7%) of the correction was due to dental movement. The amount of net molar relationship correction was 6.6 mm. 2.4 mm (36.4%) of the correction was skeletal in nature and 4.2 mm (63.6%) of the correction was dental in nature. Calculations are shown for the net overjet and net molar relationship correction on the following pages. In addition, diagrams are provided to illustrate the net anterior or posterior movement of the maxillary base, mandibular base, maxillary incisors, mandibular incisors, maxillary molars, and mandibular molars (Figures 14 and 15). A pitchfork analysis describing the net skeletal and dental contributions to overjet and molar relationship correction is shown in Figure 16.

<u>Net Overjet Correction:</u>		<u>Net Molar relationship:</u>	
Skeletal Contribution:		Skeletal Contribution:	
1) Maxilla	-0.4	1) Maxilla	-0.4
2) Mandible	2.0	2) Mandible	2.0
Dental Contribution:		Dental Contribution:	
3) Mx incisor	-3.7	3) Mx molar	-3.1
4) Md incisor	0.9	4) Md molar	1.1

$$\text{Net Overjet Correction} = \text{Maxilla} + \text{Mx incisor} - \text{Mandible} - \text{Md incisor}$$

$$\text{Net Overjet Correction} = (-0.4) + (-3.7) - 2.0 - 0.9 = -7.0 \text{ mm}$$

Figure 14. Components of net overjet correction (T2-T1)

$$\text{Net Molar Relationship Correction} = \text{Maxilla} + \text{Mx molar} - \text{Mandible} - \text{Md molar}$$

$$\text{Net Molar Relationship Correction} = (-0.4) + (-3.1) - 2.0 - 1.1 = -6.6 \text{ mm}$$

Figure 15. Components of net molar correction (T2-T1)

Figure 16. Pitchfork analysis of net overjet and molar correction (T2-T1)

Comparison of T3-T1 (Phase I Treatment Effects)

Of the 37 variables investigated, 9 showed statistically significant differences between the treatment group and control group in pooled subjects in the time period T3-T1 (Table 20). Six of the sagittal variables showed significant differences, however, only one of each of the vertical, angular, and condyle/fossa variables significant differences between the treatment and control groups. Significance differences in variables are apparent for male subjects only and female subjects only and are reported in Tables 21 and 22, respectively. Only data from pooled subjects is reported here.

Sagittal differences: The six sagittal variables that showed a significant difference between the treatment and control groups at T3-T1 were Co-A pt., Wits analysis, Is-OLp, Overjet, Ms-OLp, and molar relationship. Effective maxillary length (Co-A pt.) showed a -2.0 mm difference from the control group. The position of the maxilla relative to the mandible along the functional occlusal plane (Wits) showed a difference of -1.7 mm for the treatment group. The position of the maxillary incisor (Is-OLp) in the treatment group moved forward 1.0 mm while the control group moved forwards 3.7 mm, a net difference of 2.7 mm in a posterior direction. The maxillary molars (Ms-OLp) moved forward 0.9 mm in the treatment group and 3.1 mm anteriorly in the control group, a net difference of -2.2 mm in the treatment group. Overjet and molar relationship correction will be discussed later.

Vertical differences: All vertical variables showed no significant difference between the treatment and control groups at T3-T1 except Msc-NL. The maxillary molar (Msc-NL) erupted 0.6 mm in the treatment group and 1.7 mm in the control group, a net difference of -1.1 mm.

Angular differences: All angular variables showed no significant difference between the treatment and control groups at T3-T1 except ANB. ANB decreased 1.7 ° in the treatment group and only 0.3 ° in the control group, giving a net decrease of 1.4 °.

Condyle/Glenoid Fossa differences: Only one condyle/glenoid fossa variable, OLp-CoC, showed a significant difference between the treatment and control groups at T3-T1. Although not all significant, once again every sagittal condyle/glenoid fossa variable (OLp-CoC, OLp-GFS, OLp-GFA, and OLp-GFP) showed a forward movement in the treatment group and a backward or only slightly forward movement in the control group. Net anterior movements of 1.2 mm, 1.0 mm, 0.9 mm, and 1.3 mm were found in the treatment group relative to the control group for the condylar position (OLp-CoC), the superior aspect of the glenoid fossa (OLp-GFS), the anterior aspect of the glenoid fossa (OLp-GFA), and the posterior aspect of the glenoid fossa (OLp-GFP). No significant differences were found in the vertical condyle/glenoid fossa variables between the treatment and control groups.

Table 20. Comparison of treated vs. control in pooled subjects at T3-T1

POOLED (MALES AND FEMALES)							
Variable	Control (t3-t1)		Treated (T3-T1)		Diff	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	23.1	7.0	21.3	7.1	-1.8	0.4137	NS
Sagittal:							
1. Olp-A pt.	1.9	0.9	1.2	1.8	-0.7	0.0932	NS
2. Olp-Pg	2.8	2.7	3.4	2.4	0.6	0.5019	NS
3. Olp-Co	0.3	2.1	-0.5	1.8	-0.8	0.1299	NS
4. Co-A pt.	2.3	2.5	0.3	2.9	-2.0	0.0207	*
5. Co-Gn	4.2	2.8	4.1	2.5	-0.1	0.8907	NS
6. Co-Gn minus Co-A pt.	1.8	1.9	3.3	3.2	1.5	0.0739	NS
7. Wits	-0.5	1.1	-2.2	2.5	-1.7	0.0049	*
8. Is-Olp	3.7	1.7	1.0	3.3	-2.7	0.0018	*
9. li-Olp	3.1	1.7	3.5	2.6	0.4	0.5232	NS
10. Overjet	0.6	1.5	-2.5	2.7	-3.1	0.0001	*
11. Ms-Olp	3.1	1.6	0.9	1.9	-2.2	0.0003	*
12. Mi-Olp	3.3	1.8	4.4	2.0	1.1	0.0582	NS
13. Molar Relationship	-0.1	1.0	-3.4	2.3	-3.3	0.0001	*
Vertical:							
14. OLs-A pt.	1.6	1.2	2.3	1.4	0.7	0.1158	NS
15. ANS-Me	1.9	1.1	2.1	1.4	0.2	0.7051	NS
16. Is-NL	2.2	2.3	1.8	2.8	-0.4	0.5621	NS
17. li-ML	1.3	1.0	0.7	2.2	-0.6	0.2741	NS
18. Overbite	1.4	2.5	-0.1	3.3	-1.5	0.0811	NS
19. Msc-NL	1.7	1.8	0.6	1.2	-1.1	0.0175	*
20. Mic-ML	1.3	1.4	1.3	1.3	0.0	0.9558	NS
Angular:							
21. SNA	0.2	1.2	-0.3	2.5	-0.5	0.3549	NS
22. SNB	0.5	1.1	1.4	1.8	0.9	0.0608	NS
23. ANB	-0.3	0.8	-1.7	2.3	-1.4	0.0079	*
24. SNL-NL	-1.0	2.0	-0.6	1.9	0.4	0.4982	NS
25. SNL-ML	-0.6	1.4	-0.1	1.9	0.5	0.3355	NS
26. SNL-OL	-0.4	2.1	0.2	2.4	0.6	0.3603	NS
27. Is/NL	-0.8	4.9	-2.1	4.7	-1.3	0.4035	NS
28. li/ML	0.5	2.6	1.3	7.4	0.8	0.6296	NS
29. Interincisal Angle	-0.1	6.1	1.7	11.1	1.8	0.479	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	-0.2	1.9	1.0	1.8	1.2	0.0227	*
31. Olp-GFS	-0.1	2.5	0.9	2.0	1.0	0.0966	NS
32. Olp-GFA	0.2	1.9	1.1	1.8	0.9	0.1134	NS
33. Olp-GFP	0.0	2.5	1.3	2.6	1.3	0.1006	NS
34. Ols-CoC	1.4	1.7	1.4	1.6	0.0	0.9719	NS
35. Ols-GFS	1.0	1.6	1.0	1.8	0.0	0.9435	NS
36. Ols-GFA	1.0	1.4	0.7	1.5	-0.3	0.5025	NS
37. Ols-GFP	0.7	1.5	0.3	1.3	-0.4	0.4171	NS

Table 21. Comparison of treated vs. control in male subjects at T3-T1

MALE SUBJECTS							
Variable	Control (t3-t1)		Treated (T3-T1)		Diff	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	22.4	3.8	19.7	2.4	-2.7	0.1418	NS
Sagittal:							
1. Olp-A pt.	1.7	0.5	1.5	1.9	-0.2	0.7745	NS
2. Olp-Pg	1.3	4.1	3.3	3.0	2.0	0.3478	NS
3. Olp-Co	0.4	2.3	-0.1	1.8	-0.5	0.5958	NS
4. Co-A pt.	2.1	2.5	0.2	4.0	-1.9	0.3108	NS
5. Co-Gn	4.2	2.3	5.2	2.4	1.0	0.4326	NS
6. Co-Gn minus Co-A pt.	2.0	2.7	3.6	3.2	1.6	0.3288	NS
7. Wits	-0.2	1.4	-2.7	2.7	-2.5	0.0551	NS
8. Is-Olp	3.8	1.6	-0.7	2.3	-4.5	0.0013	*
9. li-Olp	2.9	2.2	3.8	2.2	0.9	0.4787	NS
10. Overjet	0.9	1.4	-4.5	1.7	-5.4	0.0001	*
11. Ms-Olp	2.7	2.0	0.2	1.8	-2.5	0.0326	*
12. Mi-Olp	2.8	2.6	4.7	2.2	1.9	0.1773	NS
13. Molar Relationship	-0.1	1.7	-4.5	2.1	-4.4	0.0013	*
Vertical:							
14. OLs-A pt.	1.4	0.8	2.9	0.7	1.5	0.0047	*
15. ANS-Me	2.4	1.6	2.6	0.9	0.2	0.8173	NS
16. Is-NL	2.1	2.3	0.7	2.3	-1.4	0.2937	NS
17. li-ML	1.8	1.1	-0.3	1.8	-2.1	0.0256	*
18. Overbite	1.0	1.7	-2.0	1.9	-3.0	0.0087	*
19. Msc-NL	1.4	2.2	0.7	0.9	-0.7	0.4904	NS
20. Mic-ML	1.5	0.8	2.1	0.9	0.6	0.2505	NS
Angular:							
21. SNA	-0.3	0.9	-0.5	2.1	-0.2	0.8762	NS
22. SNB	0.0	0.9	1.2	1.7	1.2	0.1089	NS
23. ANB	-0.2	1.0	-1.7	2.7	-1.5	0.2207	NS
24. SNL-NL	-1.7	2.1	0.5	1.1	2.2	0.0304	*
25. SNL-ML	-0.2	1.1	0.0	1.2	0.2	0.5917	NS
26. SNL-OL	-0.2	1.7	1.2	2.6	1.4	0.2310	NS
27. Is/NL	1.1	4.5	-4.9	2.2	-6.0	0.0081	*
28. li/ML	1.0	2.6	2.2	10.4	1.2	0.7698	NS
29. Interincisal Angle	-4.0	4.8	3.5	10.7	7.5	0.1136	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	-0.4	1.9	0.6	1.9	1.0	0.2935	NS
31. Olp-GFS	0.1	2.5	0.7	1.6	0.6	0.5932	NS
32. Olp-GFA	0.2	1.9	0.8	1.8	0.6	0.5992	NS
33. Olp-GFP	0.4	2.8	0.8	2.5	0.4	0.8194	NS
34. Ols-CoC	1.1	1.4	0.8	1.4	-0.3	0.7053	NS
35. Ols-GFS	0.9	1.6	0.0	1.8	-0.9	0.3843	NS
36. Ols-GFA	0.8	1.5	0.0	1.3	-0.8	0.2660	NS
37. Ols-GFP	0.2	1.8	-0.4	1.0	-0.6	0.3743	NS

Table 22. Comparison of treated vs. control in female subjects at T3-T1

FEMALE SUBJECTS							
Variable	Control (t3-t1)		Treated (T3-T1)		Diff	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	23.4	8.2	22.1	8.5	-1.3	0.6668	NS
Sagittal:							
1. Olp-A pt.	2.1	1.0	1.0	1.9	-1.1	0.0803	NS
2. Olp-Pg	3.5	1.6	3.4	2.2	-0.1	0.8811	NS
3. Olp-Co	0.3	2.0	-0.6	1.9	-0.9	0.1534	NS
4. Co-A pt.	2.4	2.6	0.4	2.5	-2.0	0.0375	*
5. Co-Gn	4.2	3.0	3.5	2.4	-0.7	0.5310	NS
6. Co-Gn minus Co-A pt.	1.7	1.5	3.1	3.3	1.4	0.1513	NS
7. Wits	-0.6	1.0	-2.0	2.4	-1.4	0.0511	NS
8. Is-Olp	3.6	1.7	1.8	3.5	-1.8	0.0848	NS
9. li-Olp	3.2	1.5	3.4	2.9	0.2	0.7904	NS
10. Overjet	0.4	1.6	-1.6	2.6	-2.0	0.0160	*
11. Ms-Olp	3.3	1.5	1.3	2.0	-2.0	0.0039	*
12. Mi-Olp	3.5	1.5	4.3	1.9	0.8	0.2161	NS
13. Molar Relationship	-0.1	0.7	-2.9	2.2	-2.8	0.0001	*
Vertical:							
14. Ols-A pt.	1.7	1.4	2.0	1.5	0.3	0.6332	NS
15. ANS-Me	1.7	0.3	1.9	0.3	0.2	0.7627	NS
16. Is-NL	2.3	2.4	2.3	3.0	0.0	0.9703	NS
17. li-ML	1.1	0.8	1.2	2.3	0.1	0.8463	NS
18. Overbite	1.6	2.8	0.7	3.4	-0.9	0.4504	NS
19. Msc-NL	1.9	1.6	0.5	1.3	-1.4	0.0184	*
20. Mic-ML	1.1	1.7	0.9	1.3	-0.2	0.6812	NS
Angular:							
21. SNA	0.4	1.2	-0.3	2.8	-0.7	0.3438	NS
22. SNB	0.8	1.1	1.5	2.0	0.7	0.2319	NS
23. ANB	-0.3	0.8	-1.8	2.2	-1.5	0.0204	*
24. SNL-NL	-0.7	1.9	-1.2	2.0	-0.5	0.5241	NS
25. SNL-ML	-0.8	1.5	-0.2	2.2	0.6	0.4238	NS
26. SNL-OL	-0.5	2.3	-0.2	2.2	0.3	0.7827	NS
27. Is/NL	-1.8	4.9	-0.8	5.0	1.0	0.5756	NS
28. li/ML	0.3	2.6	0.9	6.0	0.6	0.7124	NS
29. Interincisal Angle	1.6	5.9	0.9	11.5	-0.7	0.8363	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	-0.2	2.0	1.2	1.8	1.4	0.0483	*
31. Olp-GFS	-0.3	2.5	1.1	2.2	1.4	0.1171	NS
32. Olp-GFA	0.2	2.0	1.3	1.8	1.1	0.1340	NS
33. Olp-GFP	-0.1	2.5	1.6	2.7	1.7	0.0736	NS
34. Ols-CoC	1.5	1.8	1.7	1.6	0.2	0.8646	NS
35. Ols-GFS	1.1	1.7	1.4	1.7	0.3	0.5918	NS
36. Ols-GFA	1.1	1.4	1.1	1.4	0.0	0.9732	NS
37. Ols-GFP	0.9	1.4	0.7	1.2	-0.2	0.7327	NS

Overjet and Molar Relationship Correction-Treatment Group (T3-T1)

The amount of skeletal and dental contribution to the overjet and molar relationship correction in the treatment group at T3-T1 was calculated using the formula in Table 11. The amount of overjet correction in the treatment group was 2.5 mm. 2.2 mm (88.0%) of the correction was due to skeletal change. 0.3 mm (12.0%) of the correction was due to dental change. The amount of molar relationship correction was 3.5 mm. 2.2 mm (62.9%) of the correction was skeletal in nature and 1.3 mm (37.1%) of the correction was dental in nature. Calculations are shown for the overjet and molar relationship correction on the following pages. In addition, diagrams are provided to illustrate the anterior or posterior movement of the maxillary base, mandibular base, maxillary incisors, mandibular incisors, maxillary molars, and mandibular molars (Figures 17 and 18). A pitchfork analysis describing the skeletal and dental contributions to overjet and molar relationship correction is shown in Figure 19.

<u>Overjet Correction:</u>		<u>Molar relationship:</u>	
Skeletal Contribution:		Skeletal Contribution:	
1) Maxilla	1.2	1) Maxilla	1.2
2) Mandible	3.4	2) Mandible	3.4
Dental Contribution:		Dental Contribution:	
3) Mx incisor	-0.2	3) Mx molar	-0.3
4) Md incisor	0.1	4) Md molar	1.0

$$\text{Overjet Correction} = \text{Maxilla} + \text{Mx incisor} - \text{Mandible} - \text{Md incisor}$$

$$\text{Overjet Correction} = 1.2 + (-0.2) - 3.4 - 0.1 = -2.5 \text{ mm}$$

Figure 17. Components of overjet correction (T3-T1)

$$\text{Molar Relationship Correction} = \text{Maxilla} + \text{Mx molar} - \text{Mandible} - \text{Md molar}$$

$$\text{Molar Relationship Correction} = 1.2 + (-0.3) - 3.4 - 1.0 = -3.5\text{mm}$$

Molar correction
of 3.5 mm
Skeletal contribution
= 2.2 mm
Dental contribution
= 1.3 mm

Figure 18. Components of molar relationship correction (T3-T1)

Figure 19. Pitchfork analysis of overjet and molar corrections (T3-T1)

Net Overjet and Molar Relationship Correction-Tx vs. Control Group (T3-T1)

The amount of skeletal and dental contribution to the net overjet and net molar relationship correction in the treatment group vs. the control group at T3-T1 was calculated using the formulas in Table 11. The amount of net overjet correction in the treatment group relative to the control group was 3.1 mm. 1.3 mm (41.9%) of the correction was due to skeletal movement. 1.8 mm (58.1%) of the correction was due to dental movement. The amount of net molar relationship correction was 3.3 mm. 1.3 mm (39.4%) of the correction was skeletal in nature and 2.0 mm (60.6%) of the correction was dental in nature. Calculations are shown for the net overjet and net molar relationship correction on the following pages. In addition, diagrams are provided to illustrate the net anterior or posterior movement of the maxillary base, mandibular base, maxillary incisors, mandibular incisors, maxillary molars, and mandibular molars (Figures 20 and 21). A pitchfork analysis describing the net skeletal and dental contributions to overjet and molar relationship correction is shown in Figure 22.

<u>Net Overjet Correction:</u>		<u>Net Molar relationship:</u>	
Skeletal Contribution:		Skeletal Contribution:	
1) Maxilla	-0.7	1) Maxilla	-0.7
2) Mandible	0.6	2) Mandible	0.6
Dental Contribution:		Dental Contribution:	
3) Mx incisor	-2.0	3) Mx molar	-1.5
4) Md incisor	-0.2	4) Md molar	0.5

$$\text{Net Overjet Correction} = \text{Maxilla} + \text{Mx incisor} - \text{Mandible} - \text{Md incisor}$$

$$\text{Net Overjet Correction} = (-0.7) + (-2.0) - 0.6 - (-0.2) = -3.1 \text{ mm}$$

Figure 20. Components of net overjet correction (T3-T1)

$$\text{Net Molar Relationship Correction} = \text{Maxilla} + \text{Mx molar} - \text{Mandible} - \text{Md molar}$$

$$\text{Net Molar Relationship Correction} = (-0.7) + (-1.5) - 0.6 - 0.5 = -3.3 \text{ mm}$$

Molar correction
of 3.3 mm
Skeletal contribution
= 1.3 mm
Dental contribution
= 2.0 mm

Figure 21. Components of net molar correction (T3-T1)

Figure 22. Pitchfork analysis of net overjet and molar correction (T2-T1)

Comparison of T4-T1 (Residual Phase I Treatment Effects)

Of the 37 variables investigated, 13 showed statistically significant differences between the treatment group and control group in pooled subjects in the time period T4-T1 (Table 23). Seven of the sagittal variables showed significant differences, however, only one of each of the vertical and angular variables had significant differences between the treatment and control groups. Four condyle/fossa variables showed significant differences between the treatment and control groups. Significance differences in variables are apparent for male subjects only and female subjects only and are reported in Tables 24 and 25, respectively. Only data from pooled subjects is reported here.

Sagittal differences: The seven sagittal variables that showed a significant difference between the treatment and control groups at T4-T1 were OLp-Co, Co-A pt., Co-Gn , Is-OLp, Overjet, Ms-OLp, and molar relationship. The position of the condyle (OLp-Co) moved anteriorly 1.6 mm in the treatment group relative to the control group. Effective maxillary length (Co-A pt.) and mandibular length (Co-Gn) showed a -3.0 mm and a -2.6 mm difference from the control group, respectively. The position of the maxillary incisor (Is-OLp) in the treatment group moved forwards 5.1 mm while the control group moved forwards 7.2 mm, a net difference of 2.1 mm in a posterior direction. The maxillary molars (Ms-OLp) moved forward 4.4 mm in the treatment group and 7.4 mm anteriorly in the control group, a net difference of -3.0 mm in the treatment group. Overjet and molar relationship correction will be discussed in a later section.

Table 23. Comparison of treated vs. control in pooled subjects at T4-T1

POOLED (MALES AND FEMALES)							
Variable	Control (t4-t1)		Treated (T4-T1)		Diff	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	55.4	15.1	53.7	15.2	-1.6	0.7219	NS
Sagittal:							
1. Olp-A pt.	4.5	1.7	3.6	2.7	-0.9	0.1916	NS
2. Olp-Pg	6.9	2.8	6.4	3.5	-0.5	0.5671	NS
3. Olp-Co	1.7	2.4	0.1	2.5	-1.6	0.0372	*
4. Co-A pt.	6.4	3.0	3.4	4.4	-3.0	0.0125	*
5. Co-Gn	10.6	3.1	8.0	4.4	-2.5	0.0327	*
6. Co-Gn minus Co-A pt.	4.2	2.4	4.3	3.5	0.0	0.9827	NS
7. Wits	-0.8	1.3	-0.8	2.0	0.0	0.9598	NS
8. Is-Olp	7.2	2.3	5.1	3.8	-2.1	0.0332	*
9. li-Olp	6.5	2.0	6.9	3.7	0.4	0.6815	NS
10. Overjet	0.6	1.7	-1.8	2.2	-2.4	0.0002	*
11. Ms-Olp	7.4	2.5	4.4	2.7	-3.0	0.0004	*
12. Mi-Olp	7.7	2.8	7.1	3.0	-0.6	0.5011	NS
13. Molar Relationship	-0.4	1.1	-2.7	1.8	-2.3	0.0001	*
Vertical:							
14. OLs-A pt.	3.4	1.7	4.1	1.5	0.7	0.1590	NS
15. ANS-Me	5.3	2.3	3.6	3.2	-1.7	0.0505	NS
16. Is-NL	3.5	2.7	2.6	3.0	-0.9	0.2604	NS
17. li-ML	3.3	1.8	2.6	2.0	-0.7	0.2338	NS
18. Overbite	1.5	2.9	0.6	3.2	-0.9	0.3300	NS
19. Msc-NL	3.7	2.2	2.3	2.0	-1.4	0.0264	*
20. Mic-ML	2.6	1.5	2.2	1.7	-0.4	0.3738	NS
Angular:							
21. SNA	0.8	1.8	0.1	3.3	-0.7	0.3883	NS
22. SNB	1.4	1.5	1.7	2.6	0.3	0.5800	NS
23. ANB	-0.5	1.0	-1.6	1.6	-1.1	0.0131	*
24. SNL-NL	-1.5	2.0	-0.7	3.0	0.8	0.3251	NS
25. SNL-ML	-1.3	2.2	-1.6	2.8	-0.3	0.6326	NS
26. SNL-OL	-1.4	2.2	-2.5	3.3	-1.1	0.2087	NS
27. Is/NL	-1.1	5.6	0.6	6.1	1.7	0.6416	NS
28. li/ML	1.0	3.8	4.3	7.0	3.3	0.0596	NS
29. Interincisal Angle	-0.1	6.9	-2.6	11.8	-2.5	0.3908	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	-1.5	2.3	0.3	2.1	1.8	0.0099	*
31. Olp-GFS	-1.2	2.7	0.6	2.4	1.8	0.0265	*
32. Olp-GFA	-0.6	2.1	0.7	2.1	1.3	0.0471	*
33. Olp-GFP	-1.2	2.6	0.7	3.4	1.9	0.0389	*
34. Ols-CoC	3.1	2.3	2.8	2.7	-0.3	0.6539	NS
35. Ols-GFS	2.4	2.1	2.2	2.4	-0.2	0.8167	NS
36. Ols-GFA	2.3	1.9	2.0	2.0	-0.3	0.6848	NS
37. Ols-GFP	2.2	1.7	1.7	1.5	-0.5	0.2601	NS

Table 24. Comparison of treated vs. control in male subjects at T4-T1.

MALE SUBJECTS							
Variable	Control (t4-t1)		Treated (T4-T1)		Diff	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	57.1	17.3	55.1	16.9	-2.0	0.8304	NS
Sagittal:							
1. Olp-A pt.	5.1	2.3	5.2	2.9	0.1	0.9682	NS
2. Olp-Pg	6.1	4.3	8.2	2.3	2.1	0.2739	NS
3. Olp-Co	0.7	2.1	1.1	2.7	0.4	0.7552	NS
4. Co-A pt.	5.9	3.3	5.0	6.5	-0.9	0.7520	NS
5. Co-Gn	10.6	3.6	10.8	5.0	0.2	0.9194	NS
6. Co-Gn minus Co-A pt.	4.7	3.1	4.5	3.1	-0.2	0.9283	NS
7. Wits	-0.6	2.0	-1.0	1.4	-0.4	0.7368	NS
8. Is-Olp	7.9	3.4	5.7	2.9	-2.2	0.1963	NS
9. li-Olp	7.3	2.8	9.3	2.9	2.0	0.2136	NS
10. Overjet	0.6	2.5	-3.6	0.7	-4.2	0.0009	*
11. Ms-Olp	7.9	3.0	5.1	2.6	-2.7	0.0840	NS
12. Mi-Olp	8.1	3.7	8.4	3.0	0.3	0.8644	NS
13. Molar Relationship	-0.1	1.7	-3.3	1.6	-3.2	0.0036	*
Vertical:							
14. OLs-A pt.	3.7	1.7	4.2	1.7	0.5	0.5591	NS
15. ANS-Me	6.8	2.0	3.8	3.8	-3.0	0.0917	NS
16. Is-NL	3.7	2.7	1.2	2.7	-2.5	0.1035	NS
17. li-ML	4.1	2.4	1.8	0.9	-2.3	0.0373	*
18. Overbite	1.0	2.7	-1.4	2.4	-2.4	0.0939	NS
19. Msc-NL	3.9	3.1	2.6	2.6	-1.3	0.4033	NS
20. Mic-ML	3.4	1.4	3.9	1.8	0.5	0.8472	NS
Angular:							
21. SNA	0.8	1.5	1.7	2.6	0.9	0.4344	NS
22. SNB	1.1	1.5	2.9	1.7	1.8	0.0618	NS
23. ANB	-0.3	1.5	-1.1	1.6	-0.8	0.3169	NS
24. SNL-NL	-2.0	2.0	0.4	2.1	2.4	0.0494	*
25. SNL-ML	-0.8	2.8	-2.9	2.0	-2.1	0.1232	NS
26. SNL-OL	-0.9	2.2	-2.7	1.7	-1.8	0.0956	NS
27. Is/NL	0.3	5.3	1.0	4.8	0.7	0.7958	NS
28. li/ML	0.6	5.1	7.6	8.6	7.0	0.0848	NS
29. Interincisal Angle	-2.4	6.8	-5.1	9.6	-2.7	0.5433	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	-0.5	1.9	-0.3	2.2	0.2	0.8298	NS
31. Olp-GFS	0.0	2.2	0.6	1.7	0.6	0.6003	NS
32. Olp-GFA	0.1	1.9	0.4	2.7	0.3	0.8331	NS
33. Olp-GFP	0.1	2.5	0.2	2.3	0.1	0.9010	NS
34. Ols-CoC	3.3	2.7	2.2	3.9	-1.1	0.5553	NS
35. Ols-GFS	2.5	3.1	1.5	2.9	-1.0	0.5406	NS
36. Ols-GFA	2.5	2.7	1.1	2.4	-1.4	0.3163	NS
37. Ols-GFP	2.3	2.2	0.7	1.6	-1.6	0.1468	NS

Table 25. Comparison of treated vs. control group in female subjects at T4-T1.

MALE SUBJECTS							
Variable	Control (t4-t1)		Treated (T4-T1)		Diff	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	57.1	17.3	55.1	16.9	-2.0	0.8304	NS
Sagittal:							
1. Olp-A pt.	5.1	2.3	5.2	2.9	0.1	0.9682	NS
2. Olp-Pg	6.1	4.3	8.2	2.3	2.1	0.2739	NS
3. Olp-Co	0.7	2.1	1.1	2.7	0.4	0.7552	NS
4. Co-A pt.	5.9	3.3	5.0	6.5	-0.9	0.7520	NS
5. Co-Gn	10.6	3.6	10.8	5.0	0.2	0.9194	NS
6. Co-Gn minus Co-A pt.	4.7	3.1	4.5	3.1	-0.2	0.9283	NS
7. Wits	-0.6	2.0	-1.0	1.4	-0.4	0.7368	NS
8. Is-Olp	7.9	3.4	5.7	2.9	-2.2	0.1963	NS
9. li-Olp	7.3	2.8	9.3	2.9	2.0	0.2136	NS
10. Overjet	0.6	2.5	-3.6	0.7	-4.2	0.0009	*
11. Ms-Olp	7.9	3.0	5.1	2.6	-2.7	0.0840	NS
12. Mi-Olp	8.1	3.7	8.4	3.0	0.3	0.8644	NS
13. Molar Relationship	-0.1	1.7	-3.3	1.6	-3.2	0.0036	*
Vertical:							
14. OLS-A pt.	3.7	1.7	4.2	1.7	0.5	0.5591	NS
15. ANS-Me	6.8	2.0	3.8	3.8	-3.0	0.0917	NS
16. Is-NL	3.7	2.7	1.2	2.7	-2.5	0.1035	NS
17. li-ML	4.1	2.4	1.8	0.9	-2.3	0.0373	*
18. Overbite	1.0	2.7	-1.4	2.4	-2.4	0.0939	NS
19. Msc-NL	3.9	3.1	2.6	2.6	-1.3	0.4033	NS
20. Mic-ML	3.4	1.4	3.9	1.8	0.5	0.8472	NS
Angular:							
21. SNA	0.8	1.5	1.7	2.6	0.9	0.4344	NS
22. SNB	1.1	1.5	2.9	1.7	1.8	0.0618	NS
23. ANB	-0.3	1.5	-1.1	1.6	-0.8	0.3169	NS
24. SNL-NL	-2.0	2.0	0.4	2.1	2.4	0.0494	*
25. SNL-ML	-0.8	2.8	-2.9	2.0	-2.1	0.1232	NS
26. SNL-OL	-0.9	2.2	-2.7	1.7	-1.8	0.0956	NS
27. Is/NL	0.3	5.3	1.0	4.8	0.7	0.7958	NS
28. li/ML	0.6	5.1	7.6	8.6	7.0	0.0848	NS
29. Interincisal Angle	-2.4	6.8	-5.1	9.6	-2.7	0.5433	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	-0.5	1.9	-0.3	2.2	0.2	0.8298	NS
31. Olp-GFS	0.0	2.2	0.6	1.7	0.6	0.6003	NS
32. Olp-GFA	0.1	1.9	0.4	2.7	0.3	0.8331	NS
33. Olp-GFP	0.1	2.5	0.2	2.3	0.1	0.9010	NS
34. Ols-CoC	3.3	2.7	2.2	3.9	-1.1	0.5553	NS
35. Ols-GFS	2.5	3.1	1.5	2.9	-1.0	0.5406	NS
36. Ols-GFA	2.5	2.7	1.1	2.4	-1.4	0.3163	NS
37. Ols-GFP	2.3	2.2	0.7	1.6	-1.6	0.1468	NS

Overjet and Molar Relationship Correction-Treatment Group (T4-T1)

The amount of skeletal and dental contribution to the overjet and molar relationship correction in the treatment group at T4-T1 was calculated using the formulas in Table 11. The amount of overjet correction in the treatment group was 1.8 mm. 2.8 mm (155.6%) of the correction was due to skeletal change. -1.0 mm (-55.6%) of the correction was due to dental change. The amount of molar relationship correction was 2.7 mm. 2.8 mm (103.7%) of the correction was skeletal in nature and -0.1 mm (-3.7%) of the correction was dental in nature. Calculations are shown for the overjet and molar relationship correction on the following pages. In addition, diagrams are provided to illustrate the anterior or posterior movement of the maxillary base, mandibular base, maxillary incisors, mandibular incisors, maxillary molars, and mandibular molars (Figure 23 and 24). A pitchfork analysis describing the skeletal and dental contributions to overjet and molar relationship correction is shown in Figure 25.

<u>Overjet Correction:</u>		<u>Molar relationship:</u>	
Skeletal Contribution:		Skeletal Contribution:	
1) Maxilla	3.6	1) Maxilla	3.6
2) Mandible	6.4	2) Mandible	6.4
Dental Contribution:		Dental Contribution:	
3) Mx incisor	1.5	3) Mx molar	0.8
4) Md incisor	0.5	4) Md molar	0.7

$$\text{Overjet Correction} = \text{Maxilla} + \text{Mx incisor} - \text{Mandible} - \text{Md incisor}$$

$$\text{Overjet Correction} = 3.6 + 1.5 - 6.4 - 0.5 = -1.8 \text{ mm}$$

Figure 23. Components of overjet correction (T4-T1)

$$\text{Molar Relationship Correction} = \text{Maxilla} + \text{Mx molar} - \text{Mandible} - \text{Md molar}$$

$$\text{Molar Relationship Correction} = 3.6 + 0.8 - 6.4 - 0.7 = -2.7 \text{ mm}$$

Molar correction
of 2.7 mm
Skeletal contribution
= 2.8 mm
Dental contribution
= -0.1 mm

Figure 24. Components of molar relationship correction (T4-T1)

Figure 25. Pitchfork analysis of overjet and molar correction (T4-T1)

Net Overjet and Molar Relationship Correction-Tx vs. Control Group (T4-T1)

The amount of skeletal and dental contribution to the net overjet and net molar relationship correction in the treatment group vs. the control group at T4-T1 was calculated using the formulas in Table 11. The amount of net overjet correction in the treatment group relative to the control group was 2.5 mm. 0.4 mm (16.0%) of the correction was due to skeletal movement. 2.1 mm (84.0%) of the correction was due to dental movement. The amount of net molar relationship correction was 2.4 mm. 0.4 mm (16.7%) of the correction was skeletal in nature and 2.0 mm (83.3%) of the correction was dental in nature. Calculations are shown for the net overjet and net molar relationship correction on the following pages. In addition, diagrams are provided to illustrate the net anterior or posterior movement of the maxillary base, mandibular base, maxillary incisors, mandibular incisors, maxillary molars, and mandibular molars (Figures 26 and 27). A pitchfork analysis describing the net skeletal and dental contributions to overjet and molar relationship correction is shown in Figure 28.

<u>Net Overjet Correction:</u>		<u>Net Molar relationship:</u>	
Skeletal Contribution:		Skeletal Contribution:	
1) Maxilla	-0.9	1) Maxilla	-0.9
2) Mandible	-0.5	2) Mandible	-0.5
Dental Contribution:		Dental Contribution:	
3) Mx incisor	-1.2	3) Mx molar	-2.1
4) Md incisor	0.9	4) Md molar	-0.1

$$\text{Net Overjet Correction} = \text{Maxilla} + \text{Mx incisor} - \text{Mandible} - \text{Md incisor}$$

$$\text{Net Overjet Correction} = (-0.9) + (-1.2) - (-0.5) - 0.9 = -2.5 \text{ mm}$$

Figure 26. Components of net overjet correction (T4-T1)

Net Molar Relationship Correction = Maxilla + Mx molar – Mandible – Md molar

Net Molar Relationship Correction = (-0.9) + (-2.1) – (-0.5) – (-0.1) = -2.4 mm

Figure 27. Components of net molar correction (T4-T1)

Figure 28. Pitchfork analysis of net overjet and molar correction (T4-T1)

Comparison of T5-T1 (Combined Phase I and Phase II Treatment Effects)

Of the 37 variables investigated, 10 showed statistically significant differences between the treatment group and control group in pooled subjects in the time period T5-T1 (Table 26). Seven of the sagittal variables showed significant differences, however, only two of the angular variables, one of the condyle/glenoid fossa variables, and none of the vertical variables showed significant differences between the treatment and control groups. Significance differences in variables are apparent for male subjects only and female subjects only and are reported in Tables 27 and 28, respectively. Only data from pooled subjects is reported here.

Sagittal differences: The seven sagittal variables that showed a significant difference between the treatment and control groups at T5-T1 were OLp-A pt., Co-A pt., Wits analysis, Is-OLp, Overjet, Ms-OLp, and molar relationship. The position of the maxillary base (OLp-A pt.) moved forward 4.3 mm from its original position in the treatment group and in the control group it moved forward 7.1 mm. The maxillary base showed an overall net restriction of 2.8 mm in the treatment group relative to the control group at T5-T1. Effective maxillary length (Co-A pt.) showed a -3.8 mm difference from the control group. The position of the maxilla relative to the mandible along the functional occlusal plane (Wits) showed a difference of -1.6 mm for the treatment group. The position of the maxillary incisor (Is-OLp) in the treatment group moved forward 5.1 mm while the control group moved forwards 9.3 mm, a net difference of 4.2 mm in a posterior direction. The maxillary molars (Ms-OLp) moved forward 6.6 mm in the treatment group and 9.6 mm anteriorly in the control group, a net difference of -3.0 mm

in the treatment group relative to the control group. Overjet and molar relationship correction will be discussed in a later section.

Vertical differences: All vertical variables showed no significant difference between the treatment and control groups at T5-T1.

Angular differences: All angular variables showed no significant difference between the treatment and control groups at T5-T1 except SNA and ANB. A net decrease in SNA of 2.6 ° was found in the treatment group relative to the control group. ANB decreased 2.2 ° in the treatment group and only 0.1 ° in the control group, giving a net decrease of 2.1 °.

Condyle/Glenoid Fossa differences: Only one condyle/glenoid fossa variable, OLS-GFP, showed a significant difference between the treatment and control groups. Although not significant, every sagittal glenoid fossa variable (OLp-GFS, OLp-GFA, and OLp-GFP) showed a forward movement in the treatment group and a backward movement in the control group. The sagittal condyle variable OLp-CoC showed only a slight backward movement of 0.3 mm in the treatment group compared to a greater backward movement of 1.1 mm in the control group. Net anterior movements of 0.8 mm, 0.9 mm, 0.6 mm, and 1.7 mm were found in the treatment group relative to the control group for the condylar position (OLp-CoC), the superior aspect of the glenoid fossa (OLp-GFS), the anterior aspect of the glenoid fossa (OLp-GFA), and the posterior aspect of the glenoid fossa (OLp-GFP), respectively. The posterior aspect of the glenoid fossa (OLS-GFP) showed a significant upward movement in the treatment group relative to the control group. Although not significant, all other vertical condyle/glenoid fossa variables (OLS-CoC, OLS-GFS, and OLS-GFA) showed an overall upward net relative movement

of the treatment group compared to the control group. Net superior movements of 1.3 mm, 0.7 mm, 0.7 mm, and 1.1 mm were found in the treatment group relative to the control group for the condylar position (OLs-CoC), the superior aspect of the glenoid fossa (OLs-GFS), the anterior aspect of the glenoid fossa (OLs-GFA), and the posterior aspect of the glenoid fossa (OLs-GFP), respectively.

Table 26. Comparison of treated vs. control in pooled subjects at T5-T1.

POOLED (MALES AND FEMALES)							
Variable	Control (t5-t1)		Treated (T5-T1)		Diff	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	75.1	15.3	73.8	15.5	-1.3	0.7628	NS
Sagittal:							
1. Olp-A pt.	7.1	2.3	4.3	2.5	-2.8	0.0005	*
2. Olp-Pg	9.5	2.8	7.9	3.8	-1.6	0.1248	NS
3. Olp-Co	1.4	2.3	0.8	2.5	-0.6	0.3788	NS
4. Co-A pt.	8.6	3.1	4.8	3.7	-3.8	0.0006	*
5. Co-Gn	13.5	3.3	11.6	4.3	-1.9	0.0967	NS
6. Co-Gn minus Co-A pt.	5.0	2.6	6.4	3.5	1.4	0.1261	NS
7. Wits	0.0	1.7	-1.6	2.0	-1.6	0.0091	*
8. Is-Olp	9.3	2.7	5.1	4.5	-4.2	0.0004	*
9. li-Olp	8.7	2.2	7.3	3.9	-1.4	0.1735	NS
10. Overjet	0.7	1.6	-2.3	2.8	-3.0	0.0001	*
11. Ms-Olp	9.6	2.9	6.6	2.7	-3.0	0.0008	*
12. Mi-Olp	10.3	3.1	9.5	2.8	-0.8	0.3965	NS
13. Molar Relationship	-0.7	1.1	-2.9	2.0	-2.2	0.0001	*
Vertical:							
14. OLs-A pt.	4.8	2.2	5.2	2.5	0.4	0.6137	NS
15. ANS-Me	6.8	2.4	5.8	3.0	-1.0	0.2234	NS
16. Is-NL	3.9	3.0	3.0	3.4	-0.9	0.3716	NS
17. li-ML	4.5	1.9	3.6	2.3	-0.9	0.1547	NS
18. Overbite	1.7	3.2	0.3	3.2	-1.4	0.1695	NS
19. Msc-NL	4.7	2.0	3.6	2.3	-1.1	0.0834	NS
20. Mic-ML	3.9	2.2	4.1	1.6	0.2	0.7349	NS
Angular:							
21. SNA	1.8	2.3	-0.8	2.9	-2.6	0.0016	*
22. SNB	1.9	2.0	1.4	2.4	-0.5	0.3924	NS
23. ANB	-0.1	1.3	-2.2	1.6	-2.1	0.0001	*
24. SNL-NL	-0.9	2.7	0.3	3.3	1.2	0.1957	NS
25. SNL-ML	-1.3	2.3	-1.1	2.6	0.2	0.7839	NS
26. SNL-OL	-2.4	3.2	-0.9	3.2	1.5	0.1317	NS
27. Is/NL	-1.0	5.6	0.5	6.4	1.5	0.4359	NS
28. li/ML	0.0	4.9	3.0	7.7	3.0	0.1102	NS
29. Interincisal Angle	1.6	7.4	-0.3	13.4	-1.9	0.5704	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	-1.1	2.1	-0.3	2.3	0.8	0.2388	NS
31. Olp-GFS	-0.9	2.9	0.0	2.6	0.9	0.2897	NS
32. Olp-GFA	-0.1	2.5	0.5	2.5	0.6	0.4171	NS
33. Olp-GFP	-1.2	2.6	0.5	3.5	1.7	0.0705	NS
34. Ols-CoC	3.7	1.9	2.4	2.8	-1.3	0.0601	NS
35. Ols-GFS	3.0	1.9	2.3	1.9	-0.7	0.1921	NS
36. Ols-GFA	3.0	1.6	2.3	1.6	-0.7	0.1339	NS
37. Ols-GFP	3.0	1.5	1.9	1.7	-1.1	0.0226	*

Table 27. Comparison of treated vs. control in male subjects at T5-T1.

MALE SUBJECTS							
Variable	Control (t5-t1)		Treated (T5-T1)		Diff	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	78.9	19.6	77.7	18.7	-1.2	0.9130	NS
Sagittal:							
1. Olp-A pt.	8.1	2.4	6.2	2.2	-1.9	0.1389	NS
2. Olp-Pg	9.2	4.3	10.9	2.7	1.7	0.3978	NS
3. Olp-Co	0.6	3.2	1.4	3.3	0.8	0.6647	NS
4. Co-A pt.	8.8	3.9	6.4	4.4	-2.4	0.3014	NS
5. Co-Gn	14.1	3.0	15.4	4.5	1.3	0.6016	NS
6. Co-Gn minus Co-A pt.	5.4	2.8	7.7	1.8	2.3	0.0900	NS
7. Wits	0.1	2.2	-2.2	2.1	-2.3	0.0733	NS
8. Is-Olp	10.9	3.7	5.8	3.7	-5.1	0.0232	*
9. li-Olp	10.1	3.0	9.8	2.6	-0.3	0.8901	NS
10. Overjet	0.8	2.1	-4.1	1.3	-4.9	0.0003	*
11. Ms-Olp	10.3	3.8	8.2	1.7	-2.1	0.2164	NS
12. Mi-Olp	10.5	4.2	11.9	2.8	1.4	0.4903	NS
13. Molar Relationship	-0.2	1.2	-3.7	1.5	-3.5	0.0004	*
Vertical:							
14. OLs-A pt.	5.1	1.6	5.7	2.9	0.6	0.6231	NS
15. ANS-Me	8.1	2.3	7.2	3.8	-0.9	0.6006	NS
16. Is-NL	4.0	3.2	2.8	3.3	-1.2	0.5126	NS
17. li-ML	5.8	2.1	2.9	1.7	-2.9	0.0125	*
18. Overbite	1.6	3.1	-1.5	1.7	-3.1	0.0382	*
19. Msc-NL	4.4	2.7	4.0	2.8	-0.4	0.7692	NS
20. Mic-ML	4.9	1.1	5.2	1.2	0.3	0.6434	NS
Angular:							
21. SNA	1.6	1.6	0.1	2.4	-1.5	0.1717	NS
22. SNB	1.4	1.8	2.1	2.2	0.7	0.5253	NS
23. ANB	0.2	1.2	-2.1	1.6	-2.3	0.0096	*
24. SNL-NL	-1.3	2.5	-0.1	2.0	1.2	0.3341	NS
25. SNL-ML	-0.7	2.7	-2.1	2.2	-1.4	0.3192	NS
26. SNL-OL	-1.3	3.9	-1.1	3.1	0.2	0.9115	NS
27. Is/NL	0.4	6.2	-2.9	7.2	-3.3	0.3894	NS
28. li/ML	0.6	4.9	4.9	7.4	4.3	0.2306	NS
29. Interincisal Angle	-1.6	7.5	0.5	11.3	2.1	0.6931	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	-0.4	2.7	-1.0	2.9	-0.6	0.7049	NS
31. Olp-GFS	0.2	2.8	-0.6	3.1	-0.8	0.6312	NS
32. Olp-GFA	0.7	2.5	-0.2	3.4	-0.9	0.6037	NS
33. Olp-GFP	-0.3	3.5	-0.6	3.3	-0.3	0.8463	NS
34. Ols-CoC	4.6	1.3	1.6	4.4	-3.0	0.1182	NS
35. Ols-GFS	3.9	1.6	2.3	2.9	-1.6	0.2267	NS
36. Ols-GFA	3.9	1.6	2.2	2.5	-1.7	0.1589	NS
37. Ols-GFP	3.9	1.6	1.8	2.8	-2.1	0.1064	NS

Table 28. Comparison of treated vs. control in female subjects at T5-T1.

FEMALE SUBJECTS							
Variable	Control (t5-t1)		Treated (T5-T1)		Diff	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	73.5	13.2	71.9	14.1	-1.6	0.7611	NS
Sagittal:							
1. Olp-A pt.	6.6	2.1	3.5	2.3	-3.1	0.0005	*
2. Olp-Pg	9.7	1.9	6.6	3.5	-3.1	0.0054	*
3. Olp-Co	1.8	1.8	0.5	2.1	-1.3	0.0773	NS
4. Co-A pt.	8.5	2.9	4.0	3.2	-4.5	0.0004	*
5. Co-Gn	13.3	3.0	9.8	2.3	-3.5	0.0034	*
6. Co-Gn minus Co-A pt.	4.8	2.5	5.8	4.0	1.0	0.4038	NS
7. Wits	-0.1	1.6	-1.3	1.9	-1.2	0.0716	NS
8. Is-Olp	8.6	1.7	4.7	4.9	-3.9	0.0074	*
9. li-Olp	8.0	1.5	6.2	3.9	-1.8	0.0995	NS
10. Overjet	0.6	1.4	-1.4	2.9	-2.0	0.0255	*
11. Ms-Olp	9.3	2.4	5.8	2.8	-3.5	0.0009	*
12. Mi-Olp	10.2	2.7	8.4	2.0	-1.8	0.0513	NS
13. Molar Relationship	-0.8	1.0	-2.3	2.1	-1.5	0.0075	*
Vertical:							
14. OLS-A pt.	4.7	2.5	5.0	2.4	0.3	0.7889	NS
15. ANS-Me	6.2	2.3	5.1	2.4	-1.1	0.2257	NS
16. Is-NL	3.8	3.0	3.1	3.6	-0.7	0.5464	NS
17. li-ML	3.9	1.5	4.0	2.5	0.1	0.9520	NS
18. Overbite	1.7	3.3	1.2	3.4	-0.5	0.6707	NS
19. Msc-NL	4.9	1.8	3.4	2.1	-1.5	0.0433	*
20. Mic-ML	3.5	2.4	3.6	1.6	0.1	0.8386	NS
Angular:							
21. SNA	1.9	2.6	-1.3	3.1	-3.2	0.0053	*
22. SNB	2.2	2.1	1.0	2.4	-1.2	0.1653	NS
23. ANB	-0.3	1.4	-2.3	1.7	-2.0	0.0016	*
24. SNL-NL	-0.7	2.9	0.5	3.8	1.2	0.3416	NS
25. SNL-ML	-1.6	2.2	-0.7	2.7	0.9	0.3070	NS
26. SNL-OL	-2.9	2.8	-0.8	3.3	2.1	0.0762	NS
27. Is/NL	-1.6	5.4	2.0	5.7	3.6	0.0853	NS
28. li/ML	-0.3	4.0	2.2	7.9	2.5	0.2845	NS
29. Interincisal Angle	3.0	7.1	-0.7	14.6	-3.7	0.3853	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	-1.4	1.7	0.0	2.0	1.4	0.0442	*
31. Olp-GFS	-1.4	2.9	0.2	2.5	1.6	0.1018	NS
32. Olp-GFA	-0.5	2.5	0.8	2.1	1.3	0.1317	NS
33. Olp-GFP	-1.7	2.1	1.0	3.6	2.7	0.0175	*
34. Ols-CoC	3.4	2.0	2.7	1.6	-0.7	0.3416	NS
35. Ols-GFS	2.6	1.9	2.3	1.4	-0.3	0.5488	NS
36. Ols-GFA	2.6	1.5	2.3	1.1	-0.3	0.5311	NS
37. Ols-GFP	2.6	1.3	1.9	1.1	-0.7	0.1179	NS

Overjet and Molar Relationship Correction-Treatment Group (T5-T1)

The amount of skeletal and dental contribution to the overjet and molar relationship correction in the treatment group at T5-T1 was calculated using the formulas in Table 11. The amount of overjet correction in the treatment group was 2.2 mm. 3.6 mm (163.6%) of the correction was due to skeletal change. -1.4 mm (-63.6%) of the correction was due to dental change. The amount of molar relationship correction was 2.9 mm. 3.6 mm (124.1%) of the correction was skeletal in nature and -0.7 mm (-24.1%) of the correction was dental in nature. Calculations are shown for the overjet and molar relationship correction on the following pages. In addition, diagrams are provided to illustrate the anterior or posterior movement of the maxillary base, mandibular base, maxillary incisors, mandibular incisors, maxillary molars, and mandibular molars (Figures 29 and 30). A pitchfork analysis describing the skeletal and dental contributions to overjet and molar relationship correction is shown in Figure 31.

<u>Overjet Correction:</u>		<u>Molar relationship:</u>	
Skeletal Contribution:		Skeletal Contribution:	
1) Maxilla	4.3	1) Maxilla	4.3
2) Mandible	7.9	2) Mandible	7.9
Dental Contribution:		Dental Contribution:	
3) Mx incisor	0.8	3) Mx molar	2.3
4) Md incisor	-0.6	4) Md molar	1.6

$$\text{Overjet Correction} = \text{Maxilla} + \text{Mx incisor} - \text{Mandible} - \text{Md incisor}$$

$$\text{Overjet Correction} = 4.3 + 0.8 - 7.9 - (-0.6) = -2.2 \text{ mm}$$

Figure 29. Components of overjet correction (T5-T1)

$$\text{Molar Relationship Correction} = \text{Maxilla} + \text{Mx molar} - \text{Mandible} - \text{Md molar}$$

$$\text{Molar Relationship Correction} = 4.3 + 2.3 - 7.9 - 1.6 = -2.9\text{mm}$$

Molar correction
of 2.9 mm
Skeletal contribution
= 3.6 mm
Dental contribution
= -0.7 mm

Figure 30. Components of molar relationship correction (T5-T1)

Figure 31. Pitchfork analysis of overjet and molar correction

Net Overjet and Molar Relationship Correction-Tx vs. Control Group (T5-T1)

The amount of skeletal and dental contribution to the net overjet and net molar relationship correction in the treatment group vs. the control group at T5-T1 was calculated using the formulas in Table 11. The amount of net overjet correction in the treatment group relative to the control group was 2.8 mm. 1.2 mm (42.9%) of the correction was due to skeletal movement. 1.6 mm (57.1%) of the correction was due to dental movement. The amount of net molar relationship correction was 2.2 mm. 1.2 mm (54.5%) of the correction was skeletal in nature and 1.0 mm (45.5%) of the correction was dental in nature. Calculations are shown for the net overjet and net molar relationship correction on the following pages. In addition, diagrams are provided to illustrate the net anterior or posterior movement of the maxillary base, mandibular base, maxillary incisors, mandibular incisors, maxillary molars, and mandibular molars (Figures 32 and 33). A pitchfork analysis describing the net skeletal and dental contributions to overjet and molar relationship correction is shown in Figure 34.

<u>Net Overjet Correction:</u>		<u>Net Molar relationship:</u>	
Skeletal Contribution:		Skeletal Contribution:	
1) Maxilla	-2.8	1) Maxilla	-2.8
2) Mandible	-1.6	2) Mandible	-1.6
Dental Contribution:		Dental Contribution:	
3) Mx incisor	-1.4	3) Mx molar	-0.2
4) Md incisor	0.2	4) Md molar	0.8

$$\text{Net Overjet Correction} = \text{Maxilla} + \text{Mx incisor} - \text{Mandible} - \text{Md incisor}$$

$$\text{Net Overjet Correction} = (-2.8) + (-1.4) - (-1.6) - 0.2 = -2.8 \text{ mm}$$

Figure 32. Components of net overjet correction (T5-T1)

$$\text{Net Molar Relationship Correction} = \text{Maxilla} + \text{Mx molar} - \text{Mandible} - \text{Md molar}$$

$$\text{Net Molar Relationship Correction} = (-2.8) + (-0.2) - (-1.6) - 0.8 = -2.2 \text{ mm}$$

Molar correction
of 2.2 mm
Skeletal contribution
= 1.2 mm
Dental contribution
= 1.0 mm

Figure 33. Components of net molar correction (T5-T1)

Figure 34. Pitchfork analysis of net overjet and molar correction (T5-T1)

Comparison of T5-T4 (Phase II Treatment Effects)

Of the 37 variables investigated, 10 showed statistically significant differences between the treatment group and control group in pooled subjects in the time period T5-T4 (Table 29). Five of the sagittal variables, four of the angular variables, one of the condyle/glenoid fossa variables, and none of the vertical variables showed significant differences between the treatment and control groups. Significance differences in variables are apparent for male subjects only and female subjects only and are reported in Tables 30 and 31, respectively. Only data from pooled subjects is reported here.

Sagittal differences: The five sagittal variables that showed a significant difference between the treatment and control groups at T5-T4 were OLp-A pt., Co-Gn minus Co-A pt., Wits analysis, Is-OLp, and Ii-OLp. The position of the maxillary base (OLp-A pt.) moved forward 0.7 mm from T4 to T5 in the treatment group and in the control group it moved forward 2.5 mm during the same time period. The maxillary base showed an overall net backward movement of 1.8 mm in the treatment group relative to the control group from T4 to T5. The difference between the effective maxillary and mandibular length (Co-Gn minus Co-A pt.) between the treatment and control groups from T4 to T5 was significant with a 1.5 mm difference. The position of the maxilla relative to the mandible along the functional occlusal plane (Wits) showed a net difference of -1.5 mm for the treatment group relative to the control group. The position of the maxillary incisor (Is-OLp) and the mandibular incisors (Ii-OLp) in the treatment group experienced a net backwards movement of 2.2 mm and 1.7 mm, respectively from T4 to T5.

Vertical differences: All vertical variables showed no significant difference between the treatment and control groups at T5-T4.

Angular differences: Significant differences in the angular variables between the control and treatment groups were found in SNA, SNB, ANB, and SNL-OL. A net decrease of 2.0 °, 1.0 °, and 1.0 ° was found in SNA, SNB, and ANB, respectively, when the treatment group when compared to the control group at T5-T4. A net increase of 2.6 ° was seen in the treatment group when compared to the control group at this same time period.

Condyle/Glenoid Fossa differences: Only one condyle/glenoid fossa variable, OLs-CoC, showed a significant difference between the treatment and control groups. Although not significant, every sagittal condyle/glenoid fossa variable (OLp-CoC, OLp-GFS, OLp-GFA, and OLp-GFP) showed a backward movement in the treatment group and a forward movement in the control group from T4 to T5. This suggests possible relapse in the anteriorly relocated condyle and glenoid fossa in the treatment group. Net posterior movements of 1.0 mm, 0.9 mm, 0.7 mm, and 0.2 mm were found in the treatment group relative to the control group for the condylar position (OLp-CoC), the superior aspect of the glenoid fossa (OLp-GFS), the anterior aspect of the glenoid fossa (OLp-GFA), and the posterior aspect of the glenoid fossa (OLp-GFP). Although only OLs-CoC was significant, all vertical condyle/glenoid fossa variables (OLs-CoC, OLs-GFS, and OLs-GFA) showed an overall upward net relative movement of the treatment group compared to the control group from T4 to T5. Net upward movements of 1.0 mm, 0.6 mm, 0.6 mm, and 0.6 mm were found in the treatment group relative to the control group for the condylar position (OLs-CoC), the superior aspect of the glenoid fossa (OLs-GFS), the anterior aspect of the glenoid fossa (OLs-GFA), and the posterior aspect of the glenoid fossa (OLs-GFP), respectively.

Table 29. Comparison of treated vs. control group in pooled subjects at T5-T4

POOLED (MALES AND FEMALES)							
Variable	Control (t5-t4)		Treated (T5-T4)		Diff	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	19.8	8.1	20.0	6.6	0.2	0.9192	NS
Sagittal:							
1. Olp-A pt.	2.5	1.5	0.7	1.5	-1.8	0.0002	*
2. Olp-Pg	2.6	2.4	1.5	1.7	-1.1	0.1134	NS
3. Olp-Co	-0.3	2.0	0.6	1.4	0.9	0.0755	NS
4. Co-A pt.	2.2	2.1	1.4	2.1	-0.8	0.1952	NS
5. Co-Gn	2.9	2.5	3.5	2.5	0.6	0.4366	NS
6. Co-Gn minus Co-A pt.	0.7	1.8	2.2	2.3	1.5	0.0260	*
7. Wits	0.7	1.4	-0.8	1.6	-1.5	0.0022	*
8. Is-Olp	2.2	1.5	0.0	1.9	-2.2	0.0002	*
9. li-Olp	2.1	1.7	0.4	1.6	-1.7	0.0014	*
10. Overjet	0.0	0.7	-0.4	1.5	-0.4	0.1899	NS
11. Ms-Olp	2.3	1.5	2.2	1.8	-0.1	0.9175	NS
12. Mi-Olp	2.6	2.2	2.4	1.8	-0.2	0.7785	NS
13. Molar Relationship	-0.3	0.9	-0.1	1.0	0.2	0.6962	NS
Vertical:							
14. OLs-A pt.	1.5	1.6	1.1	2.0	-0.4	0.5352	NS
15. ANS-Me	1.5	1.3	2.2	2.2	0.7	0.2114	NS
16. Is-NL	0.3	1.2	0.4	1.7	0.1	0.8341	NS
17. li-ML	1.2	1.1	1.0	1.4	-0.2	0.5409	NS
18. Overbite	0.1	0.9	-0.3	1.4	-0.4	0.2443	NS
19. Msc-NL	1.0	1.0	1.3	1.4	0.3	0.4221	NS
20. Mic-ML	1.3	1.7	1.9	1.8	0.6	0.2327	NS
Angular:							
21. SNA	1.0	1.3	-1.0	2.2	-2.0	0.0008	*
22. SNB	0.6	1.4	-0.4	1.3	-1.0	0.0278	*
23. ANB	0.4	1.0	-0.6	1.2	-1.0	0.0033	*
24. SNL-NL	0.6	1.8	1.0	2.3	0.4	0.4917	NS
25. SNL-ML	-0.1	1.2	0.5	2.1	0.6	0.2802	NS
26. SNL-OL	-1.0	2.0	1.6	2.8	2.6	0.0013	*
27. Is/NL	0.1	3.1	-0.2	6.3	-0.3	0.8566	NS
28. li/ML	-1.0	2.4	-1.2	5.3	-0.2	0.8400	NS
29. Interincisal Angle	1.7	3.3	2.3	9.4	0.6	0.7573	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	0.4	2.1	-0.6	1.4	-1.0	0.0665	NS
31. Olp-GFS	0.3	2.2	-0.6	1.7	-0.9	0.1426	NS
32. Olp-GFA	0.5	2.1	-0.2	1.6	-0.7	0.2379	NS
33. Olp-GFP	0.0	2.4	-0.2	3.0	-0.2	0.8158	NS
34. Ols-CoC	0.6	1.5	-0.4	1.9	-1.0	0.0484	*
35. Ols-GFS	0.6	1.6	0.0	1.7	-0.6	0.2376	NS
36. Ols-GFA	0.8	1.5	0.2	1.7	-0.6	0.3021	NS
37. Ols-GFP	0.8	1.6	0.2	2.0	-0.6	0.2796	NS

Table 30. Comparison of treated vs. control in males subjects at T5-T4

MALE SUBJECTS							
Variable	Control (t5-t4)		Treated (T5-T4)		Diff	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	21.7	12.3	22.6	8.4	0.9	0.8814	NS
Sagittal:							
1. Olp-A pt.	3.0	1.5	1.0	1.9	-2.0	0.0503	NS
2. Olp-Pg	3.1	3.6	2.7	1.5	-0.4	0.7843	NS
3. Olp-Co	0.0	1.9	0.3	1.8	0.3	0.7295	NS
4. Co-A pt.	2.9	1.7	1.4	2.5	-1.5	0.2180	NS
5. Co-Gn	3.6	2.6	4.6	1.7	1.0	0.4192	NS
6. Co-Gn minus Co-A pt.	0.7	2.0	3.2	2.9	2.5	0.0830	NS
7. Wits	0.7	1.2	-1.2	1.9	-1.9	0.0456	*
8. Is-Olp	2.9	1.8	0.1	2.1	-2.8	0.0194	*
9. li-Olp	2.8	2.3	0.6	2.0	-2.2	0.0859	NS
10. Overjet	0.2	0.7	-0.5	1.4	-0.7	0.3142	NS
11. Ms-Olp	2.3	2.1	3.1	1.5	0.8	0.4510	NS
12. Mi-Olp	2.4	2.9	3.4	1.1	1.0	0.3899	NS
13. Molar Relationship	-0.1	1.2	-0.4	1.0	-0.3	0.6502	NS
Vertical:							
14. OLs-A pt.	1.4	1.2	1.5	2.0	0.1	0.9329	NS
15. ANS-Me	1.3	1.0	3.3	1.9	2.0	0.0262	*
16. Is-NL	0.3	1.4	1.7	1.7	1.4	0.1228	NS
17. li-ML	1.8	1.2	1.1	1.1	-0.7	0.3018	NS
18. Overbite	0.6	0.9	-0.1	1.7	-0.7	0.4060	NS
19. Msc-NL	0.5	0.9	1.4	1.2	0.9	0.1625	NS
20. Mic-ML	1.5	0.9	2.0	1.7	0.5	0.5478	NS
Angular:							
21. SNA	0.9	1.6	-1.6	2.0	-2.5	0.0238	*
22. SNB	0.4	1.9	-0.7	1.1	-1.1	0.2162	NS
23. ANB	0.5	0.8	-0.9	1.5	-1.4	0.0455	*
24. SNL-NL	0.7	1.3	-0.4	1.2	-1.1	0.1205	NS
25. SNL-ML	0.1	1.5	0.9	2.0	0.8	0.4223	NS
26. SNL-OL	-0.4	2.5	1.6	2.2	2.0	0.1207	NS
27. Is/NL	0.1	2.5	-3.9	5.7	-4.0	0.1230	NS
28. li/ML	0.1	2.6	-2.8	4.4	-2.9	0.1648	NS
29. Interincisal Angle	0.8	2.1	5.6	7.6	4.8	0.1299	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	0.1	2.0	-0.7	1.8	-0.8	0.4391	NS
31. Olp-GFS	0.2	2.0	-1.1	2.0	-1.3	0.2318	NS
32. Olp-GFA	0.6	1.2	-0.6	1.8	-1.2	0.2035	NS
33. Olp-GFP	-0.3	2.8	-0.9	2.0	-0.6	0.6958	NS
34. Ols-CoC	1.2	1.5	-0.6	2.1	-1.8	0.0836	NS
35. Ols-GFS	1.3	1.5	0.7	1.9	-0.6	0.5503	NS
36. Ols-GFA	1.4	1.2	1.1	2.0	-0.3	0.7781	NS
37. Ols-GFP	1.6	1.2	1.1	2.7	-0.5	0.6419	NS

Table 31. Comparison of treated vs. control in female subjects at T5-T4)

FEMALE SUBJECTS							
Variable	Control (t5-t4)		Treated (T5-T4)		Diff	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	18.9	5.6	18.9	5.5	0.0	0.9739	NS
Sagittal:							
1. Olp-A pt.	2.3	1.4	0.6	1.4	-1.7	0.0018	*
2. Olp-Pg	2.3	1.7	1.0	1.6	-1.3	0.0387	*
3. Olp-Co	-0.5	2.1	0.8	1.2	1.3	0.0609	NS
4. Co-A pt.	1.9	2.2	1.4	1.9	-0.5	0.5068	NS
5. Co-Gn	2.7	2.5	3.1	2.8	0.4	0.6676	NS
6. Co-Gn minus Co-A pt.	0.8	1.8	1.7	1.8	0.9	0.1734	NS
7. Wits	0.8	1.5	-0.5	1.5	-1.3	0.0255	*
8. Is-Olp	1.8	1.3	-0.1	1.9	-1.9	0.0040	*
9. li-Olp	1.8	1.3	0.3	1.4	-1.5	0.0061	*
10. Overjet	0.0	0.7	-0.4	1.6	-0.4	0.3862	NS
11. Ms-Olp	2.2	1.3	1.8	1.8	-0.4	0.4503	NS
12. Mi-Olp	2.6	1.8	1.9	1.8	-0.7	0.2831	NS
13. Molar Relationship	-0.4	0.8	-0.1	1.1	0.3	0.3879	NS
Vertical:							
14. Ols-A pt.	1.5	1.8	0.9	2.1	-0.6	0.4527	NS
15. ANS-Me	1.6	1.4	1.6	2.1	0.0	0.9652	NS
16. Is-NL	0.4	1.2	-0.1	1.4	-0.5	0.3114	NS
17. li-ML	1.0	1.0	1.0	1.5	0.0	0.9618	NS
18. Overbite	-0.1	0.9	-0.4	1.3	-0.3	0.4243	NS
19. Msc-NL	1.2	1.0	1.3	1.6	0.1	0.9450	NS
20. Mic-ML	1.2	1.9	1.9	1.9	0.7	0.3150	NS
Angular:							
21. SNA	1.0	1.2	-0.7	2.2	-1.7	0.0149	*
22. SNB	0.7	1.1	-0.2	1.4	-0.9	0.0783	NS
23. ANB	0.4	1.1	-0.5	1.0	-0.9	0.0401	*
24. SNL-NL	0.5	2.0	1.7	2.4	1.2	0.1606	NS
25. SNL-ML	-0.1	1.1	0.3	2.2	0.4	0.4708	NS
26. SNL-OL	-1.2	1.8	1.5	3.1	2.7	0.0062	*
27. Is/NL	0.1	3.4	1.6	6.0	1.5	0.4267	NS
28. li/ML	-1.5	2.2	-0.5	5.6	1.0	0.5390	NS
29. Interincisal Angle	2.1	3.7	0.8	9.9	-1.3	0.6391	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	0.5	2.2	-0.6	1.2	-1.1	0.1004	NS
31. Olp-GFS	0.3	2.3	-0.4	1.6	-0.7	0.3607	NS
32. Olp-GFA	0.5	2.4	0.0	1.6	-0.5	0.5331	NS
33. Olp-GFP	0.2	2.3	0.2	3.4	0.0	0.9711	NS
34. Ols-CoC	0.4	1.5	-0.3	1.8	-0.7	0.2820	NS
35. Ols-GFS	0.3	1.6	-0.3	1.6	-0.6	0.2974	NS
36. Ols-GFA	0.5	1.6	-0.2	1.5	-0.7	0.2683	NS
37. Ols-GFP	0.4	1.7	-0.3	1.5	-0.7	0.2892	NS

Overjet and Molar Relationship Change-Treatment Group (T5-T4)

The amount of skeletal and dental contribution to the overjet and molar relationship change in the treatment group at T5-T4 was calculated using the formulas in Table 11. The amount of overjet change in the treatment group was 0.4 mm. 0.8 mm (200.0%) of the correction was due to skeletal change. -0.4 mm (-100.0%) of the correction was due to dental change. The amount of molar relationship change was 0.2 mm. 0.8 mm (400.0%) of the correction was skeletal in nature and -0.6 mm (-300.0%) of the correction was dental in nature. Calculations are shown for the overjet and molar relationship change on the following pages. In addition, diagrams are provided to illustrate the anterior or posterior movement of the maxillary base, mandibular base, maxillary incisors, mandibular incisors, maxillary molars, and mandibular molars (Figures 35 and 36). A pitchfork analysis describing the skeletal and dental contributions to overjet and molar relationship change is shown in Figure 37.

Overjet Change:		Molar relationship change:	
Skeletal Contribution:		Skeletal Contribution:	
1) Maxilla	0.7	1) Maxilla	0.7
2) Mandible	1.5	2) Mandible	1.5
Dental Contribution:		Dental Contribution:	
3) Mx incisor	-0.7	3) Mx molar	1.5
4) Md incisor	-1.1	4) Md molar	0.9

$$\text{Overjet Change} = \text{Maxilla} + \text{Mx incisor} - \text{Mandible} - \text{Md incisor}$$

$$\text{Overjet Change} = 0.7 + (-0.7) - 1.5 - (-1.1) = -0.4 \text{ mm}$$

Overjet correction
of **0.4 mm**
Skeletal contribution
= **0.8 mm**
Dental contribution
= **-0.4 mm**

Figure 35. Components of overjet correction (T5-T4)

$$\text{Molar Relationship Change} = \text{Maxilla} + \text{Mx molar} - \text{Mandible} - \text{Md molar}$$

$$\text{Molar Relationship Change} = 0.7 + 1.5 - 1.5 - 0.9 = -0.2\text{mm}$$

Molar correction
of 0.2 mm
Skeletal contribution
= 0.8 mm
Dental contribution
= -0.6 mm

Figure 36. Components of molar relationship correction (T5-T4)

Figure 37. Pitchfork analysis of overjet and molar correction (T5-T4)

Net Overjet and Molar Relationship Change-Tx vs. Control Group (T5-T4)

The amount of skeletal and dental contribution to the net overjet and net molar relationship change in the treatment group vs. the control group at T5-T4 was calculated using the formulas in Table 11. The amount of net overjet change in the treatment group relative to the control group was 0.5 mm. 0.7 mm (140.0%) of the correction was due to skeletal movement. -0.2 mm (-40.0%) of the correction was due to dental movement. The amount of net molar relationship change was -0.1 mm. 0.7 mm (-700.0%) of the correction was skeletal in nature and -0.8 mm (800.0%) of the correction was dental in nature. Calculations are shown for the net overjet and net molar relationship change on the following pages. In addition, diagrams are provided to illustrate the net anterior or posterior movement of the maxillary base, mandibular base, maxillary incisors, mandibular incisors, maxillary molars, and mandibular molars (Figures 38 and 39). A pitchfork analysis describing the net skeletal and dental contributions to overjet and molar relationship change is shown in Figure 40.

<u>Net Overjet Change:</u>		<u>Net Molar change:</u>	
Skeletal Contribution:		Skeletal Contribution:	
1) Maxilla	-1.8	1) Maxilla	-1.8
2) Mandible	-1.1	2) Mandible	-1.1
Dental Contribution:		Dental Contribution:	
3) Mx incisor	-0.4	3) Mx molar	1.7
4) Md incisor	-0.6	4) Md molar	0.9

$$\text{Net Overjet Change} = \text{Maxilla} + \text{Mx incisor} - \text{Mandible} - \text{Md incisor}$$

$$\text{Net Overjet Change} = (-1.8) + (-0.4) - (-1.1) - (-0.6) = -0.5 \text{ mm}$$

Figure 38. Components of net overjet correction (T5-T4)

$$\text{Net Molar Relationship Change} = \text{Maxilla} + \text{Mx molar} - \text{Mandible} - \text{Md molar}$$

$$\text{Net Molar Relationship Change} = (-1.8) + 1.7 - (-1.1) - 0.9 = 0.1\text{mm}$$

Molar correction
of -0.1 mm
Skeletal contribution
= 0.7 mm
Dental contribution
= -0.8 mm

Figure 39. Components of net molar correction (T5-T4)

Figure 40. Pitchfork analysis of net overjet and molar correction (T5-T4)

Comparison of T4-T3 (Relapse after Phase I to before Phase II Treatment)

Of the 37 variables investigated, 7 showed statistically significant differences between the treatment group and control group in pooled subjects in the time period T4-T3 (Table 32). Four of the sagittal variables, one of the vertical variables, two of the angular variables, and none of the condyle/glenoid fossa variables showed significant differences between the treatment and control groups during this time period. Significance differences in variables are apparent for male subjects only and female subjects only and are reported in Tables 33 and 34, respectively. Only data from pooled subjects is reported here.

Sagittal differences: The four sagittal variables that showed a significant difference between the treatment and control groups at T4-T3 were Co-Gn, Wits analysis, Mi-OLp, and molar relationship. . Effective mandibular length (Co-Gn) showed a -2.5 mm difference in the treatment group relative to the the control group, indicating a possible “catch-up” period of mandibular growth in the control group. The position of the maxilla relative to the mandible along the functional occlusal plane (Wits) showed a net difference of 1.7 mm in the treatment group compared to the control group, suggesting a period of relapse in maxillary-mandibular relationship during this time period. The mandibular molars (Mi-OLp) moved forward a distance of 2.6 mm in the treatment group and 4.4 mm forward in the control group during this time period, suggesting a net relapse of 1.8 mm in a posterior direction in the treatment group compared to the control. Molar relationship will be addressed in a later section.

Vertical differences: All vertical variables showed no significant difference between the treatment and control groups at T4-T3 except for ANS-Me. The lower face

height (ANS-Me) decreased a net distance of 1.8 mm in the treatment group relative to the control group during this time period.

Angular differences: All angular variables showed no significant difference between the treatment and control groups at T4-T3 except for SNL-OL and Interincisal angle. A net decrease of 3.7 ° in the treatment group was found in the functional occlusal plane angle (SNL-OL), suggesting a return to the pre-treatment level. The interincisal angle decreased 4.4 ° in the treatment group relative to the control group during this time period, suggesting flaring of the maxillary and mandibular incisors. Although not significant, the maxillary incisor angle (Is/NL) and the mandibular incisor angle (Ii/ML) showed a net increase of 2.9 ° and 2.5 °, respectively, in the treatment group compared to the control group.

Condyle/Glenoid Fossa differences: None of the condyle/glenoid fossa variables showed significant differences between the treatment and control groups at T4-T3. Every sagittal condyle/glenoid fossa variable (OLp-CoC, OLp-GFS, OLp-GFA, and OLp-GFP) in the treatment group moved backward, although the distance was less than the backward movement of the sagittal condyle/glenoid fossa variables in the control group. No significant differences or trends were found in the vertical condyle/glenoid fossa variables between the treatment and control groups.

Table 32. Comparison of treated vs. control in pooled subjects at T4-T3

POOLED (MALES AND FEMALES)							
Variable	Control (t5-t4)		Treated (T5-T4)		Diff	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	19.8	8.1	20.0	6.6	0.2	0.9192	NS
Sagittal:							
1. Olp-A pt.	2.5	1.5	0.7	1.5	-1.8	0.0002	*
2. Olp-Pg	2.6	2.4	1.5	1.7	-1.1	0.1134	NS
3. Olp-Co	-0.3	2.0	0.6	1.4	0.9	0.0755	NS
4. Co-A pt.	2.2	2.1	1.4	2.1	-0.8	0.1952	NS
5. Co-Gn	2.9	2.5	3.5	2.5	0.6	0.4366	NS
6. Co-Gn minus Co-A pt.	0.7	1.8	2.2	2.3	1.5	0.0260	*
7. Wits	0.7	1.4	-0.8	1.6	-1.5	0.0022	*
8. Is-Olp	2.2	1.5	0.0	1.9	-2.2	0.0002	*
9. li-Olp	2.1	1.7	0.4	1.6	-1.7	0.0014	*
10. Overjet	0.0	0.7	-0.4	1.5	-0.4	0.1899	NS
11. Ms-Olp	2.3	1.5	2.2	1.8	-0.1	0.9175	NS
12. Mi-Olp	2.6	2.2	2.4	1.8	-0.2	0.7785	NS
13. Molar Relationship	-0.3	0.9	-0.1	1.0	0.2	0.6962	NS
Vertical:							
14. OLs-A pt.	1.5	1.6	1.1	2.0	-0.4	0.5352	NS
15. ANS-Me	1.5	1.3	2.2	2.2	0.7	0.2114	NS
16. Is-NL	0.3	1.2	0.4	1.7	0.1	0.8341	NS
17. li-ML	1.2	1.1	1.0	1.4	-0.2	0.5409	NS
18. Overbite	0.1	0.9	-0.3	1.4	-0.4	0.2443	NS
19. Msc-NL	1.0	1.0	1.3	1.4	0.3	0.4221	NS
20. Mic-ML	1.3	1.7	1.9	1.8	0.6	0.2327	NS
Angular:							
21. SNA	1.0	1.3	-1.0	2.2	-2.0	0.0008	*
22. SNB	0.6	1.4	-0.4	1.3	-1.0	0.0278	*
23. ANB	0.4	1.0	-0.6	1.2	-1.0	0.0033	*
24. SNL-NL	0.6	1.8	1.0	2.3	0.4	0.4917	NS
25. SNL-ML	-0.1	1.2	0.5	2.1	0.6	0.2802	NS
26. SNL-OL	-1.0	2.0	1.6	2.8	2.6	0.0013	*
27. Is/NL	0.1	3.1	-0.2	6.3	-0.3	0.8566	NS
28. li/ML	-1.0	2.4	-1.2	5.3	-0.2	0.8400	NS
29. Interincisal Angle	1.7	3.3	2.3	9.4	0.6	0.7573	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	0.4	2.1	-0.6	1.4	-1.0	0.0665	NS
31. Olp-GFS	0.3	2.2	-0.6	1.7	-0.9	0.1426	NS
32. Olp-GFA	0.5	2.1	-0.2	1.6	-0.7	0.2379	NS
33. Olp-GFP	0.0	2.4	-0.2	3.0	-0.2	0.8158	NS
34. Ols-CoC	0.6	1.5	-0.4	1.9	-1.0	0.0484	*
35. Ols-GFS	0.6	1.6	0.0	1.7	-0.6	0.2376	NS
36. Ols-GFA	0.8	1.5	0.2	1.7	-0.6	0.3021	NS
37. Ols-GFP	0.8	1.6	0.2	2.0	-0.6	0.2796	NS

Table 33. Comparison of treated vs. control in pooled subjects at T4-T3.

MALE SUBJECTS							
Variable	Control (t5-t4)		Treated (T5-T4)		Diff	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	21.7	12.3	22.6	8.4	0.9	0.8814	NS
Sagittal:							
1. Olp-A pt.	3.0	1.5	1.0	1.9	-2.0	0.0503	NS
2. Olp-Pg	3.1	3.6	2.7	1.5	-0.4	0.7843	NS
3. Olp-Co	0.0	1.9	0.3	1.8	0.3	0.7295	NS
4. Co-A pt.	2.9	1.7	1.4	2.5	-1.5	0.2180	NS
5. Co-Gn	3.6	2.6	4.6	1.7	1.0	0.4192	NS
6. Co-Gn minus Co-A pt.	0.7	2.0	3.2	2.9	2.5	0.0830	NS
7. Wits	0.7	1.2	-1.2	1.9	-1.9	0.0456	*
8. Is-Olp	2.9	1.8	0.1	2.1	-2.8	0.0194	*
9. li-Olp	2.8	2.3	0.6	2.0	-2.2	0.0859	NS
10. Overjet	0.2	0.7	-0.5	1.4	-0.7	0.3142	NS
11. Ms-Olp	2.3	2.1	3.1	1.5	0.8	0.4510	NS
12. Mi-Olp	2.4	2.9	3.4	1.1	1.0	0.3899	NS
13. Molar Relationship	-0.1	1.2	-0.4	1.0	-0.3	0.6502	NS
Vertical:							
14. OLs-A pt.	1.4	1.2	1.5	2.0	0.1	0.9329	NS
15. ANS-Me	1.3	1.0	3.3	1.9	2.0	0.0262	*
16. Is-NL	0.3	1.4	1.7	1.7	1.4	0.1228	NS
17. li-ML	1.8	1.2	1.1	1.1	-0.7	0.3018	NS
18. Overbite	0.6	0.9	-0.1	1.7	-0.7	0.4060	NS
19. Msc-NL	0.5	0.9	1.4	1.2	0.9	0.1625	NS
20. Mic-ML	1.5	0.9	2.0	1.7	0.5	0.5478	NS
Angular:							
21. SNA	0.9	1.6	-1.6	2.0	-2.5	0.0238	*
22. SNB	0.4	1.9	-0.7	1.1	-1.1	0.2162	NS
23. ANB	0.5	0.8	-0.9	1.5	-1.4	0.0455	*
24. SNL-NL	0.7	1.3	-0.4	1.2	-1.1	0.1205	NS
25. SNL-ML	0.1	1.5	0.9	2.0	0.8	0.4223	NS
26. SNL-OL	-0.4	2.5	1.6	2.2	2.0	0.1207	NS
27. Is/NL	0.1	2.5	-3.9	5.7	-4.0	0.1230	NS
28. li/ML	0.1	2.6	-2.8	4.4	-2.9	0.1648	NS
29. Interincisal Angle	0.8	2.1	5.6	7.6	4.8	0.1299	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	0.1	2.0	-0.7	1.8	-0.8	0.4391	NS
31. Olp-GFS	0.2	2.0	-1.1	2.0	-1.3	0.2318	NS
32. Olp-GFA	0.6	1.2	-0.6	1.8	-1.2	0.2035	NS
33. Olp-GFP	-0.3	2.8	-0.9	2.0	-0.6	0.6958	NS
34. Ols-CoC	1.2	1.5	-0.6	2.1	-1.8	0.0836	NS
35. Ols-GFS	1.3	1.5	0.7	1.9	-0.6	0.5503	NS
36. Ols-GFA	1.4	1.2	1.1	2.0	-0.3	0.7781	NS
37. Ols-GFP	1.6	1.2	1.1	2.7	-0.5	0.6419	NS

Table 34. Comparison of treated vs. control in female subjects at T4-T3.

FEMALE SUBJECTS							
Variable	Control (t5-t4)		Treated (T5-T4)		Diff	p value	Sig
	Mean	S.D.	Mean	S.D.			
Age	18.9	5.6	18.9	5.5	0.0	0.9739	NS
Sagittal:							
1. Olp-A pt.	2.3	1.4	0.6	1.4	-1.7	0.0018	*
2. Olp-Pg	2.3	1.7	1.0	1.6	-1.3	0.0387	*
3. Olp-Co	-0.5	2.1	0.8	1.2	1.3	0.0609	NS
4. Co-A pt.	1.9	2.2	1.4	1.9	-0.5	0.5068	NS
5. Co-Gn	2.7	2.5	3.1	2.8	0.4	0.6676	NS
6. Co-Gn minus Co-A pt.	0.8	1.8	1.7	1.8	0.9	0.1734	NS
7. Wits	0.8	1.5	-0.5	1.5	-1.3	0.0255	*
8. Is-Olp	1.8	1.3	-0.1	1.9	-1.9	0.0040	*
9. li-Olp	1.8	1.3	0.3	1.4	-1.5	0.0061	*
10. Overjet	0.0	0.7	-0.4	1.6	-0.4	0.3862	NS
11. Ms-Olp	2.2	1.3	1.8	1.8	-0.4	0.4503	NS
12. Mi-Olp	2.6	1.8	1.9	1.8	-0.7	0.2831	NS
13. Molar Relationship	-0.4	0.8	-0.1	1.1	0.3	0.3879	NS
Vertical:							
14. OLs-A pt.	1.5	1.8	0.9	2.1	-0.6	0.4527	NS
15. ANS-Me	1.6	1.4	1.6	2.1	0.0	0.9652	NS
16. Is-NL	0.4	1.2	-0.1	1.4	-0.5	0.3114	NS
17. li-ML	1.0	1.0	1.0	1.5	0.0	0.9618	NS
18. Overbite	-0.1	0.9	-0.4	1.3	-0.3	0.4243	NS
19. Msc-NL	1.2	1.0	1.3	1.6	0.1	0.9450	NS
20. Mic-ML	1.2	1.9	1.9	1.9	0.7	0.3150	NS
Angular:							
21. SNA	1.0	1.2	-0.7	2.2	-1.7	0.0149	*
22. SNB	0.7	1.1	-0.2	1.4	-0.9	0.0783	NS
23. ANB	0.4	1.1	-0.5	1.0	-0.9	0.0401	*
24. SNL-NL	0.5	2.0	1.7	2.4	1.2	0.1606	NS
25. SNL-ML	-0.1	1.1	0.3	2.2	0.4	0.4708	NS
26. SNL-OL	-1.2	1.8	1.5	3.1	2.7	0.0062	*
27. Is/NL	0.1	3.4	1.6	6.0	1.5	0.4267	NS
28. li/ML	-1.5	2.2	-0.5	5.6	1.0	0.5390	NS
29. Interincisal Angle	2.1	3.7	0.8	9.9	-1.3	0.6391	NS
Condyle/Glenoid Fossa:							
30. Olp-CoC	0.5	2.2	-0.6	1.2	-1.1	0.1004	NS
31. Olp-GFS	0.3	2.3	-0.4	1.6	-0.7	0.3607	NS
32. Olp-GFA	0.5	2.4	0.0	1.6	-0.5	0.5331	NS
33. Olp-GFP	0.2	2.3	0.2	3.4	0.0	0.9711	NS
34. Ols-CoC	0.4	1.5	-0.3	1.8	-0.7	0.2820	NS
35. Ols-GFS	0.3	1.6	-0.3	1.6	-0.6	0.2974	NS
36. Ols-GFA	0.5	1.6	-0.2	1.5	-0.7	0.2683	NS
37. Ols-GFP	0.4	1.7	-0.3	1.5	-0.7	0.2892	NS

Overjet and Molar Relationship Change-Treatment Group (T4-T3)

The amount of skeletal and dental contribution to the overjet and molar relationship change in the treatment group at T4-T3 was calculated using the formulas in Table 11. The amount of overjet change in the treatment group was -0.8 mm. 0.6 mm (-75.0%) of the correction was due to skeletal change. -1.4 mm (175.0%) of the correction was due to dental change. The amount of molar relationship change was -0.8 mm. 0.6 mm (-75.0%) of the correction was skeletal in nature and -1.4 mm (175.0%) of the correction was dental in nature. Calculations are shown for the overjet and molar relationship change on the following pages. In addition, diagrams are provided to illustrate the anterior or posterior movement of the maxillary base, mandibular base, maxillary incisors, mandibular incisors, maxillary molars, and mandibular molars (Figures 41 and 42). A pitchfork analysis describing the skeletal and dental contributions to overjet and molar relationship change is shown in Figure 43.

<u>Overjet Change:</u>		<u>Molar relationship change:</u>	
Skeletal Contribution:		Skeletal Contribution:	
1) Maxilla	2.4	1) Maxilla	2.4
2) Mandible	3.0	2) Mandible	3.0
Dental Contribution:		Dental Contribution:	
3) Mx incisor	1.7	3) Mx molar	1.0
4) Md incisor	0.3	4) Md molar	-0.4

$$\text{Overjet Change} = \text{Maxilla} + \text{Mx incisor} - \text{Mandible} - \text{Md incisor}$$

$$\text{Overjet Change} = 2.4 + 1.7 - 3.0 - 0.3 = 0.8 \text{ mm}$$

Overjet correction
of **-0.8 mm**
Skeletal contribution
= **0.6 mm**
Dental contribution
= **-1.4 mm**

Figure 41. Components of overjet correction (T4-T3)

$$\text{Molar Relationship Change} = \text{Maxilla} + \text{Mx molar} - \text{Mandible} - \text{Md molar}$$

$$\text{Molar Relationship Change} = 2.4 + 1.0 - 3.0 - (0.4) = 0.8\text{mm}$$

Molar correction
of -0.8 mm
Skeletal contribution
= 0.6 mm
Dental contribution
= -1.4 mm

Figure 42. Components of molar relationship correction (T4-T3)

Figure 43. Pitchfork analysis of overjet and molar correction (T4-T3)

Net Overjet and Molar Relationship Change-Tx vs. Control Group (T4-T3)

The amount of skeletal and dental contribution to the net overjet and net molar relationship change in the treatment group vs. the control group at T4-T3 was calculated using the formulas in Table 11. The amount of net overjet change in the treatment group relative to the control group was -0.8 mm. -1.0 mm (125.0%) of the correction was due to skeletal movement. 0.2 mm (-25.0%) of the correction was due to dental movement. The amount of net molar relationship change was -1.0 mm. -1.0 mm (100.0%) of the correction was skeletal in nature and 0.0 mm (0.0%) of the correction was dental in nature. Calculations are shown for the net overjet and net molar relationship change on the following pages. In addition, diagrams are provided to illustrate the net anterior or posterior movement of the maxillary base, mandibular base, maxillary incisors, mandibular incisors, maxillary molars, and mandibular molars (Figures 44 and 45). A pitchfork analysis describing the net skeletal and dental contributions to overjet and molar relationship change is shown in Figure 46.

Net Overjet Change:		Net Molar change:	
Skeletal Contribution:		Skeletal Contribution:	
1) Maxilla	-0.1	1) Maxilla	-0.1
2) Mandible	-1.1	2) Mandible	-1.1
Dental Contribution:		Dental Contribution:	
3) Mx incisor	0.8	3) Mx molar	-0.7
4) Md incisor	1.0	4) Md molar	-0.7

$$\text{Net Overjet Change} = \text{Maxilla} + \text{Mx incisor} - \text{Mandible} - \text{Md incisor}$$

$$\text{Net Overjet Change} = (-0.1) + 0.8 - (-1.1) - 1.0 = 0.8 \text{ mm}$$

Figure 44. Components of net overjet correction (T4-T3)

$$\text{Net Molar Relationship Change} = \text{Maxilla} + \text{Mx molar} - \text{Mandible} - \text{Md molar}$$

$$\text{Net Molar Relationship Change} = (-0.1) + (-0.7) - (-1.1) - (-0.7) = 1.0 \text{ mm}$$

Figure 45. Components of net molar correction (T4-T3)

Figure 46. Pitchfork analysis of net overjet and molar correction (T4-T3)

DISCUSSION

The purpose of this study was to determine the skeletal and dental changes of Class II patients treated with the crowned Herbst appliance in the early mixed dentition and followed through phase II orthodontic treatment for long-term changes. Twenty two patients were included in the study. Cephalometric analysis was performed on radiographs taken before phase I crowned Herbst treatment (T1), immediately after removal of Herbst appliance (T2), at the completion of phase I treatment (T3), prior to beginning of phase II orthodontic treatment (T4), and immediately after phase II treatment (T5). Results were compared to a control sample of 22 untreated Class II patients from the Bolton-Brush study that was matched in age, sex, and craniofacial morphology.

When investigating the correction of a Class II malocclusion, it is important to note that changes in the transverse and vertical dimensions can have positive or negative effects on the sagittal Class II correction. Although orthodontists have traditionally classified malocclusions using Angles classification system from a lateral view, it must be remembered that a complex arrangement of the teeth and jaws in the sagittal, vertical, and transverse planes is necessary to achieve optimal function, esthetics, stability, and periodontal health.

The impact of growth on Class II correction must also be considered. Although at one time it was believed that growth was entirely determined by the pre-existing genetic make-up of an individual, modern theories suggest the importance of the environment and form-function relationships in the development of the jaws. The timing of Class II

treatment can become an important consideration if one is to maximize growth potential in Class II corrective treatment.

In interpreting the results of this study, it is best to evaluate the changes that occurred in both the sagittal direction and the vertical direction. Transverse dimensional changes were not investigated in this study. Describing the changes over time in the multiple anatomic components that determine the relationships of the teeth and jaws can identify where the effects of treatment occurred and if they were stable. 37 variables were used in this study to describe the changes in position of the maxillary skeletal base, the mandibular skeletal base, the maxillary molars and incisors, the mandibular molars and incisors, and the condyle/glenoid fossa region.

Sagittal Changes (Skeletal)

Treatment with the crowned Herbst for the time period T2-T1 resulted in significant skeletal differences between the treatment and control groups for all sagittal variables except OLp-A pt., OLp-Pg, and Co-Gn. The position of the maxillary base (OLp-A pt.) in the treatment group moved forward 1.0 mm from its original position and although it was not significant, the maxillary base was restrained 0.4 mm in the treatment group relative to the control group. This was consistent with previous studies in which the maxillary base moved forward 0.1-1.2 mm during treatment,^{7,12,18,59,80,105,109,111-116} which was found to be 0.2-1.2 mm less than the forward movement observed in the control group^{12,18,115}. In some studies, A-point moved backwards 0.5-1.0 mm during treatment^{16,80,103,105,117}. During treatment, the Herbst appliance exerts a posterior and upward force on the maxilla and the maxillary dentition similar to a high-pull headgear^{11,18,81,95,118}. In the present study, the amount of forward movement of A pt.

during the short and long-term post-treatment period was 1.2 mm and 3.6 mm respectively. The reduction of the forward movement of the maxillary base in the short-term (T3-T1) and long-term (T4-T1) post-treatment periods appeared to be stable, exhibiting a net restriction of forward movement compared to the control group of 0.7 mm and 0.9 mm respectively. This was consistent with that shown in previous studies where the maxillary base moved forward 0.8-1.4 mm^{7,92,103,112} in the short-term and 1.3-5.1 mm^{12,95,99,112,114,119,120} in the long-term post-treatment period. During phase II treatment (T5-T1), A point experienced an additional net restriction of forward growth equal to 1.8 mm in the treatment group compared to the control group, giving a total net restriction of 2.8 mm. These results suggest that treatment with the edgewise crowned Herbst appliance in the mixed dentition causes a restriction of forward movement of the maxillary base that is maintained after long term follow-up through phase II comprehensive orthodontic treatment.

Another indicator of the restraining effect on maxillary growth is the SNA angle. In the present study, initial treatment with the Herbst appliance (T2-T1) led to a 0.9° decrease in the SNA angle relative to the control group. This change is supported by other studies that have reported similar decreases in the SNA angle during treatment of 0.4-1.2 °^{9,12,14,18,80-82,92,99,103,112-114,117,119,121-123}. After phase I treatment (T3-T1), the SNA angle relapsed to only a net decrease of 0.5 °, near pre-treatment levels, in the short-term post-treatment period which was consistent with most other studies^{92,112,121}. In the long-term post-treatment period (T4-T1), the SNA angle had a net decrease of 0.7 °, which was consistent with other investigations which reported a decrease of 0.6-0.8 ° during the same period. Some investigators have reported an increase in the SNA angle of 0.2-4.0 °

during this period^{12,98,119}. Over the entire treatment period (T5-T1), this study showed a net significant difference of -2.6 ° in SNA angle in the treatment group relative to the control group which supports the concept that treatment with the edgewise crowned Herbst appliance in the mixed dentition causes a restriction of forward movement of the maxillary base that is maintained for the long term through phase II comprehensive orthodontic treatment.

The changes in Co-A pt. exhibited significant differences in the treatment group relative to the control group throughout all time periods in the study. During the initial phase of treatment, a net difference of -2.6 mm was seen in the treatment group relative to the control group. Co-A pt. experienced a backwards movement of 0.5 mm in the treatment group from T1 to T2. In the short-term post-treatment period (T3-T1), a -2.0 mm net difference in treatment group relative to control group was observed. In the long-term post-treatment period (T4-T1), a -3.0 mm net difference in treatment group relative to control group was apparent. From T1 to T5, an overall net restriction of 3.8 mm in Co-A pt. was seen. This data is further evidence that restriction in maxillary growth occurs with treatment with the Herbst appliance and is stable through the long term.

In this study, the position of the mandibular base (OLp-Pg) moved forward 2.8 mm from its original position and although it was not significant, the mandibular base moved forward 2.0 mm relative to the control group in the initial time period T2-T1. This is consistent with previous studies that have shown forward movement of the mandibular jaw base (as measured by Pg-point) of 0.9-5.0 mm in response to treatment^{12,14,59,80,82,92,103,105,109-119,122-125}. In the short-term post-treatment period (T3-T1), a net increase in OLp-Pg of only 0.6 mm was shown in the treatment group relative to the

control group, a relapse of 1.4 mm. Although the lower jaw continued to move forward in the treatment group, net differences from the control group became smaller. This same trend occurred over the long-term post-treatment period (T4-T1), with the net difference of only 0.5 mm between the treatment and control groups. At T5, OLp-Pg became larger in the control group than in the treatment group with a net difference of -1.6 mm. These results suggest that the initial forward positioning of the mandibular base (OLp-Pg) in the treatment group as a response to Herbst treatment was not maintained during the follow-up period after Herbst treatment and was further reduced during phase II orthodontic treatment. Wieslander made similar conclusions when he found no significant long-term effect of Herbst treatment on the mandibular structures and in the mandibular position in comparison with changes in the control group¹²⁰.

Another indicator of the change in position of the mandibular base is the SNB angle. In this study, a net increase of 1.0° was observed in the treatment group compared to the control group at T2-T1. This is consistent with previous studies that have reported increases in the SNB angle of 0.2-2.6° in response to Herbst treatment^{7,9,12,14,18,80,81,92,96,98,112-114,117,118,121-124}. During the short-term post-treatment period (T3-T1), the net difference in the treatment group compared to the control remained virtually unchanged at 0.9°, which was consistent with previous studies^{112,118}. In the long-term post-treatment period (T4-T1), although the SNB angle in the treatment group increased by 1.7°, a net difference of only 0.3° was found between the treatment and control groups. This was consistent with previous studies that showed an increase in the SNB angle of 0.3-2.6°^{12,98,114,119}. At T5, the SNB angle became larger in the control group than in the treatment group with a net difference of -0.5°. Again, this seems to

demonstrate that the initial forward positioning of the mandibular base in the treatment group as a response to Herbst treatment was lost over the long term.

An initial increase in mandibular length as measured by Co-Gn was observed in the present study. The treatment group experienced an increase in mandibular length of 3.4 mm and the control group experienced an increase in mandibular length of 2.7 mm, giving a net increase of 0.7 mm in the treatment group relative to the control group. This is consistent with other studies that report that the Co-Gn distance increased 3.4-6.4 mm^{14,16,93,117} in response to treatment, while subjects with no treatment only experienced an increase of 2.0 mm⁹³. The increase in mandibular length was reduced in the short-term post-treatment period (T3-T1) when a net difference of -0.1 mm was seen in the treatment as compared to the control group. After the long-term post-treatment period (T4-T1), the length of the mandible in the control group was 2.6 mm longer than in the treatment group. After comprehensive phase II orthodontic treatment (T5-T1), the length of the mandible in the control group was still 1.9 mm longer than the treatment group. These results indicate that the increase in mandibular length with Herbst treatment is not maintained in the long term.

In this study, the sagittal intermaxillary jaw relationships were improved with Herbst appliance treatment. In the time period T2-T1, the Wits analysis showed a net decrease of 3.7 mm in the treatment group relative to the control group. This was slightly larger than the than the Wits decrease between 2.4 and 3.0 mm reported in other studies^{14,92,113,118,121}, however, it was consistent with the decrease in Wits of 3.0-5.1 mm seen in studies on Class II division 2 patients^{113,126}. The net difference in Wits decreased to -1.7 mm in the treatment compared to the control in the short-term post-treatment

period (T3-T1). This change was different from other studies that reported the Wits appraisal remained substantially unchanged in the short-term post-treatment period^{92,118,121,126}. The net difference in Wits between the treatment group and control group continued to decline until T4 where the treatment and control group Wits appraisal was virtually the same. During the comprehensive phase II orthodontic treatment the Wits again experienced a net decline of 1.6 mm in the treatment group relative to the control group. These results indicate that the Herbst treatment had only a temporary impact on the existing skeletofacial growth pattern. After the treatment period, the intermaxillary relationship seemed to return to its pre-treatment pattern as previously described by Pancherz⁹⁹.

Another indicator of sagittal intermaxillary jaw relationships is the ANB angle. In this study, the ANB angle decreased 2.0° in the treatment group relative to the control group at T2-T1. This was consistent with other studies that reported decreases in the ANB angle from 1.1-3.9°^{9,12,14,16,18,80,81,92,93,96,99,112-114,117,118,121-124} in response to Herbst treatment. In the short-term post-treatment period (T3-T1), the ANB angle increased slightly to a 0.6 mm net difference in treatment compared to control, which was consistent with other studies that showed slight increases in this same period of 0.1-0.4°^{7,92,98,118,121}. In the long-term post-treatment period (T4-T1), the net difference in ANB between the treatment group and control group increased to 1.1 mm although the treatment group still showed an overall decrease of 1.6° from the pretreatment value. This is consistent with other studies that have shown a 0.4-4.0° decrease in the long-term post-treatment period^{112,114,119,120}. ANB experienced a net decrease of 1.0° in the treatment group relative to the control group during phase II comprehensive orthodontic

treatment. Overall, a net decrease in ANB of 2.1° in the treatment group compared to the control group was experienced from T1 to T5.

Sagittal Changes (Dental)

The Herbst appliance exerts a posterior superior force on the maxillary dentition and an anterior inferior force on the mandibular dentition^{9,19,82,98,109,113,122}, which generally results in distalization of the maxillary molars, retroclination of the maxillary incisors, mesial movement of the mandibular molars, and proclination of the mandibular incisors^{19,82,93,122,124}.

In this study, after subtracting maxillary movement, the maxillary molars were distalized in the treatment group as measured by Ms-OLp a distance of 2.9 mm during Herbst treatment at time period T2-T1. A net molar movement of -3.1 mm was seen when the treatment group was compared to the control group. This is consistent with the amount of distal molar movement in response to Herbst treatment reported in other studies of 0.6-3.0 mm^{12,14,80-82,92,93,95,98,103,105,109,110,114,115,118,119,122,123}. In contrast, some studies found mesial movement of the maxillary molars of 0.2-0.6 mm^{18,59,117}. In the short-term post-treatment period, the maxillary molars in the treatment group moved forward 2.6 mm, but still maintained a net posterior position of 1.5 mm compared to the control group. Previous studies have reported a mesial movement of the maxillary first molars of 0.7-1.4 mm after Herbst removal in the short-term post-treatment period^{12,92,95,98,103}. In the long-term post-treatment period, the maxillary molars in the treatment group had moved forward 0.8 mm from their original position, but a net molar movement of 2.1 mm in a backwards direction was still evident in the treatment group relative to the control group. Previous studies have reported forward movement of the

maxillary molars of between 1.6 and 1.9 mm during this period^{12,98,115,119}. At the completion of phase II comprehensive orthodontic treatment (T5-T1), the maxillary molars had moved forward 2.3 mm from their original position and maintained a net posterior position of only -0.2 mm in the treatment group compared to the control group. Treatment mechanics during the phase II comprehensive orthodontic treatment may have led to the forward movement seen by the maxillary molars in the treatment group. The results of this study suggest that effective distalization of the maxillary molars occurs in response to Herbst treatment and the movement is stable in the long term, however, most of the posterior molar movement was eliminated during phase II comprehensive orthodontic treatment.

In the present study, the mandibular molars as measured by Ms-OLp moved forward a distance of 2.0 mm from their original position in the treatment group at time period T2-T1. A net mandibular molar movement of 1.1 mm in a forward direction was seen in the treatment group as a result of the anteriorly directed force of the Herbst appliance. This amount falls within the range of mandibular molar movement reported in previous studies of 0.9-5.5 mm^{7,14,18,19,59,80-82,92,93,103,105,109-111,113-115,117,119,121-124}. In the short-term post-treatment period after Herbst removal (T3-T1), mandibular molars in the treatment group moved 1.0 mm forward from their original position, indicating a backwards movement of 1.0 mm in the treatment group from T2 to T3. This number is slightly more than the amount of distal relapse reported in the short-term post-treatment period in previous studies of 0.4-0.8 mm^{92,98,103,115,119,124}. A net mandibular movement of 0.5 mm in a forward direction was seen at the time period T3-T1 when the treatment group was compared to the control group. In the long-term post-treatment period (T4-

T1), the mandibular molars in the treatment group moved 0.7 mm forward from their original position, indicating a backwards movement of 1.3 mm in the treatment group from T2 to T4. This is consistent with previous studies that have reported a continued distal movement of 0.4-0.8 mm in the mandibular molars during the long-term post-treatment period^{12,98,119}. A net mandibular movement of 0.1 mm in a backward direction was seen at the time period T4-T1 when the treatment group was compared to the control group. At the completion of phase II comprehensive orthodontic treatment (T5-T1), the mandibular molars had moved forward 1.6 mm from their original position and maintained a net anterior movement of only 0.8 mm in the treatment group when compared to the control group. Treatment mechanics during the phase II comprehensive orthodontic treatment may have led to the forward movement seen by the mandibular molars in the treatment group. The results of this study suggest that mesial movement of the mandibular molars occurs in response to Herbst treatment, however the forward movement is not stable in the long term. Treatment mechanics during the phase II comprehensive orthodontic treatment can lead to increased mandibular molar movement in an anterior direction.

In the present study, the maxillary incisors (Is-OLp) moved backwards 2.6 mm and were retroclined (Is/NL) 7.3° from their original position in the treatment group at time period T2-T1. A net maxillary incisor movement of 3.7 mm in a backward direction and a net maxillary incisor retroclination of 7.0° were seen in the treatment group in relation to the control group. This is consistent with the reported literature that shows maxillary incisor distal movement of 0.5-3.6 mm and maxillary incisor retroclination of 3.2-8.2° in response to Herbst treatment^{7,14,59,92,93,98,103,105,109-111,113,114,117-119,122,123}. In

contrast, other investigators found no significant differences in maxillary incisor position^{9,80-82} or a mesial movement of 0.8 mm¹⁸. In the short-term post-treatment period at T3, the maxillary incisors rebounded forward 2.4 mm in the treatment group, leaving them 0.2 mm behind their original position. A net backward movement of 2.0 mm was still evident in the treatment group compared to the control group at time period T3-T1. This is inconsistent with the reported literature which shows that during the short-term post-treatment period, the maxillary incisor position remained unaffected^{92,98,103,115}. In addition, the maxillary incisors were retroclined 1.3° in the treatment group compared to the control group at time period T3-T1. During the long-term post-treatment period, the maxillary incisors continued to rebound in a forward direction a distance of 4.1 mm in the treatment group from the post-treatment position at T2. The maxillary incisors were moved forward a distance of 1.5 mm from their original position in the treatment group, however they showed a net posterior movement of 1.2 mm when compared to the control group at time period T4-T1. A net proclination of 1.7° was seen in the maxillary incisors in the treatment group relative to the control group at time period T4-T1. Most reports in the literature show long-term post-treatment relapse of 0.4-2.1 mm in a mesial direction^{12,98,114}, however, other investigators did not observe a significant change in the incisor position during the same period¹¹⁹. At the completion of phase II comprehensive orthodontic treatment (T5-T1), the maxillary incisors had moved forward 0.8 mm from their original position and maintained a net posterior movement of 1.4 mm in the treatment group when compared to the control group. The net change in maxillary incisor proclination was 1.5° compared to the control group at this same time period. The results of this study suggest that the maxillary incisors are moved posteriorly in response

to Herbst treatment and although some relapse in a forward direction occurs after treatment, a net posterior movement is maintained over the long term in the treatment group relative to the control group. In addition, the maxillary incisors are initially retroclined in response to Herbst treatment, however over the long term, proclination of the maxillary incisors occurs as they relapse to their pre-treatment inclination.

In the present study, the mandibular incisors (Ii-OLp) moved forwards 2.0 mm and were proclined (Ii/ML) 7.1° from their original position in the treatment group at time period T2-T1. A net mandibular incisor movement of 0.9 mm in a forward direction and a net mandibular incisor proclination of 7.6° were seen in the treatment group in relation to the control group. This is consistent with the reported literature that shows mandibular incisor mesial movement of 0.2-4.0 mm and mandibular incisor proclination of 5.4-10.8° in response to Herbst treatment^{7,9,12,19,59,80-82,92,93,98,103,105,109,110,112-115,117-119,121-124,126-128}. In contrast, other investigators found no significant differences in mandibular incisor position¹¹⁹. It has been reported that the mandibular incisor proclination observed during Herbst treatment did not have an effect on the preexisting gingival recession or did not cause gingival recession¹²⁸. In the short-term post-treatment period at T3, the mandibular incisors rebounded backwards 0.8 mm in the treatment group, leaving them only 0.1 mm ahead of their original position. A net backward movement of 0.2 mm was evident in the treatment group compared to the control group at time period T3-T1. This is consistent with the reported literature which shows that during the short-term post-treatment period, the mandibular incisor position relapsed backwards a distance of 0.9-3.3 mm^{92,103,112,115,121}, thus returning approximately to their initial position^{92,121}. In addition, the mandibular incisors were proclined 0.8° in the treatment group compared to the

control group at time period T3-T1. The proclination of the mandibular incisors from T2 to T3 was reduced 5.8° in the treatment group. This is close to the amounts reported in previous studies in which the mandibular incisor proclination was reduced between 6° and 7.9° during the first year of the post-treatment period^{98,103,112,121}. During the long-term post-treatment period, the mandibular incisors continued to rebound in a backwards direction a distance of 1.5 mm in the treatment group from the post-treatment position at T2. The mandibular incisors were moved forward a distance of 0.5 mm from their original position in the treatment group and they showed a net anterior movement of 0.9 mm when compared to the control group at time period T4-T1. A net proclination of 3.3° was seen in the mandibular incisors in the treatment group relative to the control group at time period T4-T1. Previous studies have found that during the long-term post-treatment period the mandibular incisors moved distally 1.6-3.8 mm^{12,98,112,114,119} and retroclined 1.9-2.5° in relation to the sella-nasion line^{112,114}. At the completion of phase II comprehensive orthodontic treatment (T5-T1), the mandibular incisors had moved backward -0.6 mm from their original position, however they maintained a net forward movement of 0.2 mm in the treatment group when compared to the control group. The net change in mandibular incisor proclination was 3.0° compared to the control group at this same time period. The results of this study suggest that the mandibular incisors are initially moved forward and proclined in response to Herbst treatment but relapse to original pretreatment levels within the short-term post-treatment period.

Overjet Changes

In this study, the overjet correction was 6.4 mm in the treatment group in response to Herbst treatment. 1.8 mm (28.1%) of the correction was the result of skeletal changes

and 4.6 mm (71.9%) of the correction was the result of dental changes. When the treatment group was compared to the control group, a net overjet correction of 7.0 mm was achieved. 2.4 mm (34.3%) of the correction was the result of skeletal changes and 4.6 mm (65.7%) was the result of dental changes. In previous studies, overjet reductions ranging from 3.3-9.8 mm after Herbst treatment have been reported^{7,9,12,16,18,19,59,80,82,92,98,109-111,114-117,119,121-124,129}. In the short-term post-treatment period, the overjet correction was reduced to 2.5 mm, mostly as a result of dental relapse. 2.2 mm (85%) of the correction was the results of skeletal changes and only 0.3 mm (12.0%) was the result of dental changes. When the treatment group was compared to the control group, a net overjet correction of 3.1 mm was observed. 1.3 mm (41.9%) of the correction was the result of skeletal changes and 1.8 mm (58.1%) was the result of dental changes. Previous studies have reported that after Herbst removal the overjet relapsed 1.7-3.0 mm during the short-term post-treatment period^{92,98,103,121,129}. In the long-term post-treatment period, the overjet correction in the treatment group was reduced to 1.8 mm. 2.8 mm (155.6%) of the correction was the result of skeletal changes and dental changes relapsed to have a -1.0 mm (-55.6%) effect on the overjet correction. When the treatment group was compared to the control group, a net overjet correction of 2.5 mm was observed. Only 0.4 mm (16.0%) of the correction was the result of skeletal changes and 2.1 mm (84.0%) of the correction was the result of dental changes. Previous studies have found in the overjet of 0.3-2.4 mm in the long-term post-treatment period^{12,98,114,119,120}. In total, studies have found that the Herbst appliance caused an overjet correction between 3.3 and 5.7 mm from the pre-treatment to the long-term post-treatment period^{12,98,114,119,129}. After the completion on phase II comprehensive

orthodontic treatment, the overjet correction in the treatment group was 2.2 mm. 3.6 mm (163.6%) of the correction was the result of skeletal changes and dental changes relapsed to have a -1.4 mm (-63.6%) effect on the overjet correction. When the treatment group was compared to the control group, a net overjet correction of 2.8 mm was observed. 1.2 mm (42.9.0%) of the correction was the result of skeletal changes and 1.6 mm (57.1%) of the correction was the result of dental changes.

In summary, the Herbst appliance initially produced a net overjet correction of 7.0 mm in the treatment group relative to the control group, then relapsed in the short-term post-treatment period until a relatively stable net overjet correction between 2.5-3.0mm was maintained over the long-term. Figures 47 and 48 display graphs of the skeletal and dental contributions to net overjet correction. The skeletal contribution to net overjet correction was 2.4 mm initially but continuously dropped over the long-term post-treatment period to only 0.4 mm. Relapse in the mandible was responsible for the reduction in skeletal contribution to overjet correction as the mandible continuously moved backwards in the treatment group relative to the control group at all time periods after the initial advancement of 2.0 mm after Herbst treatment. Restriction of the forward movement of the maxilla in the treatment group relative to the control group was found following Herbst treatment and was maintained for the long term and through phase II comprehensive orthodontic treatment. The dental contribution to net overjet correction was large (4.6 mm—65.7%) immediately after Herbst treatment, but declined rapidly in the short-term post-treatment period when the maxillary and mandibular incisors relapsed significantly. The dental contribution to net overjet correction then increased during the long-term post-treatment period when the incisors appeared to compensate for the

relapsing skeletal correction as the intermaxillary relationship seemed to return to its pre-treatment pattern. The maxillary incisors are moved posteriorly in response to Herbst treatment and although some relapse in a forward direction occurs after treatment, a net posterior movement and sustained contribution to net overjet correction is maintained over the long term in the treatment group relative to the control group. The mandibular incisors are initially moved forward and proclined in response to Herbst treatment but relapse to original pretreatment levels within the short-term post-treatment period. In the long-term post-treatment period, the mandibular incisors were proclined to compensate for the relapsing intermaxillary relationship.

Figure 47. Skeletal contribution to net overjet correction

Figure 48. Contribution of the skeletal bases and incisors to net overjet correction

Molar Relationship Changes

In this study, the molar correction was 6.7 mm in the treatment group in response to Herbst treatment. 1.8 mm (26.9%) of the correction was the result of skeletal changes and 4.9 mm (73.1%) of the correction was the result of dental changes. When the treatment group was compared to the control group, a net molar correction of 6.6 mm was achieved. 2.4 mm (36.4%) of the correction was the result of skeletal changes and 4.2 mm (63.6%) was the result of dental changes. In previous studies, molar relationship corrections ranging from 3.0-9.3 mm after Herbst treatment have been reported^{12,18,19,59,80,82,92,109,113-117,122,123}. In the short-term post-treatment period, the molar correction was reduced to 3.5 mm. 2.2 mm (62.9%) of the correction was the result of skeletal changes and 1.3 mm (37.1%) was the result of dental changes. When the treatment group was compared to the control group, a net molar correction of 3.3 mm was observed. 1.3 mm (39.4%) of the correction was the result of skeletal changes and 2.0 mm (61.6%) was the result of dental changes. Previous studies have reported that after Herbst removal the molar relationship correction relapsed 1.1-1.7 mm during the short-term post-treatment period^{92,103,115}. In the long-term post-treatment period, the overjet correction in the treatment group was reduced to 2.7 mm. 2.8 mm (103.7%) of the correction was the result of skeletal changes and dental changes relapsed to have a -0.1 mm (-3.7%) effect on the molar correction. When the treatment group was compared to the control group, a net molar correction of 2.4 mm was observed. Only 0.4 mm (16.7%) of the correction was the result of skeletal changes and 2.0 mm (83.3%) of the correction was the result of dental changes. Previous studies have found relapse in the molar relationship of 0.4-2.6 mm in the long-term post-treatment period^{12,114,119}. After

the completion on phase II comprehensive orthodontic treatment, the molar correction in the treatment group was 2.9 mm. 3.6 mm (124.1%) of the correction was the result of skeletal changes and dental changes relapsed to have a -0.7 mm (-24.1%) effect on the molar correction. When the treatment group was compared to the control group, a net molar correction of 2.2 mm was observed. 1.2 mm (54.5%) of the correction was the result of skeletal changes and 1.0 mm (45.5%) of the correction was the result of dental changes.

The molar relationship correction followed the same general trends as the overjet correction. Figures 49 and 50 display graphs of the skeletal and dental contributions to net overjet correction. The Herbst appliance initially produced a net molar correction of 6.6 mm in the treatment group relative to the control group, then relapsed in the short-term post-treatment period until a relatively stable net molar correction between 2.2-3.3mm was maintained over the long-term. The skeletal contribution to net molar correction was 2.4 mm initially but continuously dropped over the long-term post-treatment period to only 0.4 mm. Relapse in the mandible was responsible for the reduction in skeletal contribution to molar correction as the mandible continuously moved backwards in the treatment group relative to the control group at all time periods after the initial advancement of 2.0 mm after Herbst treatment. Restriction of the forward movement of the maxilla in the treatment group relative to the control group was found following Herbst treatment and was maintained for the long term and through phase II comprehensive orthodontic treatment. The dental contribution to net molar correction was large (4.2 mm—63.6%) immediately after Herbst treatment, but declined rapidly in the short-term post-treatment period when the maxillary and mandibular molars relapsed

significantly. The dental contribution to net molar correction remained stable during the long-term post-treatment period when the molars appeared to compensate for the relapsing skeletal correction as the intermaxillary relationship seemed to return to its pre-treatment pattern. The maxillary molars are moved posteriorly in response to Herbst treatment and although some relapse in a forward direction occurs after treatment, a net posterior movement and sustained contribution to net overjet correction is maintained over the long term in the treatment group relative to the control group. Most of the compensation for the relapsing intermaxillary relationship occurred in the maxillary molars. In phase II comprehensive orthodontic treatment, however, the maxillary molars were brought forward approximately to their pre-treatment position presumably due to treatment mechanics in an effort to achieve a Class I occlusion. The mandibular molars are initially moved forward in response to Herbst treatment but relapsed to original pretreatment levels over the long-term post-treatment period. They did not appear to compensate for the relapsing intermaxillary relationship. The mandibular molars were brought forward during phase II comprehensive orthodontic treatment in an effort to achieve a Class I occlusion.

Figure 49. Skeletal contribution to net molar correction

Figure 50. Contribution of skeletal bases and incisors to net molar correction

Vertical Changes (Skeletal)

None of the vertical skeletal variables showed significant differences between the treatment and control group in response to treatment with the Herbst appliance in this study except for the palatal plane angle (SNL-NL) and the occlusal plane angle (SNL-OL). In this study, the palatal plane tipped downwards (counterclockwise) 1.7° in the treatment group relative to the control group in response to Herbst treatment. In previous studies, it was reported that the palatal plane tipped downwards 0.2-1.0° in response to Herbst treatment^{9,12,14,81,82,95,98,99,112,114,119,123}. In the short-term post-treatment period, the palatal plane angle in the treatment group relapsed 1.4° and showed no significant difference relative to the control group. This is consistent with previous studies that showed that the palatal plane angle did not present significant changes in the short-term post-treatment period^{95,98,99,112}. In the long-term post-treatment period, no significant differences were found in the change in the palatal plane angle in the treatment group relative to the control group in response to Herbst treatment. In the long-term post-treatment period, some studies have reported a 1.0° increase in the palatal plane angle^{95,114}, others have reported a 0.5-0.6° decrease^{98,119}, and others have reported nonsignificant changes¹¹².

In this study, the occlusal plane angle (SNL-OL) tipped clockwise 3.4° in response to treatment with the Herbst appliance. In the short-term post-treatment period, the occlusal plane angle in the treatment group relapsed in a counterclockwise direction 3.2° to approximately its pre-treatment angulation, showing no significant difference in the changes relative to the control group. In the long-term post-treatment period, further counterclockwise tipping was noted, however no significant differences were found in the changes from T1 to T4 in the treatment group relative to the control group. This is

consistent with previous studies that have shown an initial 1.1-5.1° clockwise tipping of the occlusal plane^{7,14,80,82,92,93,95,98,113,114,118,122,123}, a counterclockwise tipping of 1.3-2.8° in the short-term post-treatment period^{92,95,98}, and a further counterclockwise tipping during the long-term post-treatment period^{7,98,114}.

No significant differences were found in the changes in mandibular plane angle (SNL-ML) in the treatment group relative to the control group at any of the time periods in the study. The majority of investigators have found an increase in the mandibular plane angle during Herbst treatment^{7,9,80-82,92,98,99,105,112-114,118,121-123,130}, others have found that the mandibular plane angle decreased 0.1-2.0° during treatment^{93,103,105,117,119,130}, and others have found that it remained unchanged^{9,12,116}. In the short-term post-treatment period, some researchers have found that the mandibular plane angle decreased 0.5-0.7°,^{98,103,121} while others have reported that it remained unchanged⁹². In the long-term post-treatment period, Ruf and Pancherz concluded that the Herbst appliance does not have a significant effect on the mandibular plane angle¹³⁰.

Although the anterior lower facial height (ANS-Me) initially increased 0.8 mm and continued to increase throughout all time periods, no significant difference was found between the treatment and control groups at any of the time periods in this study. Treatment with the Herbst appliance had no effect on the anterior lower facial height at any time period and increases in this measurement are attributable to normal growth. Previous studies have reported increases of 0.4-4.1 mm in response to Herbst treatment^{9,14,80,93,105,117,124,131}, however Pancherz found that no difference was evident between the treatment and control groups in the 12-month post-treatment period⁸⁰.

Vertical Changes (Dental)

Significant differences in the change in the vertical position of the maxillary molars (Msc-NL) and mandibular incisors (Ii-ML) were seen in the treatment group relative to the control group in this study. No other significant differences were found in the vertical dental changes in response to Herbst treatment in this study.

The maxillary molars were initially intruded 1.3 mm in the treatment group compared to an extrusion of 1.3 mm in the control group. A net intrusion of 2.6 mm was seen in the maxillary molars in response to Herbst treatment in this study in the time period T2-T1. This is consistent with the reports of maxillary first molar intrusion of 0.5-1.1 mm in response to Herbst treatment reported in previous studies^{80,93,95,103,126}. Some studies reported an extrusion of the maxillary molars of 1.4-1.5 mm during the treatment period^{117,126}. In the short-term post-treatment period, 1.9 mm of extrusion in the maxillary molars was seen in the treatment group, producing an overall net intrusion of 1.1 mm in the treatment group relative to the control group in this study. This is slightly more than the 1.1-1.4 mm of extrusion noted in previous studies in the short-term post-treatment period^{95,103}. In the long-term post-treatment period, additional extrusion of 1.7 mm was seen in the treatment group totaling 3.6 mm of extrusive movement after treatment, however an overall net intrusion of 1.4 mm was found compared to the treatment group. This is consistent with the amount of extrusion reported in previous studies of 3.5 mm during the long-term post-treatment period^{95,103}. During phase II comprehensive orthodontic treatment, the maxillary molars were extruded more in the treatment group than what was shown in the control group and the significant differences

in the change in the vertical position of the maxillary molars between the treatment group and the control group disappeared.

The maxillary incisors (Is-NL) extruded 0.9 mm from their original position after Herbst treatment but experienced a relative intrusion of 0.9 mm in the treatment group compared to the control group. A relative intrusion of 0.9 remained through the long-term post-treatment period, however, there were no significant differences in the relative intrusion between the treatment and control groups in any of the time periods throughout this study. Previous studies have reported maxillary incisor extrusion of 0.2-2.2 mm after treatment^{103,105,117}, but no significant changes were found during the retention period¹⁰³.

The mandibular molars (Mic-ML) extruded 1.2 mm from their original position after Herbst treatment, but no significant changes in the vertical position of the mandibular molars existed between the treatment and control groups. Although the mandibular molar extruded 2.2 mm from its original position during the time period T4-T1, no long-term significant difference in the vertical position of the mandibular molars existed between the treatment and control groups. Previous studies have reported a molar extrusion of 1.3-2.8 mm after treatment^{80,93,103,105,124,126} followed by addition extrusion of 0.6 mm in the short-term post-treatment period¹⁰³.

The mandibular incisors were initially intruded 0.8 mm in the treatment group compared to an extrusion of 1.0 mm in the control group. A net intrusion of 1.8 mm was seen in the mandibular incisors in response to Herbst treatment in this study in the time period T2-T1. Although the differences became insignificant, a relative intrusion of 0.6 mm in the short-term post-retention period and a relative intrusion of 0.7 mm was seen in the long-term post-treatment. No significant changes in the vertical position of the

mandibular incisors between the treatment and control groups occurred during phase II comprehensive orthodontic treatment. Previous studies report mandibular incisor intrusion of 0.4-2.4 mm in response to Herbst treatment^{80,93,103,105,124,126}, followed by an extrusion of 0.6 mm in the short-term post-treatment period¹⁰³.

The overbite was initially reduced 1.1 mm in the treatment group compared to an increase of 1.3 mm in the control group. A net decrease in overbite of 2.4 mm was seen in response to Herbst treatment in this study in the time period T2-T1. The overbite reduction relapsed to approximate pre-treatment levels in the short-term post-treatment period and remained relatively stable through the long-term post-treatment period and phase II comprehensive orthodontic phase. A relative decrease in overbite in the treatment group compared to the control group was maintained over the long-term. Previous studies have reported a reduction in overbite of 1.9-5.6 mm after Herbst treatment^{7,9,12,80,96,98,116,117,124,126,129}. A relapse of 1.7-1.8 mm during the short-term post-treatment period^{80,119} followed by an increase of 0.5-1.1 mm during the long-term post-treatment period^{12,98,129} was reported in the previous literature.

Condyle/Glenoid Fossa Changes

Only two condyle/glenoid fossa variables showed significant differences between the treatment and control groups at T2-T1; OLp-CoC and OLp-GFA. Although not all significant, every sagittal condyle/glenoid fossa variable (OLp-CoC, OLp-GFS, OLp-GFA, and OLp-GFP) showed a forward movement in the treatment group and a backward movement in the control group. Net anterior movements of 1.7 mm, 1.0 mm, 2.1 mm, and 1.6 mm were found in the treatment group relative to the control group for the condylar position (OLp-CoC), the superior aspect of the glenoid fossa (OLp-GFS),

the anterior aspect of the glenoid fossa (OLp-GFA), and the posterior aspect of the glenoid fossa (OLp-GFP). No significant differences were found in the vertical condyle/glenoid fossa variables between the treatment and control groups.

Only one condyle/glenoid fossa variable, OLp-CoC, showed a significant difference between the treatment and control groups at T3-T1. Although not all significant, once again every sagittal condyle/glenoid fossa variable (OLp-CoC, OLp-GFS, OLp-GFA, and OLp-GFP) showed a forward movement in the treatment group and a backward or only slightly forward movement in the control group. Net anterior movements of 1.2 mm, 1.0 mm, 0.9 mm, and 1.3 mm were found in the treatment group relative to the control group for the condylar position (OLp-CoC), the superior aspect of the glenoid fossa (OLp-GFS), the anterior aspect of the glenoid fossa (OLp-GFA), and the posterior aspect of the glenoid fossa (OLp-GFP). No significant differences were found in the vertical condyle/glenoid fossa variables between the treatment and control groups at this time period.

Four condyle/glenoid fossa variables showed significant differences between the treatment and control groups at T4-T1; OLp-CoC, OLp-GFS, OLp-GFA, and OLp-GFP. Every sagittal condyle/glenoid fossa variable (OLp-CoC, OLp-GFS, OLp-GFA, and OLp-GFP) showed a forward movement in the treatment group and a backward movement in the control group. Net anterior movements of 1.8 mm, 1.8 mm, 1.3 mm, and 1.9 mm were found in the treatment group relative to the control group for the condylar position (OLp-CoC), the superior aspect of the glenoid fossa (OLp-GFS), the anterior aspect of the glenoid fossa (OLp-GFA), and the posterior aspect of the glenoid

fossa (OLp-GFP). No significant differences were found in the vertical condyle/glenoid fossa variables between the treatment and control groups.

Only one condyle/glenoid fossa variable, OLs-GFP, showed a significant difference between the treatment and control groups after phase II comprehensive orthodontic treatment (T5-T1). Although not significant, every sagittal glenoid fossa variable (OLp-GFS, OLp-GFA, and OLp-GFP) showed a forward movement in the treatment group and a backward movement in the control group. The sagittal condyle variable OLp-CoC showed only a slight backward movement of 0.3 mm in the treatment group compared to a greater backward movement of 1.1 mm in the control group. Net anterior movements of 0.8 mm, 0.9 mm, 0.6 mm, and 1.7 mm were found in the treatment group relative to the control group for the condylar position (OLp-CoC), the superior aspect of the glenoid fossa (OLp-GFS), the anterior aspect of the glenoid fossa (OLp-GFA), and the posterior aspect of the glenoid fossa (OLp-GFP), respectively. The posterior aspect of the glenoid fossa (OLs-GFP) showed a significant upward movement in the treatment group relative to the control group. Although not significant, all other vertical condyle/glenoid fossa variables (OLs-CoC, OLs-GFS, and OLs-GFA) showed an overall upward net relative movement of the treatment group compared to the control group. Net superior movements of 1.3 mm, 0.7 mm, 0.7 mm, and 1.1 mm were found in the treatment group relative to the control group for the condylar position (OLs-CoC), the superior aspect of the glenoid fossa (OLs-GFS), the anterior aspect of the glenoid fossa (OLs-GFA), and the posterior aspect of the glenoid fossa (OLs-GFP), respectively.

None of the condyle/glenoid fossa variables showed significant differences between the treatment and control groups at T4-T3. Every sagittal condyle/glenoid fossa

variable (OLp-CoC, OLp-GFS, OLp-GFA, and OLp-GFP) in the treatment group moved backward, although the distance was less than the backward movement of the sagittal condyle/glenoid fossa variables in the control group. No significant differences or trends were found in the vertical condyle/glenoid fossa variables between the treatment and control groups.

Only one condyle/glenoid fossa variable, OLs-CoC, showed a significant difference between the treatment and control groups during phase II comprehensive orthodontic treatment (T5-T4). Although not significant, every sagittal condyle/glenoid fossa variable (OLp-CoC, OLp-GFS, OLp-GFA, and OLp-GFP) showed a backward movement in the treatment group and a forward movement in the control group from T4 to T5. This suggests possible relapse in the anteriorly relocated condyle and glenoid fossa in the treatment group. Net posterior movements of 1.0 mm, 0.9 mm, 0.7 mm, and 0.2 mm were found in the treatment group relative to the control group for the condylar position (OLp-CoC), the superior aspect of the glenoid fossa (OLp-GFS), the anterior aspect of the glenoid fossa (OLp-GFA), and the posterior aspect of the glenoid fossa (OLp-GFP). Although only OLs-CoC was significant, all vertical condyle/glenoid fossa variables (OLs-CoC, OLs-GFS, and OLs-GFA) showed an overall upward net relative movement of the treatment group compared to the control group from T4 to T5. Net upward movements of 1.0 mm, 0.6 mm, 0.6 mm, and 0.6 mm were found in the treatment group relative to the control group for the condylar position (OLs-CoC), the superior aspect of the glenoid fossa (OLs-GFS), the anterior aspect of the glenoid fossa (OLs-GFA), and the posterior aspect of the glenoid fossa (OLs-GFP), respectively.

Previous studies have reported that the placement of the Herbst appliance caused an anterior and downward movement of the condyle which induced adaptive growth, modeling, and remodeling of the condyle, the glenoid fossa, and the articular tubercle^{7,9,132}. It has been shown that adaptive growth in the condyle and remodeling of the glenoid fossa contribute to forward relocation of the mandible^{7,50,133}. These changes have been reported to be stable after Herbst treatment¹³².

In summary, in response to Herbst treatment, the entire glenoid fossa appears to move in an anterior direction. The condyle appears to shift forward slightly within the anteriorly relocated glenoid fossa. Movement of the entire glenoid fossa in the control group appeared to occur in a posterior direction, compounding the net anterior movement of the glenoid fossa in the treatment group. Slight relapse in the anterior movement of the entire glenoid fossa occurs in the short-term post-treatment period, however the entire glenoid fossa maintained a net anterior position in the treatment group relative to the control group. The condyle appeared to return to a more centered position in the fossa during this time period. During the long-term post-treatment period, the entire glenoid fossa appeared to return to its normal pattern of backward and downward movement, however the net anterior relocation was maintained. During phase II comprehensive orthodontic treatment, the entire glenoid fossa showed a net backward movement in the treatment group relative to the control suggesting possible relapse in the anteriorly relocated condyle and glenoid fossa in the treatment group. After phase II comprehensive orthodontic treatment, the glenoid fossa appeared to have relocated in an anterior superior direction in the treatment group relative to the control group. Relocation of the glenoid fossa in the treatment group appears to occur in an anterior and

superior direction relative to the control group in response to Herbst treatment and this relative change in position appears to be stable over the long term. From a study on nonhuman primates treated with the Herbst appliance, Voudouris et al.⁸⁸ reported that the growth modification measured in the glenoid fossa was in an inferior and anterior direction. In addition, he noted that restriction of the downward and backward growth of the fossa observed in the control subjects might additionally contribute to the Class II correction.

CHAPTER V: SUMMARY, CONCLUSIONS, RECOMMENDATIONS

Summary

The purpose of this study was to investigate the skeletal and dental changes of Class II patients treated with the crowned Herbst appliance in the early mixed dentition and examine the long term stability of these changes. Cephalometric analysis was performed on radiographs taken before phase I treatment (T1), immediately after Herbst removal during phase I treatment (T2), at the completion of phase I treatment (T3), prior to beginning of phase II orthodontic treatment (T4), and immediately following phase II orthodontic treatment (T5). Measurements were compared to a matched control sample of untreated Class II patients from the Bolton-Brush study. The results of this study should provide important information on the effectiveness of early treatment with the crowned Herbst appliance and offer new information on the long term stability of these treatment effects. This information could ultimately be used by clinicians to evaluate the best time and most effective technique for treating skeletal Class II deformities.

The difference in each variable between the treatment and control groups across the five time periods (T1 through T5) was analyzed for pooled subjects, and separately for male and female subjects. A repeated measures ANOVA was performed to determine if the differences between the treatment and control groups were the same across the five time periods.

The differences between certain time points were analyzed to investigate: **T2-T1:** treatment effects of the Herbst appliance (Tx (T2-T1)) minus (Control (t2-t1)), **T3-T1:**

Phase I treatment effects (Tx (T3-T1)) minus (Control (t3-t1)), **T4-T1**: residual Phase I treatment effects (Tx (T4-T1)) minus (Control (t4-t1)), and **T5-T1** combined Phase I and Phase II treatment effects (Tx (T5-T1)) minus (Control (t5-t1)). In addition, **T5-T4**: phase II treatment effects (Tx (T5-T4)) minus (Control (t5-t4)) were evaluated as well as **T4-T3**: the relapse that occurred from after Phase I treatment to before Phase II treatment (Tx (T4-T3)) minus (Control (t4-t3)).

For all time periods, the change in the values of the variables for pooled subjects, male subjects, and female subjects in the treatment group were compared to the change in the values of the variables for pooled subjects, male subjects, and female subjects in the control group, respectively. Matched pairs t-tests were performed for every variable at each time period to identify significant differences from the control group. In total, 37 variables were evaluated for each group including sagittal variables, vertical variables, angular variables, and condyle/glenoid fossa variables. In addition, an evaluation of the overjet correction and molar relationship correction for the treatment groups and an evaluation of the net overjet correction and net molar relationship correction for the treatment vs. control groups at each time period for pooled subjects were performed.

The results of this study were interpreted by evaluating changes that occurred in the sagittal and vertical directions. Transverse dimensional changes were not investigated in this study. Changes in the position of the maxillary skeletal base, the mandibular skeletal base, the maxillary molars and incisors, the mandibular molars and incisors, and the condyle/glenoid fossa region in response to treatment with the crowned Herbst appliance in the early mixed dentition were identified and followed over the long term through phase II orthodontic treatment.

Conclusions

Treatment of Class II patients treated with the crowned Herbst appliance in the early mixed dentition resulted in the following changes relative to normal growth:

1) The forward movement of the maxillary base (OLp-A pt) was initially restrained after treatment (T2-T1) and gradually became more restrained in the short-term (T3-T1) and long-term (T4-T1) post-treatment periods. An even greater restraint was seen after phase II orthodontics (T5-T1).

2) The mandibular base (OLp-Pg) was initially moved forward after treatment (T2-T1), however, a gradual relapse was seen in the short-term (T3-T1) and long-term (T4-T1) post-treatment periods. Additional relapse in a posterior direction was seen after phase II orthodontics (T5-T1).

3) The maxillary molars (Ms-OLp) were initially distalized (T2-T1), relapsed slightly in the short-term post-retention period (T3-T1), and became distalized again in the long-term post-treatment period (T4-T1). The maxillary molars were mesialized during phase II orthodontic treatment (T5-T4) and most of the overall posterior molar movement was eliminated after this period (T5-T1).

4) The mandibular molars (Mi-OLp) were initially mesialized after treatment (T2-T1), however gradual relapse occurred during the short-term post-treatment period (T3-T1) until they returned to their pre-treatment position after the long-term post-treatment period (T4-T1). They were mesialized again after phase II orthodontic treatment (T5-T1).

5) The maxillary incisors (Is-OLp) moved backward and retroclined after treatment (T2-T1), then relapsed slightly during the short-term (T3-T1) and long-term

(T4-T1) post-treatment period. A net posterior movement was maintained through the long-term post-treatment period (T4-T1). This posterior position of the maxillary incisor remained stable through phase II treatment (T5-T1).

6) The mandibular incisors (Ii-OLp) moved forward and proclined after treatment (T2-T1), then relapsed to their pre-treatment position after the short-term post-treatment period (T3-T1). Forward movement and proclination occurred during the long-term retention period (T4-T3), giving a net forward movement and proclination after this period (T4-T1). The mandibular incisors returned to their pre-treatment position after phase II orthodontic treatment (T5-T1).

7) A net overjet correction of 7.0 mm occurred after treatment (T2-T1), then relapsed in the short-term post-treatment period (T3-T1) until a relatively stable net overjet correction between 2.5-3.0mm was maintained over the long-term (T4-T1). The overjet correction remained stable through phase II treatment (T5-T1).

8) A molar relationship correction of 6.6 mm occurred after treatment (T2-T1), then relapsed in the short-term post-treatment period (T3-T1) until a relatively stable net molar correction between 2.2-3.3mm was maintained over the long-term (T4-T1). The molar correction remained stable through phase II treatment (T5-T1).

9) Relocation of the glenoid fossa occurred in an anterior and superior direction after treatment (T2-T1) and this relative change in position was stable over the long term (T4-T1). Restriction of the downward and backward movement of the fossa was observed and might additionally contribute to Class II correction.

Recommendations

Upon completion of this study, the following recommendations were made:

- 1) Repeating the study with images from cone beam CT scans would allow more accurate identification of landmarks and more precise visualization of anatomic structures. Analysis of the changes, especially temporomandibular joint changes could be more accurately identified and observed. It is realized that it may be difficult to identify an adequate control sample due to the increased exposure to radiation with these scans.
- 2) A repeat study matching the treatment group to the control group based on skeletal maturation (determined by cervical vertebrae maturation) as opposed to age would provide more detailed information on the treatment responses of the Herbst appliance in relation to development and provide interesting insight into the importance of treatment timing.
- 3) Future studies directly comparing an early treatment group treated with the edgewise crowned Herbst appliance with a late treatment group of patients treated with the edgewise crowned Herbst appliance would be interesting.

REFERENCES

1. Andresen, V., and Häupl, K.: Funktions-Kieferorthopädie. H. Meusser. Leipzig, 1936.
2. Balters, W.: Die Technik und Übung der allfemeinen und speziellen Bionatortherapie. Quintessenz, 1: 77, 1964.
3. Fränkel, R.: Funktionskeiferorthopädie und der Mundhof als apparative Basis. V.E.B. Verlag Volk & Gesundheit. Berlin, 1967.
4. Pancherz, H. The Herbst Appliance Editorial Aquarium 1995; Barcelona Spain.
5. McNamara, J.A. Jr., Carlson, D.S. Quantitative analysis of temporomandibular joint adaptation to protrusive function. Am J Orthod. 1979; 76: 593-611.
6. Woodside, D.G., Metaxas, A, Altuna, G. The influence of functional appliance therapy on glenoid fossa remodeling. Am J Orthod Dentofacial Orthop. 1987; 92: 181-198.
7. Paulsen, H. U., Karle, A, Bakke, M., Heskind, A. CT scanning and radiographic analysis of temperomandibular joints and cephalometric analysis in a case of Herbst treatment in late puberty. Eur J Orthod. 1995; 17: 165-75.
8. Bakke, M., Paulsen, H. U., Herbst treatment in late adolescence: clinical, electromyographic, kenesiographic, and radiographic analysis of one case. Eur J Orthod. 1989; 11: 3997-407.
9. Pancherz, H.: Treatment of Class II malocclusions by jumping the bite with the Herbst appliance. A cephalometric investigation. Am J Orthod. 76: 423-442, 1979.
10. Hagg U, Pancherz H. Dentofacial orthopedics in relation to chronological age, growth period and skeletal development. An analysis of 72 male patients with Class II division 1 malocclusion treated with the Herbst appliance. Eur. J Orthod. 1988; 10:169-176.
11. Pancherz H. The effects, limitations, and long-term dentofacial adaptations to treatment with the Herbst appliance. Sem Ortho. 1997; 3: 232-243.
12. Hansen, K., and Pancherz, H. Long-term effects of Herbst treatment in relation to normal growth development: a cephalometric study. Eur. J. Orthod., 14: 285-295, 1992.

13. McNamara, JA Jr. Fabrication of the acrylic splint Herbst appliance. *Am J Orthod Dentofacial Orthop.* 1988; 94: 10-18.
14. Windmiller EC. The acrylic-splint Herbst appliance. *Am J Orthod Dentofacial Orthop.* 1993; 104: 73-84.
15. Jakobsson SO: Cephalometric evaluation of treatment effect on Class II, Division I malocclusions. *Am J Orthod Dentofacial Orthop* 53: 446-457, 1967.
16. Wieslander, L. Intensive treatment of severe Class II malocclusion with a Headgear-Herbst appliance in the early mixed dentition. *Am J Orthod.* 1984; 86: 1-13.
17. Baumrind S, Korn EL, Isaacson RJ, et al.: Quantitative analysis of the orthodontic and orthopedic effects of maxillary traction. *Am J Orthod Dentofacial Orthop* 84: 384-398, 1983.
18. Croft, RS, Buschang, PH, English, JD, and Meyer R. A cephalometric and tomographic evaluation of Herbst treatment in the mixed dentition. *Am J Orthod Dentofacial Orthop.* 1999; 116: 435-443.
19. Pancherz H, Hagg U. Dentofacial orthopedics in relation to somatic maturation. An analysis of 70 cases treated with the Herbst appliance. *Am J Orthod.* 1985; 88: 273-287.
20. Tulloch JF, Profitt WR, Phillips C: Outcomes in a 2-phase randomized controlled clinical trial of early Class II treatment. *Am J Orthod Dentofacial Orthop* 125: 657-667, 2004.
21. Keeling SD, Wheeler TT, King GJ, et al: Anteroposterior skeletal and dental changes after early Class II treatment with bionators and headgear. *Am J Orthod Dentofacial Orthop* 113: 40-50, 1998.
22. Cozza P, Baccetti, T, Franchi L, Toffol LD, McNamara JA. Mandibular changes produced by functional appliances in Class II malocclusion: A systematic review. *Am J Orthod Dentofacial Orthop.* 2006; 129: 599.e1-599.e12.
23. Larsen, C.S.: *Bioarchaeology: interpreting behavior from the human skeleton*, 1997, Cambridge, Mass., Cambridge University Press.
24. Corrucini, R.S.: Anthropological aspects of orofacial and occlusal variations and anomalies. In Kelly MA, Larsen CS (editors), *Advances in dental anthropology*, New York, 1991, Wiley-Liss.
25. Corrucini, R.S., Pacciani, E.: "Orthodontistry" and dental occlusion in Etruscans, *Angle Orthod.* 59: 61-64, 1989.

26. Kingsley, N.W.: Treatise on oral deformities as a branch of mechanical surgery, New York, 1880, Appleton.
27. Angle, E.H.: Treatment of malocclusion of teeth and fractures of the maxillae, Angle's system, ed. 6, Philadelphia, 1900, SS White Dental Mfg Co.
28. Profitt W.R., Fields, H.W. Contemporary Orthodontics. 3rd ed. Moseby Inc. St. Louis, MO 2000.
29. McLain, J.B., Profitt, W.R. Oral Health Status in the United States: Prevalence of Malocclusion. J Dent Educ. 1985; 49: 386-396.
30. Kelly, J.E., Sanchez, M., Vankirk, L.E. An assessment of the occlusion of the teeth of children. DHEW Publication No. (HRA) 74-1612, Washington, DC: National Center for Health Statistics, 1973.
31. Kelly, J.E., Harvey, C. An assessment of the teeth of youths 12-17 years, DHEW Publication No. (HRA) 77-1644, Washington, DC: National Center for Health Statistics, 1977.
32. McLain, J.B., Steedle, J.R., Vig, P.S. Face height and dental relationships in 1600 children: A survey. J Dent Res. 1983; 62: 308.
33. Enlow, D.H. Facial Growth. 3rd ed. WB Saunders Co. 1990.
34. McNamara, James Jr., Brudon, W. Orthodontic and Orthopedic treatment in the Mixed Dentition. Needham Press Inc. Ann Arbor, MI 1993.
35. McNamara, JA Jr. Components of Class II Malocclusion in children 8-10 years of age. Angle Orthod. 1981; 51: 177-202.
36. Ngan, P.W., Byczek, E., Scheik. Longitudinal Evaluation of Growth changes in Class II division subjects. Seminars in Orthod. 3: 4 Dec 1997 pp. 222-231.
37. Riedel, R.A. The relationship of maxillary structures to cranium in malocclusion and normal occlusion. Angle Orthod. 1952; 22: 142-145.
38. Steiner, CC. Cephalometrics for you and me. Am J Orthod. 1953; 39: 729-755.
39. McNamara, JA Jr. A method of cephalometric evaluation. Am J Orthod. 1984; 86: 449-469.
40. Ricketts, RM. The influence of orthodontic treatment on facial growth and development. Angle Orthod. 1960; 30: 103-133.

41. Schudy, FF. Vertical growth versus antero-posterior growth as related to function and treatment. *Angle Orthod.* 1965; 35: 36-50.
42. Schudy, FF. The rotation of the mandible resulting from growth: Its implications in orthodontic treatment. *Angle Orthod.* 1965; 35: 36-50.
43. Tollaro I, Baccetti T, Franchi L, et al. Interarch transverse discrepancy in Class II malocclusion during the mixed dentition. *Am J Orthod Dentofacial Orthop* 1996.
44. Baccetti T, Franchi L, McNamara JA Jr, et al. Early Dentofacial features of Class II malocclusion: A longitudinal study from the deciduous through mixed dentition. *Am J Orthod* 1973; 63: 610-621.
45. Ayra BS, Savara BS, Thomas DR. Prediction of 1st molar occlusion. *Am J Orthod* 1973; 63: 610-621.
46. Bishara SE, Hoppens BJ, Jakobsen JR, et al. Changes in the molar relationship between the deciduous and permanent dentitions: A longitudinal study. *Am J Orthod Dentofacial Orthop* 1988; 93: 19-28.
47. Spillane LM, McNamara JA Jr. Maxillary adaptations following expansion in the mixed dentition. *Sem Orthod* 1995; 1: 176-187.
48. McNamara JA Jr, Ellis E. Cephalometric analysis of untreated adults with ideal facial and occlusal relationships. *Int J Ault Orthodont Oral Surgery* 1988; 3: 221-231.
49. Ruf, S and Pancherz, H. Herbst/multibracket appliance treatment of Class II division I malocclusions in early and late adulthood. A prospective cephalometric study of consecutively treated subjects. *Eur J Orthod.* 2006; 28: 352-360.
50. Ruf, S, Pancherz, H. Temporomandibular joint remodeling in adolescents and young adults during Herbst treatment: a prospective longitudinal magnetic resonance imaging and cephalometric radiographic investigation. *Am J Orthod Dentofacial Orthop* 1999; 115: 607-618.
51. Moore, RN. Principles of Dentofacial Orthopedics. *Sem Orthod.* 1997; 3: 4 212-21.
52. Weinberger, WW. Orthodontics. A historical review of its origin and evolution. Vol. II. The Mosby Company, 1926.
53. Breitner, C.: Experimentelle Veränderungen der mesiodistalen Beziehungen der oberen und untern Zahnreihen. *Zschr. Stomatol.*, 28: 620-635, 1930.

54. Nelson, C., Harkness, M., Herbison, P. Mandibular changes during functional appliance treatment. *Am J Orthod Dentofac Orthop.* 1993; 104 (2): 153-61.
55. Mills, JR. The effect of functional appliances on the skeletal pattern. *Br J Orthod.* 1991 Nov; 18 (4): 267-75.
56. Teuscher, U. A growth-related concept for skeletal Class II treatment. *Am J Orthod.* 1978. Sept; 74(3): 258-75.
57. Rudzki-Janson, I, Noachter, R. Functional appliance therapy with the Bionator. *Sem Orthod.* 1998; 4: 33-45.
58. Aelbers, CMF, Dermault, LR. Orthopedics in orthodontics: Part I, fiction or reality—a review of the literature. *Am J Orthod Dentofac Orthop.* 1996; 110: 513-19.
59. O'Brien et al. Effectiveness of treatment for Class II malocclusion with the Herbst or Twin-block appliances: A randomized, controlled trial. *Am J Orthod Dentofacial Orthop.* 2003; 124: 128-137.
60. Schwarz, M.: Erfahrungen mit dem Herbstschen Scharnier zur Behandlung des Distalbisses. *Zahnärztl. Rundschau*, 43: 47-54, 91-100, 1934.
61. Herbst, E.: Dreissigjährige Erfahrungen mit dem Retentionsscharnier. *Zahnärztl. Rundschau*, 43: 1515-1524, 1563-1568, 1611-1616, 1934.
62. Goodman, P, McKenna, P. Modified for the mixed dentition. *J Clinc. Ortho.* 1985; 19: 811-814.
63. Dischinger, TG. Edgewise bioprogressive Herbst appliance. *J Clinc. Ortho.* 1989; 23: 608-617.
64. Dischinger, TG. Edgewise Herbst Appliance. *J Clinc. Ortho.* 1995; 29: 738-742.
65. Held, A.J., Spirgi, M., and Cimasoni, G.: An orthopedically treated adult case of Class II malocclusion. *Am. J. Orthod.* 49: 761-765, 1963.
66. Egermark-Eriksson, I.; Carlsson, G.E., and Ingervall, B. Function and dysfunction of the masticatory system in individuals with dual bite. *Eur J. Orthod.* 1: 107-117: 1979.
67. Moss, ML. The primacy of functional matrices on orofacial growth. *Dent Pract* 19: 65-73, 1968.
68. Brodie, AG. On the growth pattern of the human head from third month to the eighth year of life. *Am J Orthod* 27: 633-647, 1941.

69. Von Bremen, J, Pancherz, H. Efficiency of early and late Class II Division I treatment. *Am J Orthod Dentofacial Orthop.* 2002; 121: 31-37.
70. Tulloch, J.F., Phillips, C., and Profitt, W. Benefits of early Class II treatment: Progress report of a two-phase randomized clinical trial. *Am J Orthod Dentofacial Orthop.* 1998; 113: 62-72.
71. Viazis AD. Efficient orthodontic treatment timing. *Am J Orthod Dentofacial Orthop.* 1995; 108: 560-561.
72. Ghafari JG. Emerging paradigms in orthodontics. *Am J Orthod Dentofacial Orthop.* 1997; 111: 573-580.
73. Nelson G. Phase I treatment. *Am J Orthod Dentofacial Orthop.* 1997; 111: 239-240.
74. Gianelly AA. Crowding: timing of treatment. *Angle Orthod* 1994; 64: 415-418.
75. Gianelly AA. One-phase versus two-phase treatment. *Am J Orthod Dentofacial Orthop.* 1995; 108: 556-559.
76. Tung AW, Kiyak HA. Pshychological influences on the timing of orthodontic treatment. *Am J Orthod Dentofacial Orthop.* 1998; 113: 29-39.
77. O'Brien et al. Effectiveness of early orthodontic treatment with the Twin-block appliance: A multicenter, randomized, controlled trial. Part 2: Pshchosocial effects. *Am J Orthod Dentofacial Orthop.* 2003; 124: 488-494.
78. Yang EY, Kiyak HA. Orthodontic treatment timing: A survey of orthodontists. *Am J Orthod Dentofacial Orthop.* 1998; 113: 96-102.
79. Lai M, McNamara JA Jr. An evaluation of two phase treatment with the Herbst appliance and pre-adjusted edgewise therapy. *Sem Ortho* 1998; 4: 46-58.
80. Pancherz H. The Herbst appliance—it's biological effects and clinical use. *Am J Orthod.* 1985; 87: 1-20.
81. Valant JR, Sinclair PM. Treatment effects of the Herbst appliance. *Am J Orthod Dentofacial Orthop.* 1989; 95: 138-147.
82. Pancherz H. The mechanism of Class II correction in Herbst appliance treatment. A cephalometric investigation. *Am J Orthod.* 1982a; 82:104-113.
83. McNamara JA Jr. Neuromuscular and skeletal adaptations to altered function in the orofacial region. *Am J Orthod* 1973; 64: 578-606.

84. Xiong H, Hagg U, Tang G-H, Rabie ABM, Robinson W. The effect of continuous bite-jumping in adult rats: a morphological study. *Angle Orthod* 2004; 74: 86-92.
85. Chen JY, Will LA, Niederman R. Analysis of the efficacy of functional appliances on mandibular growth. *Am J Orthod Dentofacial Orthop* 2002; 122: 470-476.
86. Pancherz H, Littmann C. Somatische Reif undd morphologische Veranderungen des Unterkiefers bei der Herbst-Behandlung. *Inf. Orthod. Kieferorthop.* 1988; 20: 455-470.
87. Pancherz, H. and Littmann, C. Morphologie und Lage des Unferkiefers bei der Herbst-Behandlung. Eine kephalometrische Analyse der Veränderungen bis zum Wachstumsabschluss. *Inf. Orthod. Keiferorthop.*, 21: 493-513, 1989.
88. Voudouris et al. Condyle-fossa modifications and muscle interactions during Herbst treatment, Part 2. Results and conclusions. *Am J Orthod Dentofacial Orthop.* 2003; 124: 13-29.
89. Araujo AM, Buschang PH, Melo ACM. Adaptive condylar growth and mandibular remodeling changes with bionator therapy—an implant study. *Eur. J Orthod.* 2004; 26: 515-522.
90. Popowich K, Nebbe B, and Major P. Effect of Herbst treatment on temporomandibular joint morphology: A systematic literature review. *Am J Orthod Dentofacial Orthop.* 2003; 123: 388-394.
91. Rabie et al. Osteogenesis in the glenoid fossa in response to mandibular advancement. *Am J Orthod Dentofacial Orthop.* 2001; 119: 390-399.
92. Pancherz H, Hansen K. Occlusal changes during and after Herbst treatment: a cephalometric investigation. . *Eur. J Orthod.* 1986; 8: 215-228.
93. McNamara JA Jr, Howe RP, Dischinger TG. A comparison of the Herbst and Frankel appliance in the treatment of Class II malocclusions. *Am J Orthod Dentofacial Orthop.* 1990; 98: 134-144.
94. Pancherz H. The effect of continuous bite jumping on the Dentofacial complex: A follow-up study after Herbst appliance treatment of Class II malocclusions. *Eur J Orthod.* 1981; 3: 49-60.
95. Pancherz H, Anehus Pancherz M. The head-gear effect of the Herbst appliance. *Am J Orthod Dentofacial Orthop.* 1993; 103: 510-520.

96. Pancherz, H. Vertical dentofacial changes during Herbst appliance treatment. *Swed. Dent. J. Suppl.*, 15: 189-196, 1982b.
97. Broadbent, B.H., Sr., Broadbent, B.H., Jr. and Golden, W. Bolton standards of dentofacial developmental growth. The C.V. Mosby Comp. St. Louis, 1975.
98. Pancherz, H. The nature of Class II relapse after Herbst appliance treatment: A cephalometric long-term investigation. *Am. J. Orthod. Dentofacial Orthop.*, 100: 220-233, 1991.
99. Pancherz H, Fackel U. The skeletofacial growth pattern pre-and post-dentofacial orthopaedics: a long-term study of Class II malocclusions treated with the Herbst appliance. *Eur J Orthod.* 1990; 12: 209-218.
100. Voudouris JC, Kuftinec MM. Improved clinical use of Twin-block and Herbst as a result of radiating viscoelastic tissue forces on the condyle and fossa in treatment and long-term retention: Growth relativity. *Am. J. Orthod. Dentofacial Orthop.* 2000; 117: 247-266.
101. Berger et al. Long-term comparison of treatment outcome and stability of Class II patients treated with functional appliances versus bilateral sagittal split ramus osteotomy. *Am. J. Orthod. Dentofacial Orthop.* 2005; 127: 451-464.
102. VanLaecken R, Martin C, Dischinger T, Razmus T, and Ngan P. Treatment effects of the edgewise Herbst appliance: A cephalometric and tomographic investigation. *Am. J. Orthod. Dentofacial Orthop.* 2006; 130: 582-591.
103. Hagg U, Du X, Rabie ABM. Initial and late treatment effects of headgear-Herbst appliance with mandibular step-by-step advancement. *Am. J. Orthod. Dentofacial Orthop.* 2002; 122: 477-485.
104. Dischinger T. Dentofacial orthopedics without regard to patient cooperation. West Virginia Orthodontic Alumni Association Meeting; 2005 Sep 9; Morgantown, West Virginia 2005.
105. Du X, Hagg U, Rabie ABM. Effects of headgear Herbst and mandibular step-by-step advancement versus conventional Herbst appliance and maximal jumping of the mandible. *Eur J Orthod.* 2002; 24: 167-174.
106. Rabie et al. The Correlation of Replicating Cells and Osteogenesis in the Condyle During Stepwise Advancement. *Angle Orthodontist.* 2003; 73: 457-465.
107. Baumrind S, Miller DM. Computer-aided head film analysis: the University of California San Francisco method. *Am J Orthod.* 1980; 78:41-65.

108. Bjork, A. The face in profile: An anthropological x-ray investigation of Swedish children and Conscripts. Lund: Berlingska Boktryckeriet 1947; 40: 58.
109. Konik M, Pancherz H, Hansen K. The mechanism of Class II correction in late Herbst treatment. *Am J Orthod Dentofacial Orthop* 1997; 112:87-91.
110. Ruf S, Pancherz H. Dentoskeletal effects and facial profile changes in young adults treated with the Herbst appliance. *Angle Orthod* 1999; 69: 239-246.
111. Ruf S, Pancherz H. The mechanism of Class II correction during Herbst therapy in relation to the vertical jaw base relationship: a cephalometric roentgenographic study. *Angle Orthod* 1997; 67: 271-276.
112. Hansen K, Koutsonas TG, Pancherz H. Long-term effects of Herbst treatment on the mandibular incisor segment: a cephalometric and biometric investigation. *Am J Orthod Dentofacial Orthop* 1997; 112:92-103.
113. Obijou C, Pancherz H. Herbst appliance treatment on Class II, division 2 malocclusions. *Am J Orthod Dentofacial Orthop* 1997; 112:287-291.
114. Omblus J, Malmgren O, Pancherz H, Hagg U, Hansen K. Long-term effects of Class II correction in Herbst and Bass therapy. *Eur J Orthod* 1997; 19: 185-193.
115. Franchi L, Baccetti T, McNamara JA Jr. Treatment and post-treatment effects of acrylic splint Herbst appliance therapy. *Am J Orthod Dentofacial Orthop* 1999; 115:429-438.
116. Nelson B, Hansen K, Hagg U. Class II correction in patients treated with class II elastics and with fixed functional appliances: a comparative study. *Am J Orthod Dentofacial Orthop* 2000; 118:142-149.
117. Burkhart DR, McNamara JA Jr, Baccetti T. Maxillary molar distalization or mandibular enhancement: a cephalometric comparison of comprehensive orthodontic treatment including the pendulum and Herbst appliances. *Am J Orthod Dentofacial Orthop* 2003; 123:108-116.
118. Eberhard H, Hirschfelder U. Treatment of Class II, Division 2 in the late growth period. *J Orofac Orthop* 1998; 59: 352-361.
119. Hansen K, Pancherz H, Hagg U. Long-term effects of the Herbst appliance in relation to the treatment growth period: a cephalometric study. *Eur J Orthod* 1991; 13: 471-481.
120. Wieslander L. Long-term effect of treatment with the headgear-Herbst appliance in the early mixed dentition. Stability or relapse? *Am J Orthod Dentofacial Orthop* 1993; 104:319-329.

121. Pancherz H, Hansen K. Mandibular anchorage in Herbst treatment. *Eur J Orthod* 1988; 10: 149-164.
122. Pancherz H, Malmgren O, Hagg U, Omblus J, Hansen K. Class II correction in Herbst and Bass therapy. *Eur J Orthod* 1989; 11: 17-30.
123. Wong GW, So LL, Hagg U. A comparative study of sagittal correction with the Herbst appliance in two different ethnic groups. *Eur J Orthod* 1997;19: 195-204.
124. Sidhu MS, Kharbanda OP, Sidhu SS. Cephalometric analysis of changes produced by a modified Herbst appliance in the treatment of Class II division 1 malocclusion. *Br J Orthod* 1995; 22: 1-12.
125. Baltromejus S, Ruf S, Pancherz H. Effective temporomandibular joint growth and chin position changes: activator versus Herbst treatment. A cephalometric roentgenographic study. *Eur J Orthod* 2002; 24: 627-637.
126. Schweitzer M, Pancherz H. The incisor-lip relationship in Herbst/multibracket appliance treatment of Class II, Division 2 malocclusions. *Angle Orthod* 2001; 71: 358-363.
127. Ruf S, Pancherz H. Long-term TMJ effects of Herbst treatment: a clinical and MRI study. *Am J Orthod Dentofacial Orthop* 1998; 114:475-483.
128. Ruf S, Hansen K, Pancherz H. Does orthodontic proclination of lower incisors in children and adolescents cause gingival recession? *Am J Orthod Dentofacial Orthop* 1998; 114:100-106.
129. Hansen K, Iemamnueisuk P, Pancherz H. Long-term effects of the Herbst appliance on the dental arches and arch relationships: a biometric study. *Br J Orthod* 1995; 22: 123-134.
130. Ruf S, Pancherz H. The effect of Herbst appliance treatment on the mandibular plane angle: a cephalometric roentgenographic study. *Am J Orthod Dentofacial Orthop* 1996; 110:225-229.
131. Schiavoni R, Grenga V, Macri V. Treatment of Class II high angle malocclusions with the Herbst appliance: a cephalometric investigation. *Am J Orthod Dentofacial Orthop* 1992; 102:393-409.
132. Paulsen HU. Morphologic changes of the TMJ condyles of 100 patients treated with the Herbst appliance in the period of puberty to adulthood: a long-term radiographic study. *Eur J Orthod* 1997; 19: 657-668.

133. Ruf S, Pancherz H. Temporomandibular joint growth adaptation in Herbst treatment: a prospective magnetic resonance imaging and cephalometric roentgenographic study. *Eur J Orthod* 1998; 20: 375-388.

APPENDICES

APPENDIX A

IRB exemption

Expedited - IRB Protocol - Exemption

To: Ngan, Peter
From: WVU Office of Research Compliance
Date: Monday, September 17, 2007
Subject: No action required

Tracking #: H-20364
Title: Long-Term Follow-Up of Patients Treated with the Edgewise Crowned Herbst Appliance in the Mixed Dentition.

The above-referenced study was reviewed by the Institutional Review Board and was granted exemption on [Review Date Not Found] in accordance with 45 CFR 46.101(4).

While no action is required on your part, the IRB made the following findings:

This research study was granted an exemption in accordance with Research on existing data, documents, records, pathological specimens, or diagnostic specimens [45 CFR 46.101(4)]. Please adhere to the requirements for disclosure of data as outlined in your Data Use Agreement. In accordance with the Health Insurance Portability and Accountability Act, a waiver of research authorization has been granted. Please fulfill the subject accounting requirements associated with the granting of this waiver. If you have questions please refer to the IRB website.

The following documents have been approved and validated for use in this study and are available in the BRAAN system:

HIPAA waiver has been acknowledged.

Thank you.

Board Designee: White, Barbara

Letter Sent By: White, Barbara, 9/17/2007 1:36 PM

APPENDIX B

Approval for the use of orthodontic records from Dr. Terry Dischinger

Permission is granted to Dr. Timothy Wigal, Dr. Peter Ngan, and co-workers to use the cephalometric radiographs provided by this office for research and educational purposes in the completion of the master's thesis "Long-Term Follow-Up of Patients Treated with the Edgewise Crowned Herbst appliance in the Mixed Dentition".

Sincerely,

Dr. Terry Dischinger

APPENDIX C

Approval for the use of orthodontic records from Dr. Mark Hans

Permission is granted to Dr. Timothy Wigal, Dr. Peter Ngan, and co-workers to use the cephalometric radiographs provided by this office for research and educational purposes in the completion of the master's thesis "Long-Term Follow-Up of Patients Treated with the Edge-wise Crowned Herbst appliance in the Mixed Dentition".

Mark Huns, D.D.S., M.S.D.
Bolton-Brush Growth Study Center

APPENDIX D

Control Group—Pooled—Distribution of Sagittal Variable Measurements

Control Group--All Subjects Sagittal Variables (mm)	T1			T2			T3		
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MAX
Skeletal:									
1. Olp-A pt.	68.3	4.2	77.7	63.2	70.8		78.4	64.7	79.8
2. Olp-Pg	71.0	5.5	87.3	63.4	73.4	4.5	80.8	66.2	85.7
3. Olp-Co	9.6	2.1	13.4	6.0	9.9	2.1	12.6	6.7	14.0
4. Co-A pt.	78.3	4.3	86.6	71.7	81.0	3.7	86.7	76.4	88.0
5. Co-Gn	95.5	5.0	103.5	87.1	98.8	3.9	105.9	93.2	110.5
6. Co-Gn minus Co-A pt.	17.1	2.9	22.2	11.6	17.8	2.6	22.8	13.5	24.3
7. Wits	1.1	1.6	4.1	-1.8	0.8	1.6	3.7	-1.4	4.0
Dental:									
8. Is-Olp	73.5	5.6	85.1	62.9	77.1	5.6	85.5	69.6	90.0
9. Ii-Olp	68.8	4.4	77.3	61.2	71.5	4.9	79.9	65.8	83.9
10. Overjet	4.7	2.1	9.8	0.4	5.6	1.8	10.0	3.4	9.2
11. Ms-Olp	46.0	3.7	53.5	38.6	48.3	3.9	55.5	41.6	60.0
12. Mi-Olp	45.7	4.3	54.5	36.9	48.0	4.5	56.4	40.9	61.8
13. Molar Relationship	0.3	0.9	2.5	-0.9	0.2	0.7	1.0	-1.4	1.5

Control Group--All Subjects Sagittal Variables (mm)	T4			T5		
	MEAN	SD	MAX	MIN	MEAN	SD
Skeletal:						
1. Olp-A pt.	72.9	4.7	82.2	66.3	75.4	5.0
2. Olp-Pg	77.9	5.2	87.3	69.8	80.5	5.1
3. Olp-Co	11.4	2.6	15.9	5.9	11.0	2.2
4. Co-A pt.	84.7	3.6	91.2	78.4	86.9	3.9
5. Co-Gn	106.1	5.7	114.0	97.8	109.0	5.7
6. Co-Gn minus Co-A pt.	21.4	3.5	28.8	17.1	22.1	3.6
7. Wits	0.3	1.9	4.8	-2.8	1.1	2.0
Dental:						
8. Is-Olp	80.6	5.7	92.3	71.7	82.8	6.0
9. Ii-Olp	75.4	5.4	87.0	67.3	77.5	5.7
10. Overjet	5.3	1.3	7.9	2.8	5.3	1.5
11. Ms-Olp	53.4	4.8	62.4	45.0	55.6	4.7
12. Mi-Olp	53.4	5.1	63.7	44.1	55.9	4.8
13. Molar Relationship	0.0	0.9	1.5	-1.9	-0.3	0.7

APPENDIX E

Control Group—Pooled— Distribution of Vertical Variable Measurements

Control Group--All Subjects Vertical Variables (mm)	T1			T2			T3		
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MIN
Skeletal:									
14. OLS-A pt.	25.2	2.2	29.0	20.3	26.1	2.1	29.7	22.8	22.7
15. ANS-Me	57.0	4.6	64.9	48.5	59.4	5.5	66.6	49.9	49.6
Dental:									
16. Is-NL	23.7	4.1	29.8	11.7	25.8	2.4	29.8	20.9	21.1
17. Ii-ML	34.1	3.2	40.1	28.5	35.4	3.1	40.8	31.2	29.9
18. Overbite	1.6	3.0	4.5	-6.1	2.9	1.8	5.3	-1.6	0.7
19. Msc-NL	16.7	3.0	20.3	7.7	17.8	2.2	21.8	13.7	13.7
20. Mic-ML	25.7	1.9	29.5	21.9	26.7	2.0	30.0	23.6	23.3

Control Group--All Subjects Vertical Variables (mm)	T4			T5		
	MEAN	SD	MAX	MIN	MEAN	SD
Skeletal:						
14. OLS-A pt.	28.6	2.0	33.2	25.7	30.0	1.9
15. ANS-Me	62.3	5.7	72.3	50.8	63.7	5.8
Dental:						
16. Is-NL	27.2	2.4	32.2	23.0	27.6	2.4
17. Ii-ML	37.3	3.4	44.1	31.4	38.6	3.8
18. Overbite	3.1	1.3	6.5	0.8	3.3	1.1
19. Msc-NL	20.5	2.3	25.6	16.2	21.5	2.4
20. Mic-ML	28.3	2.5	32.9	23.6	29.6	2.9

APPENDIX F

Control Group--All Subjects Angular Variables (mm)										T1				T2				T3			
										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:																					
21. SNA										79.9	3.2	85.5	71.0	79.9	2.6	84.5	75.0	80.1	2.8	85.5	74.0
22. SNB										75.3	3.0	80.5	70.0	75.5	3.0	79.5	71.0	75.8	2.9	82.0	71.0
23. ANB										4.6	1.3	6.5	1.0	4.4	1.7	7.5	2.0	4.3	1.3	6.5	2.0
24. SNL-NL										7.5	3.2	13.0	1.0	6.3	2.8	11.0	2.5	6.4	2.9	11.5	0.0
25. SNL-ML										34.1	4.6	42.5	25.0	33.6	5.5	41.0	25.0	33.4	4.8	41.0	22.5
26. SNL-OL										20.3	3.5	28.0	14.5	20.1	3.2	27.0	16.5	19.9	3.1	27.5	15.5
Dental:																					
27. Is/NL										111.0	5.9	127.5	100.0	109.3	5.1	115.0	99.0	110.1	5.0	120.0	102.0
28. li/ML										94.6	5.7	107.5	85.0	93.3	5.1	100.0	84.0	95.1	6.0	107.0	85.0
29. Interincisal Angle										127.6	7.9	138.5	111.0	129.0	8.2	141.0	114.5	127.5	7.5	140.0	115.0

Control Group--All Subjects Angular Variables (mm)										T4				T5			
										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:																	
21. SNA										80.7	3.0	87.0	74.0	81.7	3.0	88.5	76.0
22. SNB										76.6	3.1	83.0	71.5	77.2	3.1	83.5	72.0
23. ANB										4.1	1.6	7.5	1.5	4.5	1.6	7.5	1.5
24. SNL-NL										6.0	2.8	12.5	0.0	6.6	3.4	14.0	1.0
25. SNL-ML										32.8	5.2	41.0	22.5	32.8	5.5	40.0	21.5
26. SNL-OL										18.9	3.3	25.0	12.5	18.0	4.0	26.0	11.5
Dental:																	
27. Is/NL										109.9	6.1	126.0	101.0	110.0	5.2	119.0	101.5
28. li/ML										95.5	5.0	103.5	88.0	94.6	4.8	102.5	85.0
29. Interincisal Angle										127.5	8.2	145.5	112.5	129.2	7.8	145.0	116.0

APPENDIX G

Control Group--All Subjects Condyle/Glenoid Fossa Variables (mm)	T1			T2			T3		
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MIN
Sagittal:									
30. OIp-CoC	-5.9	2.0	-2.4	-9.7	-5.9	2.3	-2.1	-9.6	-10.9
31. OIp-GFS	-6.1	2.4	-0.5	-9.9	-5.9	2.2	-3.3	-10.2	-11.0
32. OIp-GFA	-1.8	2.1	3.1	-5.3	-1.5	2.1	1.0	-5.0	-5.6
33. OIp-GFP	-11.7	2.2	-8.7	-15.8	-11.7	2.6	-7.6	-16.5	-17.7
Vertical:									
34. OIs-CoC	21.7	2.3	26.1	16.8	22.9	3.0	26.4	17.7	17.0
35. OIs-GFS	15.8	2.4	19.5	10.6	16.5	2.8	20.0	11.1	10.3
36. OIs-GFA	17.3	2.3	20.4	11.5	17.9	2.6	21.0	12.4	11.9
37. OIs-GFP	19.2	2.2	22.0	12.8	19.5	2.3	22.4	13.9	13.6

Control Group--All Subjects Condyle/Glenoid Fossa Variables (mm)	T4				T5			
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Sagittal:								
30. OIp-CoC	-7.4	2.7	-2.3	-11.6	-7.0	2.3	-0.8	-10.4
31. OIp-GFS	-7.3	2.7	-2.0	-12.0	-7.0	2.3	-1.0	-10.7
32. OIp-GFA	-2.5	2.4	1.8	-7.1	-2.0	2.2	2.4	-7.6
33. OIp-GFP	-13.0	3.1	-6.5	-18.9	-12.9	2.6	-4.8	-16.8
Vertical:								
34. OIs-CoC	24.8	2.7	32.7	19.5	25.4	2.8	32.2	19.5
35. OIs-GFS	18.2	2.9	25.5	11.2	18.8	2.8	25.2	13.5
36. OIs-GFA	19.6	2.7	26.4	12.8	20.3	2.5	26.1	15.2
37. OIs-GFP	21.4	2.5	27.7	14.5	22.2	2.2	27.6	17.5

APPENDIX H

Control Group--Male Subjects Sagittal Variables (mm)										T1				T2				T3			
Skeletal:										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
1. Olp-A pt.										72.5	4.4	77.7	65.7	73.7	3.9	78.4	67.3	74.3	4.3	79.8	68.1
2. Olp-Pg										75.0	6.9	87.3	66.7	74.5	5.4	80.8	67.3	76.4	5.8	85.7	69.8
3. Olp-Co										9.2	2.5	12.7	6.0	9.4	2.2	12.5	6.7	9.6	2.3	13.8	6.4
4. Co-A pt.										82.0	3.2	86.7	77.2	83.4	3.6	86.7	76.4	84.2	3.4	88.0	78.4
5. Co-Gn										99.1	3.5	103.5	93.9	100.6	4.2	105.9	93.2	103.3	4.8	110.5	97.0
6. Co-Gn minus Co-A pt.										17.0	3.4	22.0	11.6	17.2	2.5	21.0	13.5	19.1	3.2	24.3	14.3
7. Wits										2.2	1.5	4.1	0.0	1.9	1.2	3.7	0.0	1.9	1.5	4.0	-0.6
Dental:																					
8. Is-Olp										78.1	6.4	85.1	66.6	80.3	5.9	85.5	69.6	81.9	6.4	90.0	70.9
9. Ii-Olp										72.7	4.5	77.3	64.5	74.1	5.2	79.9	65.8	75.6	5.7	83.9	67.6
10. Overjet										5.4	2.5	9.8	2.2	6.2	2.1	10.0	3.8	6.3	1.9	9.2	3.3
11. Ms-Olp										48.5	4.1	53.5	42.3	49.5	4.7	55.5	41.6	51.3	5.1	60.0	44.0
12. Mi-Olp										48.5	5.0	54.5	39.7	49.6	5.3	56.4	40.9	51.3	5.6	61.8	44.7
13. Molar Relationship										0.1	1.2	2.5	-0.9	-0.1	0.8	0.8	-1.4	-0.1	1.0	0.9	-1.8

Control Group--Male Subjects Sagittal Variables (mm)										T4				T5			
Skeletal:										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
1. Olp-A pt.										77.6	4.5	82.2	70.1	80.6	4.8	86.7	73.4
2. Olp-Pg										81.0	5.9	87.3	70.4	84.1	6.0	91.3	76.8
3. Olp-Co										9.9	2.9	14.8	5.9	9.8	2.8	13.1	4.6
4. Co-A pt.										87.9	3.3	91.2	82.8	90.8	3.7	94.5	83.9
5. Co-Gn										109.7	4.4	113.9	103.3	113.2	5.9	121.3	103.2
6. Co-Gn minus Co-A pt.										21.7	2.3	24.9	18.9	22.4	3.4	27.0	18.9
7. Wits										1.6	2.0	4.8	-1.1	2.3	1.9	4.2	-0.8
Dental:																	
8. Is-Olp										86.0	5.8	92.3	77.8	88.9	6.2	96.6	78.6
9. Ii-Olp										80.0	5.8	87.0	71.0	82.8	6.4	91.7	74.0
10. Overjet										6.0	1.2	7.9	4.2	6.2	1.3	8.0	4.6
11. Ms-Olp										56.5	5.2	62.4	47.8	58.8	5.7	65.8	51.7
12. Mi-Olp										56.6	5.5	63.7	46.8	59.0	5.9	66.8	51.5
13. Molar Relationship										-0.1	1.2	1.5	-1.5	-0.2	0.6	0.8	-1.0

APPENDIX I

Control Group--Male Subjects Vertical Variables (mm)	T1				T2				T3			
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:												
14. OLS-A pt.	25.0	2.3	28.6	22.4	26.0	2.3	29.7	22.8	26.5		2.0	23.9
15. ANS-Me	60.9	3.7	64.9	55.9	62.9	4.1	66.6	55.5	63.4		4.7	57.1
Dental:												
16. Is-NL	25.5	3.8	29.8	18.0	26.9	2.0	29.8	24.9	27.6		2.2	2.2
17. Ii-ML	36.5	2.8	40.1	33.2	37.3	2.9	40.8	34.3	38.3		3.0	34.2
18. Overbite	1.8	2.8	4.5	-3.2	2.6	2.4	5.3	-1.6	2.9		2.1	0.7
19. Msc-NL	17.4	3.2	20.3	11.0	18.3	2.4	21.8	15.1	18.8		1.8	16.3
20. Mic-ML	27.2	2.0	29.5	24.7	27.8	1.8	30.0	25.3	28.8		2.2	26.2

Control Group--Male Subjects Vertical Variables (mm)	T4				T5			
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:								
14. OLS-A pt.	28.7	2.2	33.2	26.5	30.1	1.8	33.0	27.9
15. ANS-Me	67.7	3.6	72.3	62.6	69.0	4.2	73.9	63.2
Dental:								
16. Is-NL	29.1	1.6	32.2	27.0	29.4	1.8	33.2	27.3
17. Ii-ML	40.5	2.5	44.1	37.0	42.3	2.8	45.7	37.7
18. Overbite	2.8	1.8	6.5	0.8	3.4	1.6	5.9	1.2
19. Msc-NL	21.3	1.9	24.7	19.1	21.8	1.8	24.1	19.6
20. Mic-ML	30.6	1.7	32.9	28.7	32.1	2.1	35.7	29.8

APPENDIX J

Control Group--Male Subjects Angular Variables (mm)	T1			T2			T3		
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN
Skeletal:									
21. SNA	79.7	1.8	81.5	76.0	79.8	1.4	82.0	77.5	79.4
22. SNB	74.4	1.8	76.5	71.0	74.4	2.1	77.0	71.0	74.3
23. ANB	5.4	0.4	6.0	5.0	5.4	1.3	7.5	4.0	5.1
24. SNL-NL	7.9	2.6	13.0	5.0	7.0	2.2	11.0	4.0	6.1
25. SNL-ML	35.9	3.4	39.5	31.5	36.4	3.8	41.0	30.5	35.6
26. SNL-OL	20.4	3.3	23.0	14.5	20.9	2.5	25.0	18.5	20.1
Dental:									
27. Is/NL	108.7	3.6	114.0	105.5	109.3	5.2	115.0	100.0	109.9
28. Ii/ML	93.2	4.6	98.0	85.0	92.9	5.2	98.0	84.0	94.3
29. Interindisal Angle	130.1	5.5	138.5	125.0	128.4	8.3	141.0	118.0	126.1

Control Group--Male Subjects Angular Variables (mm)	T4			T5		
	MEAN	SD	MAX	MIN	MEAN	SD
Skeletal:						
21. SNA	80.5	1.7	84.0	79.0	81.4	1.6
22. SNB	75.4	2.6	79.5	71.5	75.8	2.4
23. ANB	5.1	1.4	7.5	3.5	5.6	1.2
24. SNL-NL	5.9	3.4	12.5	1.5	6.6	3.5
25. SNL-ML	35.1	5.2	39.0	27.5	35.1	4.8
26. SNL-OL	19.5	3.7	23.5	13.5	19.1	4.2
Dental:						
27. Is/NL	109.0	5.0	116.0	103.0	109.1	6.0
28. Ii/ML	93.8	5.0	103.5	88.0	93.9	4.6
29. Interindisal Angle	127.8	8.5	140.0	116.0	128.6	8.9

APPENDIX K

Control Group--Male Subjects Condyle/Glenoid Fossa Variables (mm)	T1			T2			T3					
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Sagittal:												
30. OIp-CoC	-5.3	2.4	-2.4	-8.6	-5.3	2.3	-2.1	-8.4	-5.8	2.5	-1.9	-10.2
31. OIp-GFS	-5.7	2.2	-2.4	-8.7	-5.2	2.0	-3.3	-8.6	-5.6	2.6	-1.4	-10.2
32. OIp-GFA	-1.3	2.4	3.1	-4.2	-0.5	1.5	1.0	-3.2	-1.0	2.2	0.8	-5.6
33. OIp-GFP	-11.2	2.3	-8.7	-14.2	-11.0	2.7	-7.6	-16.1	-10.8	3.0	-5.3	-15.1
Vertical:												
34. OIs-CoC	22.2	3.2	26.1	16.8	23.0	3.0	26.0	18.1	23.3	3.7	28.4	17.0
35. OIs-GFS	16.0	3.4	19.4	10.6	16.5	3.1	19.4	11.1	17.0	3.7	21.8	10.3
36. OIs-GFA	17.5	3.4	20.4	11.5	18.0	2.9	20.7	12.4	18.3	3.3	22.3	11.9
37. OIs-GFP	19.3	3.4	22.0	12.8	19.6	2.7	21.8	13.9	19.5	3.1	22.8	13.6

Control Group--Male Subjects Condyle/Glenoid Fossa Variables (mm)	T4				T5			
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Sagittal:								
30. OIp-CoC	-5.8	2.9	-2.3	-10.9	-5.7	2.7	-0.8	-8.8
31. OIp-GFS	-5.7	2.8	-2.0	-11.1	-5.5	2.5	-1.0	-8.5
32. OIp-GFA	-1.1	2.5	1.8	-5.7	-0.6	2.0	2.4	-3.5
33. OIp-GFP	-11.2	3.4	-6.5	-17.4	-11.5	3.6	-4.8	-14.9
Vertical:								
34. OIs-CoC	25.5	4.1	32.7	19.8	26.7	3.7	32.2	20.7
35. OIs-GFS	18.6	4.6	25.5	11.2	19.9	3.8	25.2	13.5
36. OIs-GFA	19.9	4.3	26.4	12.8	21.3	3.4	26.1	15.2
37. OIs-GFP	21.6	4.1	27.7	14.5	23.2	3.1	27.6	17.5

APPENDIX L

Control Group--Female Subjects Sagittal Variables (mm)	T1				T2				T3				
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	
Skeletal:													
1. Olp-A pt.	66.4	2.3	71.1	63.2	67.4		1.6	69.1	64.7	68.5	2.6	73.9	64.8
2. Olp-Pg	69.1	3.7	74.9	63.4	72.0		3.1	74.9	66.2	72.7	3.9	80.7	67.7
3. Olp-Co	9.8	2.0	13.4	7.1	10.5		2.0	12.6	7.6	10.2	2.1	14.0	6.6
4. Co-A pt.	76.6	3.5	82.1	71.7	78.3		0.9	79.8	77.1	79.1	3.5	83.6	73.3
5. Co-Gn	93.8	4.8	102.7	87.1	96.8		2.4	100.6	94.7	98.0	4.8	106.4	89.7
6. Co-Gn minus Co-A pt.	17.2	2.8	22.2	13.8	18.4		2.8	22.8	15.5	18.9	3.0	24.1	15.1
7. Wits	0.6	1.4	2.9	-1.9	-0.4		0.9	0.9	-1.4	0.0	1.5	2.7	-4.0
Dental:													
8. Is-Olp	71.3	3.7	76.5	62.9	73.3		1.8	75.0	71.0	75.0	3.3	81.0	67.7
9. li-Olp	67.0	3.1	71.2	61.2	68.4		2.1	71.7	65.8	70.2	3.3	75.1	63.9
10. Overjet	4.3	1.8	7.4	0.4	4.9		1.3	6.5	3.4	4.8	1.3	7.3	3.6
11. Ms-Olp	44.9	2.9	48.4	38.6	46.9		2.3	49.0	43.4	48.2	2.8	53.4	43.7
12. Mi-Olp	44.4	3.3	49.0	36.9	46.3		2.6	48.3	42.7	47.9	3.2	53.2	42.2
13. Molar Relationship	0.5	0.7	1.7	-0.6	0.6		0.5	1.0	-0.4	0.4	0.8	1.5	-1.8

Control Group--Female Subjects Sagittal Variables (mm)	T4				T5			
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:								
1. Olp-A pt.	70.7	2.7	75.2	66.3	73.0	2.8	77.2	68.6
2. Olp-Pg	76.5	4.3	82.9	69.8	78.8	3.8	85.3	72.1
3. Olp-Co	12.1	2.3	15.9	6.9	11.6	1.6	14.0	8.3
4. Co-A pt.	83.2	2.6	87.9	78.4	85.1	2.5	88.5	80.4
5. Co-Gn	104.4	5.6	114.0	97.8	107.1	4.6	115.4	99.9
6. Co-Gn minus Co-A pt.	21.2	4.0	28.8	17.1	22.0	3.7	31.2	17.1
7. Wits	-0.2	1.5	2.5	-2.8	0.5	1.8	4.3	-2.8
Dental:								
8. Is-Olp	78.1	3.6	83.5	71.7	79.9	3.2	84.9	73.0
9. li-Olp	73.2	3.6	78.0	67.3	75.0	3.4	79.7	68.6
10. Overjet	4.9	1.3	7.8	2.8	4.9	1.4	8.8	3.3
11. Ms-Olp	51.9	3.9	56.9	45.0	54.2	3.5	58.9	48.1
12. Mi-Olp	51.9	4.3	57.4	44.1	54.5	3.6	59.9	48.4
13. Molar Relationship	0.0	0.8	1.2	-1.9	-0.4	0.7	1.3	-1.4

APPENDIX M

Control Group--Female Subjects Vertical Variables (mm)	T1				T2				T3			
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:												
14. OLs-A pt.	25.2	2.2	29.0	20.3	26.2	2.1	29.3	23.7	27.0	2.4	31.1	22.7
15. ANS-Me	55.1	3.9	62.0	48.5	55.3	3.9	60.2	49.9	56.9	3.9	64.2	49.6
Dental:												
16. Is-NL	22.9	4.2	26.5	11.7	24.4	2.3	26.9	20.9	25.2	2.4	28.4	21.1
17. Ii-ML	32.9	2.8	38.5	28.5	33.1	1.6	35.7	31.2	34.1	2.5	40.0	29.9
18. Overbite	1.5	3.2	4.2	-6.1	3.3	1.0	4.4	2.1	3.2	0.9	5.3	1.8
19. Msc-NL	16.4	2.9	20.2	7.7	17.2	2.0	18.8	13.7	18.4	2.2	21.7	13.7
20. Mic-ML	25.0	1.5	27.2	21.9	25.4	1.5	27.2	23.6	26.2	2.0	30.0	23.3

Control Group--Female Subjects Vertical Variables (mm)	T4				T5			
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:								
14. OLs-A pt.	28.5	2.1	31.9	25.7	29.9	2.0	33.8	27.5
15. ANS-Me	59.7	4.7	68.2	50.8	61.3	4.8	69.9	52.7
Dental:								
16. Is-NL	26.3	2.3	29.8	23.0	26.7	2.2	30.8	22.4
17. Ii-ML	35.9	2.8	41.1	31.4	36.9	2.8	42.4	32.6
18. Overbite	3.3	1.0	4.9	1.5	3.2	0.8	4.9	1.8
19. Msc-NL	20.1	2.4	25.6	16.2	21.3	2.8	26.6	17.0
20. Mic-ML	27.3	2.2	31.2	23.6	28.5	2.5	34.0	24.9

APPENDIX N

Control Group--Female Subjects Angular Variables (mm)				T1			T2			T3					
	MEAN	SD		MAX	MIN		MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	
Skeletal:															
21. SNA	79.9	3.8		85.5	71.0		80.1		3.7	84.5	75.0	80.4	3.2	85.5	74.0
22. SNB	75.7	3.4		80.5	70.0		76.9		3.5	79.5	72.0	76.5	3.0	82.0	71.5
23. ANB	4.3	1.4		6.5	1.0		3.2		1.2	5.0	2.0	3.9	1.3	5.5	2.0
24. SNL-NL	7.3	3.5		13.0	1.0		5.4		3.3	10.5	2.5	6.5	3.0	11.5	0.0
25. SNL-ML	33.2	4.9		42.5	25.0		30.3		5.6	41.0	25.0	32.4	5.0	41.0	22.5
26. SNL-OL	20.3	3.7		28.0	15.5		19.3		3.9	27.0	16.5	19.8	3.3	27.5	15.5
Dental:															
27. Is/NL	112.1	6.5		127.5	100.0		109.4		5.4	114.0	99.0	110.3	5.4	120.0	102.0
28. Ii/ML	95.2	6.1		107.5	88.0		93.8		5.5	100.0	85.0	95.5	6.9	107.0	85.0
29. Interincisal Angle	126.4	8.8		138.5	111.0		129.8		8.6	140.0	114.5	128.1	8.5	140.0	115.0

Control Group--Female Subjects Angular Variables (mm)				T4			T5			
	MEAN	SD		MAX	MIN		MEAN	SD	MAX	MIN
Skeletal:										
21. SNA	80.8	3.5		87.0	74.0		81.8		88.5	76.0
22. SNB	77.2	3.2		83.0	72.0		77.8		83.5	72.5
23. ANB	3.6	1.4		5.5	1.5		4.0		7.5	1.5
24. SNL-NIL	6.1	2.6		10.0	0.0		6.6		3.4	1.0
25. SNL-ML	31.8	5.1		41.0	22.5		31.6		40.0	21.5
26. SNL-OL	18.7	3.3		25.0	12.5		17.4		26.0	12.0
Dental:										
27. Is/NIL	110.4	6.6		126.0	101.0		110.5		119.0	101.5
28. Ii/ML	96.4	4.9		103.5	89.5		94.9		102.5	85.0
29. Interincisal Angle	127.4	8.3		145.5	112.5		129.5		145.0	116.0

APPENDIX O

Control Group--Female Subjects Condyle/Glenoid Fossa Variables (mm)										T1				T2				T3			
										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Sagittal:																					
30. OIp-CoC										-6.2	1.9	-3.8	-9.7	-6.7	2.2	-3.5	-9.6	-6.4	2.1	-3.2	-10.9
31. OIp-GFS										-6.3	2.5	-0.5	-9.9	-6.8	2.3	-4.3	-10.2	-6.6	2.3	-3.1	-11.0
32. OIp-GFA										-2.1	2.1	0.9	-5.3	-2.6	2.1	0.0	-5.0	-1.9	2.2	1.9	-5.3
33. OIp-GFP										-11.9	2.2	-9.3	-15.8	-12.5	2.5	-9.5	-16.5	-12.1	2.5	-8.2	-17.7
Vertical:																					
34. OIs-CoC										21.5	1.8	24.1	17.0	22.9	3.2	26.4	17.7	23.1	2.7	27.7	18.2
35. OIs-GFS										15.7	2.0	19.4	11.5	16.4	2.8	20.0	12.1	16.9	2.6	21.2	12.4
36. OIs-GFA										17.2	1.7	20.1	13.3	17.8	2.4	21.0	14.2	18.4	2.2	22.1	14.5
37. OIs-GFP										19.1	1.5	21.1	15.5	19.4	1.9	22.4	17.0	20.0	2.0	22.9	16.1

Control Group--Female Subjects Condyle/Glenoid Fossa Variables (mm)										T4				T5			
										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Sagittal:																	
30. OIp-CoC										-8.2	2.3	-3.0	-11.6	-7.7	1.9	-3.6	-10.4
31. OIp-GFS										-8.0	2.3	-3.4	-12.0	-7.7	1.9	-3.4	-10.7
32. OIp-GFA										-3.1	2.1	0.0	-7.1	-2.6	2.1	0.2	-7.6
33. OIp-GFP										-13.8	2.7	-7.6	-18.9	-13.6	1.8	-9.2	-16.8
Vertical:																	
34. OIs-CoC										24.5	1.8	26.8	19.5	24.8	2.0	27.8	19.5
35. OIs-GFS										18.0	1.9	20.9	13.5	18.4	2.2	21.7	13.7
36. OIs-GFA										19.4	1.6	21.4	15.5	19.9	1.9	22.7	15.8
37. OIs-GFP										21.3	1.5	23.5	18.7	21.7	1.6	23.9	18.7

APPENDIX P

Treatment Group--All Subjects Sagittal Variables (mm)										T1			T2			T3					
										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:																					
1. Olp-A pt.										70.6	3.3	76.6	64.5	71.6	2.8	76.0	65.3	71.9	3.3	77.3	67.1
2. Olp-Pg										71.9	4.5	78.8	63.1	74.8	4.9	84.8	67.3	75.3	4.9	84.6	66.0
3. Olp-Co										8.2	2.9	15.2	2.3	7.7	3.0	12.8	1.4	7.7	2.6	12.1	0.9
4. Co-A pt.										79.7	4.9	87.7	71.6	79.7	3.2	84.8	74.4	80.1	3.8	86.9	73.2
5. Co-Gn										95.1	4.9	103.2	84.5	98.8	4.0	108.1	94.0	99.3	5.5	109.0	85.2
6. Co-Gn minus Co-A pt.										15.8	3.8	24.7	9.4	19.1	3.8	26.3	13.6	19.2	3.7	25.9	12.1
7. Wits										1.1	1.9	5.6	-2.2	-2.8	2.6	1.5	-7.2	-1.2	1.9	1.2	-6.9
Dental:																					
8. Is-Olp										76.6	4.3	83.8	68.6	75.8	3.8	82.8	68.9	77.7	3.8	84.0	68.7
9. li-Olp										71.0	3.5	76.8	62.0	75.6	4.7	83.8	65.3	74.6	3.7	82.8	67.6
10. Overjet										5.6	2.6	9.7	-0.2	0.2	2.4	4.6	-3.3	3.1	1.5	5.1	0.0
11. Ms-Olp										47.9	2.7	53.0	42.0	46.2	3.6	50.9	38.7	48.9	3.2	55.8	43.7
12. Mi-Olp										47.1	2.9	52.1	41.9	51.3	2.8	56.9	46.9	51.6	3.2	59.0	46.7
13. Molar Relationship										0.8	2.0	4.5	-3.3	-5.1	2.3	-0.5	-9.4	-2.7	2.0	0.2	-6.8

Treatment Group--All Subjects Sagittal Variables (mm)									
Skeletal:									
MEAN		SD	T4		T5		T5		
			MAX	MIN	MEAN	SD	MAX	MIN	
1. Olp-A pt.									
74.3		4.3	82.4	67.5	75.0	3.9	82.0		67.9
2. Olp-Pg									
78.3		6.5	89.6	66.6	79.9	6.5	91.7		68.3
3. Olp-Co									
8.4		3.2	14.5	0.6	9.0	3.0	16.6		3.0
4. Co-A pt.									
83.1		5.3	95.1	74.1	84.5	4.8	92.6		73.9
5. Co-Gn									
103.2		6.5	115.7	91.1	106.7	6.6	120.6		92.3
6. Co-Gn minus Co-A pt.									
20.1		4.1	28.6	12.2	22.2	4.6	29.8		10.8
7. Wits									
0.3		1.7	3.1	-4.3	-0.5	2.2	3.2		-5.9
Dental:									
8. Is-Olp									
81.7		5.5	91.1	72.5	81.7	5.4	91.8		73.1
9. li-Olp									
77.9		5.6	87.0	67.2	78.3	5.4	87.2		68.7
10. Overjet									
3.8		1.1	5.6	1.3	3.4	0.9	5.3		2.3
11. Ms-Olp									
52.3		4.7	60.7	44.2	54.5	4.6	63.7		46.8
12. Mi-Olp									
54.3		4.9	63.5	46.1	56.7	4.4	64.9		50.0
13. Molar Relationship									
-1.9		1.8	0.3	-7.1	-2.1	1.5	-0.2		-8.1

APPENDIX Q

Treatment Group--All Subjects Vertical Variables (mm)										T1				T2				T3				
										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	
Skeletal:																						
14. OLs-A pt.										22.8		4.1	30.9	12.7	24.7	3.9	30.4	15.2	25.2	4.2	33.8	16.1
15. ANS-Me										56.9		3.2	64.4	51.2	58.7	3.2	65.4	54.3	59.0	2.8	65.7	53.1
Dental:																						
16. Is-NL										23.6		2.8	27.6	17.2	25.2	1.2	27.4	23.2	25.5	1.4	27.9	22.8
17. Ii-ML										33.2		2.4	36.9	25.9	33.0	1.9	36.1	30.3	34.0	2.0	36.8	29.4
18. Overbite										1.4		3.4	5.4	-10.7	0.5	1.6	4.2	-2.6	1.3	1.2	3.5	-1.3
19. Msc-NL										17.0		1.9	21.1	14.1	15.8	1.8	19.3	13.0	17.6	2.0	22.8	13.9
20. Mic-ML										25.6		2.1	29.5	21.2	26.7	2.0	28.4	21.7	26.9	2.1	29.5	22.4

Treatment Group--All Subjects Vertical Variables (mm)										T4				T5				
										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	
Skeletal:																		
14. OLs-A pt.										26.9		4.0	33.7	16.0	28.0	4.5	34.8	17.1
15. ANS-Me										60.5		3.5	67.7	54.5	62.6	3.9	72.4	57.0
Dental:																		
16. Is-NL										26.2		1.7	29.3	23.7	26.7	1.9	30.8	23.3
17. Ii-ML										35.8		2.2	41.3	31.6	36.9	2.0	41.7	33.8
18. Overbite										2.0		1.4	5.0	-0.4	1.7	1.0	3.5	0.2
19. Msc-NL										19.3		2.2	24.0	15.1	20.6	2.2	24.8	16.2
20. Mic-ML										27.8		2.3	31.7	22.7	29.7	2.2	33.3	25.6

APPENDIX R

Treatment Group--All Subjects Angular Variables (mm)										T1			T2			T3					
										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:																					
21. SNA										81.4	3.9	89.0	73.0	80.3	4.1	85.0	72.5	81.0	3.8	88.5	73.5
22. SNB										75.0	3.6	80.0	65.0	76.0	3.9	83.5	70.0	76.4	3.6	83.0	69.5
23. ANB										6.4	2.1	10.5	2.0	4.3	3.0	7.5	-3.0	4.6	2.4	9.0	0.5
24. SNL-NL										8.3	3.6	17.0	3.0	9.0	3.9	16.5	3.0	7.6	3.0	14.5	1.5
25. SNL-ML										34.4	7.9	62.0	27.0	34.7	8.8	59.5	27.5	34.2	6.8	57.0	25.0
26. SNL-OL										22.3	4.2	36.0	16.0	25.5	5.0	34.0	16.0	22.5	3.7	31.5	14.0
Dental:																					
27. Is/NL										109.6	6.0	121.0	99.0	103.0	7.5	118.0	88.5	107.5	6.1	119.0	100.0
28. Ii/ML										96.0	9.3	113.5	80.5	103.0	9.8	120.0	86.0	97.4	7.6	113.0	81.0
29. Interincisal Angle										126.7	10.3	143.0	106.5	128.1	8.8	140.0	116.5	128.5	8.4	139.0	106.0

Treatment Group--All Subjects Angular Variables (mm)										T4				T5			
										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:																	
21. SNA										81.5	3.1	87.0	74.0	80.5	3.0	88.0	76.0
22. SNB										76.7	3.6	85.0	70.0	76.4	3.5	86.0	70.0
23. ANB										4.8	1.7	8.5	2.0	4.2	2.1	8.0	-1.0
24. SNL-NL										7.6	3.2	14.5	0.5	8.6	2.8	14.0	4.5
25. SNL-ML										32.8	7.1	55.0	22.5	33.3	7.3	57.5	23.5
26. SNL-OL										19.8	4.6	29.0	12.0	21.4	4.3	31.5	11.0
Dental:																	
27. Is/NL										110.2	7.1	122.0	96.5	110.0	6.2	126.5	98.5
28. Ii/ML										100.3	8.2	119.0	82.5	99.0	9.9	117.0	77.0
29. Interincisal Angle										124.0	9.4	140.0	103.0	126.4	10.6	146.0	109.0

APPENDIX S

Treatment Group--All Subjects Condyle/Glenoid Fossa Variables (mm)	T1			T2			T3		
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MAX
Sagittal:									
30. OIp-CoC	-5.1	2.8	0.5	-12.1	-4.3	2.8	2.1	-9.4	2.6
31. OIp-GFS	-5.9	2.9	-0.4	-12.2	-5.2	3.1	1.3	-11.3	-4.9
32. OIp-GFA	-1.4	2.5	3.2	-6.7	-0.2	2.9	6.0	-4.3	2.1
33. OIp-GFP	-11.8	3.4	-5.6	-19.8	-11.0	3.5	-4.8	-18.1	-10.4
Vertical:									
34. OIs-CoC	20.9	2.6	25.2	15.3	21.8	3.1	27.1	17.3	22.3
35. OIs-GFS	14.8	2.8	19.5	9.2	15.8	3.1	20.3	10.4	15.8
36. OIs-GFA	16.6	2.6	21.1	11.2	17.4	2.6	21.5	13.0	17.3
37. OIs-GFP	19.0	2.5	23.7	14.1	19.8	2.3	25.1	16.7	19.4

Treatment Group--All Subjects Condyle/Glenoid Fossa Variables (mm)	T4			T5		
	MEAN	SD	MAX	MIN	MEAN	SD
Sagittal:						
30. OIp-CoC	-4.8	3.1	2.9	-10.4	-5.4	3.0
31. OIp-GFS	-5.3	3.1	2.2	-10.8	-5.9	3.1
32. OIp-GFA	-0.8	2.7	5.1	-5.9	-0.9	2.9
33. OIp-GFP	-11.1	3.7	-2.5	-16.9	-11.3	4.2
Vertical:						
34. OIs-CoC	23.7	3.4	32.9	18.7	23.3	3.2
35. OIs-GFS	17.0	3.2	25.0	12.7	17.1	3.4
36. OIs-GFA	18.6	2.9	26.0	14.9	18.9	3.2
37. OIs-GFP	20.7	2.8	27.4	16.6	20.9	3.3

APPENDIX T

Treatment Group--Male Subjects Sagittal Variables (mm)	T1				T2				T3			
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:												
1. Olp-A pt.	71.4	3.3	74.9	64.5	71.8	3.5	76.0	65.3	72.9	3.8	77.3	67.3
2. Olp-Pg	72.5	5.5	78.8	63.1	75.4	5.6	84.8	67.3	75.8	5.2	84.6	67.9
3. Olp-Co	9.2	4.3	15.2	2.3	8.5	2.7	12.8	5.1	9.0	2.6	12.1	4.3
4. Co-A pt.	82.4	4.0	87.7	74.7	80.8	2.4	84.8	77.5	82.6	2.6	86.9	80.5
5. Co-Gn	97.3	4.6	103.2	88.7	100.9	4.2	108.1	96.2	102.5	4.0	109.0	96.8
6. Co-Gn minus Co-A pt.	16.2	2.9	20.6	12.7	20.1	3.8	26.3	15.9	19.9	3.1	23.4	15.8
7. Wits	1.9	2.1	5.6	-0.3	-3.5	2.5	-0.3	-7.2	-0.9	1.3	0.8	-2.8
Dental:												
8. Is-Olp	78.4	4.6	83.8	70.9	75.3	4.5	82.8	68.9	77.7	4.0	83.7	71.6
9. Ii-Olp	70.7	5.0	76.8	62.0	75.7	5.7	83.8	65.3	74.5	3.8	79.9	67.6
10. Overjet	7.7	1.2	9.1	5.9	-0.4	2.7	3.6	-3.3	3.2	1.0	4.4	1.6
11. Ms-Olp	48.6	3.8	53.0	42.0	46.2	3.9	49.7	38.7	48.8	4.1	55.8	43.7
12. Mi-Olp	46.4	3.4	50.9	41.9	51.5	2.9	56.9	48.1	51.1	3.0	56.4	47.8
13. Molar Relationship	2.2	1.3	3.7	0.2	-5.3	2.9	-0.5	-9.4	-2.3	2.2	-0.3	-6.5

Treatment Group--Male Subjects Sagittal Variables (mm)	T4				T5			
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:								
1. Olp-A pt.	76.6	5.4	82.4	67.5	77.6	3.9	82.0	71.6
2. Olp-Pg	80.7	7.1	89.5	68.9	83.4	6.5	91.7	74.3
3. Olp-Co	10.2	3.3	14.5	5.4	10.6	3.8	16.6	5.0
4. Co-A pt.	87.3	4.6	95.1	81.3	88.7	2.9	92.6	84.1
5. Co-Gn	108.1	4.6	115.7	103.7	112.6	3.9	120.6	108.5
6. Co-Gn minus Co-A pt.	20.7	3.5	26.9	16.6	23.9	3.4	28.0	17.6
7. Wits	1.0	1.4	3.1	-0.5	-0.3	2.9	2.5	-5.9
Dental:								
8. Is-Olp	84.0	6.1	90.5	72.5	84.1	5.9	91.8	74.7
9. Ii-Olp	79.9	6.8	87.0	67.2	80.5	5.6	87.2	71.5
10. Overjet	4.1	1.2	5.2	1.8	3.6	0.7	4.6	2.8
11. Ms-Olp	53.7	6.1	60.7	44.2	56.8	5.2	63.7	49.1
12. Mi-Olp	54.8	5.9	62.0	46.1	58.2	5.2	64.9	51.4
13. Molar Relationship	-1.1	1.0	0.1	-2.5	-1.5	0.7	-0.2	-2.3

APPENDIX U

Treatment Group--Male Subjects Vertical Variables (mm)										T1				T2				T3			
										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:																					
14. OLs-A pt.										24.5		3.2	29.7	20.9	26.7	2.7	30.4	23.1	27.4	3.2	32.0
15. ANS-Me										57.0		2.3	58.9	52.4	59.1	2.8	61.7	54.3	59.7	2.1	62.1
Dental:																					
16. Is-NL										24.7		2.1	27.6	22.1	25.7	1.3	27.4	23.2	25.4	1.1	27.4
17. Ii-ML										34.7		1.1	35.9	32.9	32.8	2.0	35.7	30.3	34.4	2.3	36.7
18. Overbite										3.3		1.4	5.4	1.3	0.7	0.8	1.5	-0.4	1.2	0.9	2.4
19. Msc-NL										17.3		2.3	21.1	14.3	16.0	1.9	19.3	13.0	18.1	2.3	22.8
20. Mic-ML										25.1		2.4	27.2	21.2	26.7	2.3	28.4	21.7	27.3	2.4	29.5

Treatment Group--Male Subjects Vertical Variables (mm)										T4				T5			
										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:																	
14. OLs-A pt.										28.7		3.0	33.6	24.2			
15. ANS-Me										60.9		2.9	65.9	56.9			
Dental:																	
16. Is-NL										25.8		1.5	28.4	24.6			
17. Ii-ML										36.4		1.2	38.0	34.7			
18. Overbite										1.8		1.4	3.6	0.0			
19. Msc-NL										19.9		1.8	22.2	17.4			
20. Mic-ML										28.3		2.3	31.5	25.9			

APPENDIX V

Treatment Group--Male Subjects Angular Variables (mm)										T1				T2				T3			
										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:																					
21. SNA										80.6	3.9	85.0	73.0	79.2	3.9	83.5	72.5	80.1	4.0	85.0	73.5
22. SNB										74.9	3.6	79.5	68.0	76.1	3.1	80.0	70.0	76.1	3.5	80.0	69.5
23. ANB										5.8	2.2	9.5	2.0	3.1	3.1	6.0	-3.0	4.1	2.4	8.0	0.5
24. SNL-NL										7.6	3.7	14.0	3.0	8.6	3.6	12.5	3.0	8.1	3.6	14.5	3.0
25. SNL-ML										33.2	6.1	46.0	28.0	33.5	5.0	44.0	28.5	33.3	4.8	43.5	29.0
26. SNL-OL										20.6	3.7	26.5	16.0	25.0	5.6	34.0	16.0	21.9	4.4	27.5	14.0
Dental:																					
27. Is/NL										112.3	7.4	121.0	103.5	101.8	9.4	118.0	88.5	107.4	7.0	116.0	100.0
28. Ii/ML										94.3	10.6	113.5	80.5	101.6	11.3	120.0	86.0	96.6	5.0	102.0	89.5
29. Interincisal Angle										127.3	12.7	143.0	106.5	131.4	9.4	140.0	117.5	130.9	5.9	139.0	124.0

Treatment Group--Male Subjects Angular Variables (mm)										T4				T5			
										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:																	
21. SNA										82.4	3.9	85.5	74.0				
22. SNB										77.7	3.8	82.0	70.0				
23. ANB										4.6	1.4	6.5	2.5				
24. SNL-NL										7.9	3.6	14.5	3.5				
25. SNL-ML										30.3	5.5	41.5	23.0				
26. SNL-OL										17.9	3.7	24.0	12.0				
Dental:																	
27. Is/NL										113.3	7.1	122.0	101.0				
28. Ii/ML										101.9	5.0	108.0	92.0				
29. Interincisal Angle										122.1	5.6	131.0	112.0				

APPENDIX W

Treatment Group--Male Subjects Condyle/Glenoid Fossa Variables (mm)	T1				T2				T3				
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	
Sagittal:													
30. OIp-CoC	-6.1		4.1	0.5	-12.1	-5.0	2.5	-2.1	-9.4	-5.5	2.7	0.0	-8.3
31. OIp-GFS	-6.9		3.9	-0.4	-12.2	-6.1	3.0	-2.4	-11.3	-6.1	2.7	-1.2	-9.2
32. OIp-GFA	-2.0		3.3	3.2	-6.7	-1.2	2.6	3.6	-4.3	-1.2	2.4	3.6	-3.2
33. OIp-GFP	-12.9		4.9	-5.6	-19.8	-11.4	3.6	-7.6	-18.1	-12.1	2.8	-7.5	-15.6
Vertical:													
34. OIs-CoC	21.3		3.3	25.2	15.3	22.2	3.7	27.1	17.3	22.1	2.9	25.4	17.7
35. OIs-GFS	15.8		3.3	19.2	9.5	16.3	3.6	20.3	10.4	15.8	2.7	19.2	11.7
36. OIs-GFA	17.9		2.7	21.1	13.1	17.8	2.9	21.2	13.0	17.8	2.5	20.8	14.0
37. OIs-GFP	20.6		2.2	23.7	17.1	19.9	2.1	22.3	16.7	20.1	2.2	22.9	16.7

Treatment Group--Male Subjects Condyle/Glenoid Fossa Variables (mm)		T4				T5			
		MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Sagittal:									
30. OIp-CoC		-6.4		3.3	-1.0	-10.4			
31. OIp-GFS		-6.3		3.2	-1.3	-10.1			
32. OIp-GFA		-1.6		3.0	2.6	-4.4			
33. OIp-GFP		-12.7		3.0	-7.7	-16.1			
Vertical:									
34. OIs-CoC		23.5		4.6	32.9	18.7			
35. OIs-GFS		17.3		4.1	25.0	12.7			
36. OIs-GFA		19.0		3.9	26.0	14.9			
37. OIs-GFP		21.3		3.5	27.4	17.0			

APPENDIX X

Treatment Group--Female Subjects Sagittal Variables (mm)	T1				T2				T3			
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:												
1. Olp-A pt.	70.3	3.3	76.6	65.4	71.3		2.0	74.1	68.5	71.4	3.1	76.5
2. Olp-Pg	71.6	4.1	76.8	64.2	74.2		4.3	79.2	67.9	75.1	5.0	83.4
3. Olp-Co	7.8	2.0	11.7	4.9	6.6		3.2	9.9	1.4	7.1	2.5	9.9
4. Co-A pt.	78.5	4.9	86.7	71.6	78.4		3.6	84.4	74.4	78.9	3.8	84.3
5. Co-Gn	94.1	4.9	102.9	84.5	96.3		1.7	98.2	94.0	97.7	5.6	108.5
6. Co-Gn minus Co-A pt.	15.6	4.3	24.7	9.4	17.9		3.7	22.4	13.6	18.8	4.0	25.9
7. Wits	0.7	1.8	4.2	-2.2	-2.0		2.7	1.5	-6.8	-1.3	2.1	1.2
Dental:												
8. Is-Olp	75.8	4.1	82.1	68.6	76.4		2.9	81.3	73.2	77.7	3.9	84.0
9. Ii-Olp	71.1	2.8	75.5	66.5	75.4		3.6	82.1	72.1	74.6	3.8	82.8
10. Overjet	4.7	2.6	9.7	-0.2	0.9		2.1	4.6	-0.8	3.1	1.7	5.1
11. Ms-Olp	47.7	2.0	51.8	44.6	46.3		3.5	50.9	41.5	49.0	2.8	54.2
12. Mi-Olp	47.5	2.7	52.1	42.1	51.2		2.9	56.1	46.9	51.8	3.4	59.0
13. Molar Relationship	0.1	1.9	4.5	-3.3	-4.9		1.6	-2.5	-7.0	-2.8	2.0	0.2

Treatment Group--Female Subjects Sagittal Variables (mm)	T4				T5			
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:								
1. Olp-A pt.	73.2	3.4	80.6	67.7	73.8		3.4	80.7
2. Olp-Pg	77.2	6.2	89.6	66.6	78.2		6.1	89.7
3. Olp-Co	7.5	2.8	12.4	0.6	8.3		2.4	12.2
4. Co-A pt.	81.1	4.5	88.4	74.1	82.5		4.2	88.6
5. Co-Gn	100.9	6.1	115.5	91.1	104.0		5.8	116.0
6. Co-Gn minus Co-A pt.	19.8	4.5	28.6	12.2	21.5		5.0	29.8
7. Wits	0.0	1.7	2.6	-4.3	-0.5		1.9	3.2
Dental:								
8. Is-Olp	80.6	5.1	91.1	72.9	80.6		4.9	90.1
9. Ii-Olp	77.0	4.9	86.5	69.6	77.3		5.1	87.0
10. Overjet	3.7	1.0	5.6	1.3	3.3		1.0	5.3
11. Ms-Olp	51.7	3.9	60.1	47.1	53.5		4.0	59.6
12. Mi-Olp	54.0	4.5	63.5	48.6	55.9		3.9	62.5
13. Molar Relationship	-2.3	1.9	0.3	-7.1	-2.5		1.7	-1.1

APPENDIX Y

Treatment Group--Female Subjects Vertical Variables (mm)		T1			T2			T3					
		MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:													
14. Ols-A pt.		22.1	4.3	30.9	12.7	22.3	4.0	26.6	15.2	24.1	4.4	33.8	16.1
15. ANS-Me		56.8	3.7	64.4	51.2	58.2	3.8	65.4	54.3	58.7	3.1	65.7	53.1
Dental:													
16. Is-NL		23.2	3.0	26.3	17.2	24.7	1.0	26.0	23.3	25.5	1.6	27.9	22.8
17. Ii-ML		32.6	2.5	36.9	25.9	33.1	2.0	36.1	31.1	33.9	1.9	36.8	29.4
18. Overbite		0.5	3.7	4.0	-10.7	0.4	2.2	4.2	-2.6	1.3	1.4	3.5	-1.3
19. Msc-NL		16.8	1.8	20.4	14.1	15.6	1.9	18.5	13.4	17.4	1.9	20.9	13.9
20. Mic-ML		25.8	2.0	29.5	23.0	26.6	1.8	28.2	23.6	26.8	2.0	29.0	22.4

Treatment Group--Female Subjects Vertical Variables (mm)		T4				T5			
		MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:									
14. OLS-A pt.		26.1	4.2	33.7	16.0	27.0	4.3	34.2	17.1
15. ANS-Me		60.3	3.9	67.7	54.5	61.9	4.2	72.4	57.0
Dental:									
16. Is-NL		26.4	1.8	29.3	23.7	26.3	1.7	30.8	24.5
17. Ii-ML		35.6	2.5	41.3	31.6	36.5	2.2	41.7	33.8
18. Overbite		2.1	1.5	5.0	-0.4	1.7	1.1	3.5	0.2
19. Msc-NL		19.0	2.4	24.0	15.1	20.2	2.4	24.8	16.2
20. Mic-ML		27.6	2.4	31.7	22.7	29.4	2.2	33.3	25.6

APPENDIX Z

Treatment Group--Female Subjects Angular Variables (mm)										T1				T2				T3			
										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:																					
21. SNA										81.7	3.9	89.0	73.0	81.7	4.2	85.0	75.0	81.4	3.8	88.5	73.5
22. SNB										75.1	3.8	80.0	65.0	75.8	5.0	83.5	70.0	76.6	3.8	83.0	70.0
23. ANB										6.7	2.1	10.5	2.0	5.8	2.3	7.5	1.5	4.8	2.4	9.0	1.0
24. SNL-NL										8.6	3.7	17.0	4.0	9.5	4.6	16.5	5.0	7.4	2.8	13.5	1.5
25. SNL-ML										34.9	8.8	62.0	27.0	36.1	12.3	59.5	27.5	34.7	7.6	57.0	25.0
26. SNL-OL										23.0	4.3	36.0	17.5	26.0	4.7	32.0	20.5	22.8	3.5	31.5	16.0
Dental:																					
27. Is/NL										108.3	5.1	117.0	99.0	104.5	4.8	110.0	98.0	107.5	5.9	119.0	101.0
28. I/ML										96.8	9.0	110.0	82.0	104.7	8.5	117.5	92.5	97.8	8.7	113.0	81.0
29. Interincisal Angle										126.4	9.5	140.0	114.0	124.3	7.0	134.5	116.5	127.4	9.3	138.0	106.0

Treatment Group--Female Subjects Angular Variables (mm)										T4				T5			
										MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Skeletal:																	
21. SNA										81.1	2.8	87.0	76.0	80.5	3.2	88.0	76.0
22. SNB										76.3	3.5	85.0	70.0	76.1	3.7	86.0	70.0
23. ANB										4.9	1.9	8.5	2.0	4.4	2.1	8.0	1.0
24. SNL-NL										7.4	3.2	13.0	0.5	9.1	2.7	14.0	4.5
25. SNL-ML										33.9	7.6	55.0	22.5	34.2	7.8	57.5	23.5
26. SNL-OL										20.7	4.8	29.0	12.5	22.2	4.6	31.5	11.0
Dental:																	
27. Is/NL										108.7	6.8	118.5	96.5	110.3	7.1	126.5	98.5
28. I/ML										99.5	9.4	119.0	82.5	99.0	11.4	117.0	77.0
29. Interincisal Angle										124.9	10.7	140.0	103.0	125.7	12.0	146.0	109.0

APPENDIX AA

Treatment Group--Female Subjects Condyle/Glenoid Fossa Variables (mm)	T1			T2			T3					
	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN	MEAN	SD	MAX	MIN
Sagittal:												
30. OIp-CoC	-4.6	2.0	-1.5	-8.2	-3.5	3.2	2.1	-6.5	-3.4	2.4	3.0	-6.3
31. OIp-GFS	-5.4	2.3	-2.2	-9.5	-4.2	3.1	1.3	-6.8	-4.3	2.2	1.3	-7.7
32. OIp-GFA	-1.2	2.1	1.8	-4.4	1.1	2.9	6.0	-1.7	0.2	1.8	4.3	-2.5
33. OIp-GFP	-11.3	2.5	-8.1	-16.3	-10.5	3.6	-4.8	-14.6	-9.6	2.7	-3.7	-14.3
Vertical:												
34. OIs-CoC	20.7	2.4	24.5	17.1	21.4	2.3	25.1	17.9	22.4	2.4	26.6	18.8
35. OIs-GFS	14.4	2.5	19.5	9.2	15.2	2.7	19.8	11.9	15.8	2.4	20.3	12.5
36. OIs-GFA	16.0	2.4	21.0	11.2	17.1	2.4	21.5	14.1	17.1	2.3	21.4	13.7
37. OIs-GFP	18.3	2.3	23.0	14.1	19.8	2.8	25.1	16.8	19.0	2.4	24.2	15.3

Treatment Group--Female Subjects Condyle/Glenoid Fossa Variables (mm)									

APPENDIX AB

Olp-Apt

Overall

Males

Females

Olp-Pg

Overall

Males

Females

Olp-Co

Overall

Males

Females

Co-Apt

Overall

Males

Females

C0-Gn

Overall

Males

Females

Co-Gn minus Co Apt

Overall

Males

Females

Wits Analysis

Overall

Males

Females

Is-Olp

Overall

Males

Females

Ii-Olp

Overall

Males

Females

Overjet

Overall

Males

Females

Ms-OLp

Overall

Males

Females

Mi-OLp

Overall

Males

Females

Molar Relationship

Overall

Males

Females

OLs-Apt

Overall

Males

Females

ANS-Me

Overall

Males

Females

Is-NL

Overall

Males

Females

Ii-ML

Overall

Males

Females

Overbite

Overall

Males

Females

Msc-NL

Overall

Males

Females

Mic-ML

Overall

Males

Females

SNA

Overall

Males

Females

SNB

Overall

Males

Females

ANB

Overall

Males

Females

SNL-NL

Overall

Males

Females

SNL-ML

Overall

Males

Females

SNL-OL

Overall

Males

Females

Is/NL

Overall

Males

Females

Ii/ML

Overall

Males

Females

Interincisal Angle

Overall

Males

Females

OLp-COC

Overall

Males

Females

OLp-GFS

Overall

Males

Females

OLp-GFA

Overall

Males

Females

OLp-GFP

Overall

Males

Females

OLs-COC

Overall

Males

Females

OLs-GFS

Overall

Males

Females

OLs-GFA

Overall

Males

Females

OLs-GFP

Overall

Males

Females

CURRICULUM VITAE

Name: Timothy G. Wigal, D.D.S.

Date of Birth: January 5, 1979

Place of Birth: Washington D.C.

Education:

August 1997- May 2001: West Virginia University
Morgantown, West Virginia
Bachelor of Arts, Biology
Minors in Business and Communications
Graduated with Honors

August 2001-May 2005: West Virginia University School of Dentistry
Morgantown, West Virginia
Doctorate of Dental Surgery

July 2005-Present: West Virginia University School of Dentistry
Department of Orthodontics
Morgantown, West Virginia
Masters of Science (anticipated May 2008)

Professional Memberships:

August 2001-May 2005: American Student Dental Association

May 2005-Present: American Dental Association

May 2005-Present: Omicron Kappa Upsilon-Honorary Dental Fraternity

July 2005-Present: American Association of Orthodontists