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Long-Term Changes in the Dental Occlusion of Subjects Treated Orthodontically

Abstract

A major challenge in orthodontics is to provide a treatment result that remains stable after appliances are removed. Orthodontic treatment can move teeth from their neutral positions, which increases potential for future relapse. The literature from the University of Washington, Seattle, shows that relapse is pervasive and of considerable magnitude (Little RM. Stability and relapse of mandibular anterior alignment: University of Washington studies. *Semin Orthod* 1999;5:191-204). The intent of this study was to quantify the posttreatment dental changes that occurred over approximately a quarter-century in a cohort of women who had received comprehensive orthodontic treatment as teenagers. Dental casts of 52 individuals were made at the start of treatment, at the end of the active phase of treatment, and at the long-term recall examination. Subjects were treated comprehensively by a single experienced orthodontist using Tweed edgewise mechanics. The amount of in-treatment change is one of the few identifiable predictors of the vectors of posttreatment relapse. Arch length and width decreased with age, accompanied by a 1.1 mm "relapse" in Incisor Irregularity during the posttreatment period. Arch depth decreased 1.3 mm during the posttreatment interval. Intercanine width was increased (2.2 mm) during treatment, but decreased (1.2 mm) towards the initial dimension after treatment. About half (1.0 mm) of the in-treatment intercanine expansion persisted at the recall examination. Intermolar width did not change significantly after treatment. Overjet increased and overbite deepened after treatment. Half (0.6 mm) of the treatment correction in overbite was lost during the posttreatment period. Buccal segment and canine relationship both remained stable after treatment. This suggests that, once established, cusp-fossa relationships tend to persist with time. Correction of the maxillary Incisor Irregularity remained stable with age (1% relapse). 65% of the correction in mandibular Incisor Irregularity was maintained over the long-term period. The mandibular Incisor Irregularity at the recall examination was less than 3.5 mm in 77% of the cases, which is the upper limit suggested as being clinically acceptable. The University of Washington studies reported that less than 30% of their cases exhibited clinically acceptable long-term mandibular Incisor Irregularity (Little RM, Wallen TR, Riedel RA. Stability and relapse of mandibular anterior alignment-first premolar extraction cases treated by traditional edgewise orthodontics. *Am J Orthod* 1981;80:349-65). The present results exhibit less relapse than those reported in most long-term recall studies, which suggests that the extent of relapse may be less in other venues.

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Comments

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**LONG-TERM CHANGES IN THE DENTAL OCCLUSION OF SUBJECTS
TREATED ORTHODONTICALLY**

A Thesis
Presented for
The Graduate Studies Council
The University of Tennessee
Health Science Center

In Partial Fulfillment
Of the Requirements for the Degree
Master of Dental Science
From The University of Tennessee

By
Kenneth Cooper Dyer IV, D.D.S.
May 2010

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ABSTRACT

A major challenge in orthodontics is to provide a treatment result that remains stable after appliances are removed. Orthodontic treatment can move teeth from their neutral positions, which increases potential for future relapse. The literature from the University of Washington, Seattle, shows that relapse is pervasive and of considerable magnitude (Little RM. Stability and relapse of mandibular anterior alignment: University of Washington studies. *Semin Orthod* 1999;5:191-204). The intent of this study was to quantify the posttreatment dental changes that occurred over approximately a quarter-century in a cohort of women who had received comprehensive orthodontic treatment as teenagers. Dental casts of 52 individuals were made at the start of treatment, at the end of the active phase of treatment, and at the long-term recall examination. Subjects were treated comprehensively by a single experienced orthodontist using Tweed edgewise mechanics. The amount of in-treatment change is one of the few identifiable predictors of the vectors of posttreatment relapse. Arch length and width decreased with age, accompanied by a 1.1 mm "relapse" in Incisor Irregularity during the posttreatment period. Arch depth decreased 1.3 mm during the posttreatment interval. Inter canine width was increased (2.2 mm) during treatment, but decreased (1.2 mm) towards the initial dimension after treatment. About half (1.0 mm) of the in-treatment inter canine expansion persisted at the recall examination. Intermolar width did not change significantly after treatment. Overjet increased and overbite deepened after treatment. Half (0.6 mm) of the treatment correction in overbite was lost during the posttreatment period. Buccal segment and canine relationship both remained stable after treatment. This suggests that, once established, cusp-fossa relationships tend to persist with time. Correction of the maxillary Incisor Irregularity remained stable with age (1% relapse). 65% of the correction in mandibular Incisor Irregularity was maintained over the long-term period. The mandibular Incisor Irregularity at the recall examination was less than 3.5 mm in 77% of the cases, which is the upper limit suggested as being clinically acceptable. The University of Washington studies reported that less than 30% of their cases exhibited clinically acceptable long-term mandibular Incisor Irregularity (Little RM, Wallen TR, Riedel RA. Stability and relapse of mandibular anterior alignment-first premolar extraction cases treated by traditional edgewise orthodontics. *Am J Orthod* 1981;80:349-65). The present results exhibit less relapse than those reported in most long-term recall studies, which suggests that the extent of relapse may be less in other venues.

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CHAPTER 1. INTRODUCTION

A major challenge in orthodontics is to provide a treatment result that remains stable after appliances are removed. Prior to treatment, teeth are in a neutral position dictated by bony and soft tissue pressures (Melrose and Millett 1998). Orthodontic treatment moves the teeth from these neutral positions, which increases potential for future relapse. Relapse, as defined by Horowitz and Hixon (1969), is a return toward the pretreatment condition. Forces from the surrounding musculature and alveolar fibrous system continue to influence the teeth toward their pretreatment position (Reitan 1967).

Stability, as defined by the Merriam-Webster Dictionary, is “the ability of not being moved, fixed.” Without permanent retention, orthodontic results are not truly fixed. Instability of the orthodontic treatment result occurs to some extent in practically every patient (Joondeph and Riedel 1994). Possible factors affecting stability include extraction versus non-extraction treatment, age at treatment, type of treatment mechanics employed, and length of retention.

The stability of long-term orthodontic treatment results has been of interest for several decades in the literature. The extensive literature from the University of Washington, Seattle, shows that relapse is pervasive and of considerable magnitude (*e.g.*, Riedel *et al.* 1992; Årtun *et al.* 1996; Haruki and Little 1998; Little 1999, 2002; Ormiston *et al.* 2005). Little (1999) reported that about 30% of orthodontic patients exhibit acceptable long-term results. Findings of considerable relapse puts orthodontic treatment in a poor light, but critics of these findings contend that they do not represent the quality of treatment provided by experienced specialists in the private sector, where the bulk of the nation’s cases are treated. Critics argue that relapse is greater in the university-setting because the residents do not diagnose and/or treat cases to the same high standards common to private practitioners – thus accounting for greater relapse. Intuitively, this is a persuasive argument, though it wholly discounts the facts that cases treated in a specialty program (A) are the patients of record of the overseeing faculty member, not the student, (B) diagnosis and treatment planning are predominantly the results of faculty decisions, and (C) the limited quantitative evidence (*e.g.*, Cook *et al.* 2005) finds no difference in the quality of treatment of cases in these two settings.

The present study further explores the stability of orthodontic cases from the private sector. Dental casts ($n = 52$ individuals) were made at the start of treatment, at the end of the active phase of treatment, and at the long-term recall examination. These subjects were treated comprehensively by a single experienced orthodontist. The average long-term recall period for these patients

is 24 years out of the active phase of treatment. The purpose of the present study is to use these dental casts to evaluate the long-term changes that occur in the dental arch 20 or more years out of treatment. Changes over this interval of roughly two-and-a-half decades include whatever relapse was going to occur (*cf.* Horowitz and Hixon 1969) in combination with aging changes during the 20s and 30s of adulthood. Posttreatment changes in the dental arch observed in the present study are then compared to reports in the literature.

CHAPTER 2. REVIEW OF THE LITERATURE

Tooth Position

Several environmental factors inflict opposing forces and pressures on the individual dental units determining tooth position. Weinstein *et al.* (1963) reported of an “equilibrium theory of tooth position” in which the conflicting forces and pressures from the natural environment are self negating. Proffit (1978) identified four primary factors that create the dental equilibrium:

1. Intrinsic forces by tongue and lips
2. Extrinsic forces: habits, orthodontic appliances
3. Forces from dental occlusion
4. Forces from the periodontal membrane

Weinstein *et al.* (1963) concluded that (1) forces exerted upon the teeth by the surrounding soft tissue may cause tooth movement much like orthodontic appliances, (2) each tooth may have more than one position of stable equilibrium within the system imposed by the natural oral environment, and (3) forces of even small magnitude, if applied over a considerable period of time, can cause important changes in tooth position.

Posttreatment Stability

Orthodontic stability involves placement of the teeth in a stable and balanced position with the ability to resist the tendency to relapse. Horowitz and Hixon (1969) described relapse as a result of physiological recovery, normal dentitional changes throughout life, and a result of the natural history of the dentition. Normal physiological forces represent a recovery or rebound of the individual's teeth toward their original positions. Horowitz and Hixon (1969) argue that relapse should be used to describe changes that result from improper treatment, inadequate mechanics, or poor patient cooperation. Because the dentition naturally changes with age, regardless of orthodontic treatment, some of the changes that occur following treatment should be considered physiological recovery or rebound provided that the diagnosis and orthodontic treatment were correct.

Etiology of Relapse

Joondeph and Riedel (1994) defined relapse as the tendency of teeth to return toward their pretreatment positions. Relapse is a complex problem that appears to be multifactorial in nature. Several factors can be linked to relapse including unfavorable skeletal growth patterns, uncooperative patients, muscular function and habits, changes in arch form, occlusion, and transseptal fibers.

Facial Growth

Most orthodontic patients are treated in their adolescence, leaving ample opportunity for subsequent growth of the maxillary and mandibular complexes to move the teeth into unstable positions (Vaden, Harris and Gardner 1997; Gardner, Harris and Vaden 1998; Harris, Gardner and Vaden 1999). The literature provides conflicting reports on the effect of facial growth on incisor stability. If a patient continues to grow after treatment, there may be increased pressure on the lower incisors when they are forced in a lingual direction with the advancement of the mandible (Ricketts *et al.* 1972). Perera (1987) reported a relationship between mandibular growth and lower anterior crowding in untreated subjects ($n = 29$). Perera indicated that forward rotational growth in the mandible is closely related to lower incisor crowding that commonly occurs after the adolescent years. However, Shields, Little and Chapko (1985) determined that horizontal and vertical growth failed to show any statistical association with posttreatment mandibular anterior irregularity.

Muscular Function

Weinstein (1967) suggested that the oral musculature had significant influence on the equilibrium of tooth position. He derived a stiffness factor, or elastic index, of the cheeks and tongue that contribute to this force on the dentition. The mean resting stiffness factor based on a group of children was 4.89 grams. Weinstein then found that forces as low as 1.68 grams were capable of moving teeth. Weinstein concluded that the oral musculature could affect long-term stability, especially if the dentition were placed outside the equilibrium with the oral musculature.

Arch Form

McCauley (1944) believed that the molar and canine width must remain in their original positions and the arches should be built around them. Strang (1949) theorized that the mandibular intercanine and intermolar arch widths are accurate indicators of where the teeth have reached an equilibrium with the cheek and lip muscle forces. These dimensions dictate the boundaries of arch expansion during treatment. Steadman (1961) concluded that, regardless of the retention period, an expanded intercanine dimension will not be maintained if this distance is not balanced with the forces acting on the mandibular canines.

De La Cruz *et al.* (1995) evaluated records of 45 patients with Class I and 42 patients with Class II, division 1 malocclusions, all treated with first premolar extractions. The sample consisted of 31 males and 56 females. Dental casts were collected at the start of treatment ($\bar{x}$ age = 13.0 years), the end of active treatment ($\bar{x}$ age = 15.7 years), and a minimum of 10 years posttreatment ($\bar{x}$ age = 33.7 years). The average posttreatment period was 18.0 years. Intermolar width, intercanine width, arch length, and Irregularity Index were measured on dental casts. The change in arch shape over time was evaluated using computer generated arch forms by fitting arcs of conic sections to the set of data points for each dental arch. The midincisal point of anterior teeth and the buccal cusp tips of posterior teeth defined the anatomic landmarks. Eccentricity represented the shape of the conic sections. A greater eccentricity value represents a more tapered arch form.

Change in eccentricity, intercanine width, intermolar width, arch length, and Irregularity Index from the end of treatment to the posttreatment examination were all statistically significant ($P < 0.05$). At the posttreatment examination, intercanine width, intermolar width, and arch length decreased, while Irregularity Index increased (Table 2-1). During treatment, arch form tends to become more rounded as shown by a decrease in eccentricity. At the posttreatment examination, arches exhibited a trend toward more tapered shapes, and they often tended toward the original pretreatment shapes. A greater treatment change in arch form was significantly correlated with a greater tendency for relapse.

Occlusion

Angle (1907) stated that orthodontic corrections would remain stable if the teeth were in proper occlusion. He thought that the influence of each jaw on the other maintained the form and size of the dental arches. Riedel (1969) said that proper occlusion is a factor in holding teeth in their corrected positions. Proper

Table 2-1. Mean changes in mandibular arch form from the end to treatment to the posttreatment examination as reported by De La Cruz *et al.* (1995).

Variable	Posttreatment change
Eccentricity	0.06
Inter canine width	-1.8
Inter molar width	-1.2
Arch length	-2.4
Irregularity Index	2.6

Source: De La Cruz A, Sampson P, Little RM, Artun J, Shapiro PA. Long-term changes in arch form after orthodontic treatment and retention. *Am J Orthod Dentofacial Orthop* 1995;107:518-30.

intercuspatation or interlocking of the teeth might contribute to stability, but studies show that, in the absence of periodontal disease, the teeth do not move in response to forces resulting from regular grinding and tapping (Riedel 1969).

Supporting Tissues

Both the periodontal ligament with its supporting fibers and the alveolar bone undergo significant changes during tooth movement. Compression of the periodontal ligament results in resorption of the alveolar bone, while new alveolar bone is deposited as a result of stretching of the periodontal ligament.

The free gingival fibers of the supralveolar tissue maintain the tooth in its original position (Reitan 1969). Tooth migration occurs as a result of elongation of the principal fibers and widening of the periodontal space. These stretched collagen fiber networks around the teeth have a tendency to contract, which serves to resorb the newly remodeled bone adjacent to the teeth (Reitan 1959). This resorption causes relapse, even after a period of retention.

Long Term Changes in Untreated Arches

While orthodontic patients tend to exhibit a long term decrease in stability, arch length decreases and incisor crowding increases in the dental arch in patients without orthodontic treatment (Sinclair and Little 1983; Sinclair and Little 1985; Richardson and Gormley 1998; Richardson 1999). Untreated patients exhibit a decrease in arch length without change to the arch width in the permanent dentition (Lundström 1969; Knott 1972).

Lundström (1969) evaluated untreated subjects in the early permanent dentitions and then again 14 years later for changes in the dimensions in the dental arches. The early permanent dentition represented 100 subjects most aged between 12 and 15 years. 41 of the subjects returned for the examination 14 years later. Arch width was measured at the first premolar and first molar, and arch length was measured as the distance between the line joining the first molars and the incisal edge of the central incisors. Arch crowding was simply given a value ranging from +2 for spacing to -4 for more severe crowding.

Lundström (1969) found that arch length was reduced by an average of 1-2 mm while the mean arch width remained at zero. These changes in the dental arch were accompanied by an increase in crowding. Lundström (1969) concluded that the increase in crowding is due more to a reduction in the anteroposterior than in the transverse dimensions. Lundström (1969) suggested

that the decrease in arch length could be attributed to a mesial migration of the lateral teeth or to the anterior teeth being forced backwards.

Knott (1972) evaluated dental casts of 21 males and 14 females without orthodontic treatment for changes in the dental arch width. Dental casts were measured in the permanent dentition ($\bar{x}$ age = 13.6 years) and in the young adult dentition ($\bar{x}$ age = 25.9 years). In agreement with Lundström (1969), Knott (1972) found little change in the arch width during the permanent dentition. There was no statistical difference found in the change in arch width for males and females.

Richardson and Gormley (1998) evaluated 20 males and 26 females without orthodontic treatment for changes in the lower arch dimensions and crowding in the adult dentition. The sample represented a variety of malocclusions as well as normal and near normal occlusions. Study casts were collected at age 18 (T1), 21 (T2), and 28 (T3) years of age. Space condition, intercanine width, intermolar width, and arch length were measured on the mandibular casts at all three time points. The space condition is defined as arch perimeter minus total tooth size with a negative value indicating crowding. Mean changes are shown in Table 2-2.

A statistically significant mean increase in crowding ($\bar{x}$ = 0.1 mm) was observed from T1 to T2. Arch length also decreased significantly by 0.2 mm. No change was found for arch widths from T1 to T2.

Changes from T2 to T3 were similar in kind to the changes from T1 to T2 but to a greater extent. Crowding increased significantly ($\bar{x}$ = 0.2 mm) with a significant decrease in arch length ($\bar{x}$ = 0.4 mm). Arch width again did not show a significant change from T2 to T3 for the grouped sample. Molar width did increase significantly in males ($\bar{x}$ = 0.2 mm), but not in females ($\bar{x}$ = 0.0 mm).

Richardson and Gormley (1998) reported significant changes from T1 to T3 for crowding and arch length. Crowding increased by 0.3 mm, and arch length decreased by 0.6 mm. Molar width exhibited a significant increase in males ($\bar{x}$ = 0.2 mm), but not in females ($\bar{x}$ = -0.1 mm). No significant difference was noted between males and females except for molar width.

The average increases in lower arch crowding, although statistically significant, were very small only averaging 0.4 mm from T1 to T3. Richardson and Gormley (1998) suggested that increases in crowding of less than 1.0 mm are scarcely visible to the naked eye and are of little clinical significance. They concluded that changes in lower dental arch alignment and dimensions in untreated subjects during the third decade of life are very small and in most cases undetectable clinically.

Table 2-2. Mean change (mm) between the three examination intervals (sexes pooled) in the study of Richardson and Gormley (1998).

Variable	T2 - T1	T3 - T2	T3 - T1
Space condition	-0.1*	-0.2**	-0.3**
Inter canine width	-0.1	0.0	0.0
Inter molar width	0.0	0.1	0.1
Arch length	-0.2**	-0.4**	-0.6**

* $P < 0.05$; ** $0.01 > P > 0.001$.

Source: Richardson ME, Gormley JS. Lower arch crowding in the third decade. Eur J Orthod 1998;20:597-607.

Richardson (1999) evaluated the changes in alignment in the untreated lower arch at various developmental stages: 7 to 15 years, 13 to 18 years, 18 to 21 years, and 18 to 50 years. Each time interval represented subject samples from different longitudinal growth studies. Dental casts were measured for changes in lower incisor crowding calculated as the difference between arch perimeter and the sum of mesiodistal incisor widths.

Richardson (1999) first evaluated dental casts of 48 children from the Belfast Growth Study at four developmental stages: at an average age of 7.8 years of age with the permanent lower incisors at least partially erupted (T1), at an average age of 10.9 years with lower permanent canines at least partially erupted (T2), at an average age of 12.5 years with the lower second molars at least partially erupted (T3), and at an average age of 15.5 years three years after full eruption of the lower second molars (T4). A significant decrease in crowding of 0.9 mm was exhibited from T1 to T2, but the decrease was small and not significant at 0.2 mm from T2 to T3. From T3 to T4, there was a significant increase in crowding of 0.4 mm.

Richardson (1999) evaluated dental casts of 51 patients from the Belfast Third Molar Study at 13 and 18 years of age. Crowding increased significantly by an average of 2.3 mm.

Dental casts of 60 students from the Belfast Adult Growth Study were evaluated at 18 and 21 years of age by Richardson (1999). No significant change was found for the change in crowding or position of lower first molar between the ages of 18 and 21 years. Dental casts of 46 of the students from the previous study were evaluated again at 28 years of age. A significant average increase in crowding of 0.2 mm was exhibited between 21 and 28 years of age.

Richardson (1999) evaluated dental casts of 16 adults for change in crowding at the ages of 18 and 50 years. While two of the subjects exhibited no change in crowding, all others had an increase in crowding with a range of 0.2 to 2.5 mm. No average crowding value was reported.

After evaluation of the dental arch at various developmental stages, Richardson (1999) concluded that the greatest increase in amount of lower incisor crowding occurs between the ages of 13 and 18 years of age ($\bar{x} = 2.3$ mm). Crowding decreased between 7 and 12 years of age ($\bar{x} = 1.1$ mm) and increased thereafter. Small increases in crowding occurred between 18 and 50 years of age in individuals with a range of 0.2 to 2.5 mm.

Sinclair and Little (1983) reported on a sample of 65 subjects with normal occlusions for changes in the dental arch from the mixed dentition, to early

permanent dentition, and into early adulthood. A normal occlusion was defined as untreated individuals with dental and skeletal Angle Class I relationships. The sample was obtained from records of children in the Burlington Growth Center Study, Ontario, Canada. The Irregularity Index (Little 1975), mandibular arch length, mandibular intercanine width, overbite, and overjet were measured. Measurements were made at three time points: (T0) mixed dentition, (T1) early permanent dentition, and (T2) adult (18 years of age) dentition stages. The purpose of their study was to describe the dental changes seen during development and to analyze relationships between the variables measured in an effort to identify trends, predictors, and associations.

In a few cases, near perfect alignment progressed to mild or moderate crowding by early adulthood. Females tended toward greater arch constriction and incisor crowding than males (Table 2-3). Overjet and overbite exhibited only minor overall changes.

Sinclair and Little (1983) found that arch length decreased from the mixed dentition into early adulthood while Incisor Irregularity increased from 13 to 20 years of age. Changes in mandibular arch length, mandibular intercanine width, overbite, and overjet were not associated with the extent of relapse as measured by the change in Incisor Irregularity. Sinclair and Little (1983) concluded that, because there were no clinically significant variables that were predictive of posttreatment mandibular anterior crowding, the changes were due to normal maturational processes.

The measurements of this untreated sample were compared to data from treated Class I samples studied by Little, Wallen and Riedel (1981). While the mean annual decrease in arch length was similar for each group, the change in overbite, overjet, and intercanine width exhibited significant differences (Table 2-4). While the treated cases showed a posttreatment increase in overbite and overjet, the untreated group showed a decrease. Intercanine width showed a tendency to decrease in both groups, but the rate of decrease was three times faster for the treated group. Sinclair and Little (1983) concluded that changes in the permanent dentition of untreated normal occlusions are similar in kind, but less in extent, compared to the posttreatment changes seen in orthodontically treated cases. The authors argued that the decrease in arch length was attributable to normal growth, not necessarily relapse of expansion attained in orthodontic treatment.

Table 2-3. Mean changes (mm) for males and females in the study of Sinclair and Little (1983).

Variable	Sex	T0 to T1	T1 to T2
Arch length	Female	-3.5*	-1.6*
	Male	-2.2*	-2.2*
Incisor Irregularity	Female	-0.3	+0.9*
	Male	-0.2	+0.6*

*P < 0.05.

Source: Sinclair PM, Little RM. Maturation of untreated normal occlusions. Am J Orthod 1983;83:114-23.

Table 2-4. Mean annual changes (mm) in orthodontically treated versus untreated cases as reported by Sinclair and Little (1983).

Variable	Untreated	Treated
Arch length	-0.3	-0.3
Inter canine width*	-0.1	-0.2
Overjet*	-0.1	+0.1
Overbite*	-0.1	+0.1
Incisor Irregularity*	+0.1	+0.2

*P < 0.05.

Source: Sinclair PM, Little RM. Maturation of untreated normal occlusions. Am J Orthod 1983;83:114-23.

Posttreatment Dental Arch Changes

Several studies have evaluated posttreatment dental arch changes comparing different treatment methods. The University of Washington has reported on posttreatment stability of several different treatment methods employed at the university (Riedel *et al.* 1992; Årtun *et al.* 1996; Haruki and Little 1998; Little 1999, 2002; Ormiston *et al.* 2005). Posttreatment records were evaluated in search for trends or clues to cause and effect relationships of orthodontic relapse.

Treatment of Arches with Generalized Spacing

It has been argued whether or not patients exhibiting pretreatment spacing, instead of crowding, were less likely to relapse than those patients with pretreatment crowding. Little and Riedel (1989) studied dental casts of 30 cases with generalized spacing in the permanent dentition with records taken at the start of treatment, at the end of active treatment, and at a minimum of 10 years posttreatment. Median ages for the sample were 12.9, 15.4, and 32.1 years, respectively, with a 14.3 year median posttreatment interval. All casts had minor or no deviations from normal anterior arch alignment and minor or no rotated teeth at the pretreatment examination. The Irregularity Index, mandibular arch length, mandibular intercanine width, overbite, and overjet were measured from each cast.

After standard Edgewise treatment and retention, arch length and width continued to decrease thereafter. Posttreatment stability was found to be satisfactory with more than 50% of the patients exhibiting minor (3.5 mm) irregularity at the recall examination. Mean irregularity at the posttreatment recall examination was higher than mean pretreatment irregularity (Table 2-5). Lower arch spaces did not reopen in any cases, and overbite and overjet exhibited less than 1 mm change posttreatment. Even with less than 50% unacceptable relapse, the authors' hypothesis that no retention was needed in cases with generalized spacing patients was incorrect. No predictor indicated which correction would be a potential failure.

First Premolar Extraction Treatment

Patients treated with first premolar extractions ($n = 65$) were evaluated at the start of treatment, at the end of the active phase of treatment, and a minimum of 10 years posttreatment (Little, Wallen and Riedel 1981). The sample consisted of 24 males and 41 females with 53% Class I, 43% Class II, division 1, and 13%

Table 2-5. Incisor Irregularity (mm) in the study of Little and Riedel (1989).

Time period	Mean	Range
Pretreatment	2.5	1.0 to 7.2
End of treatment	1.5	0.3 to 3.0
Posttreatment	3.8	1.3 to 9.3

Source: Little RM, Riedel RA. Postretention evaluation of stability and relapse-mandibular arches with generalized spacing. Am J Orthod Dentofacial Orthop 1989;95:37-41.

Class II, division 2 malocclusions. The sample had a median age of 13.0 years pretreatment, 15.2 years at the end of the active phase of treatment, 30.1 years posttreatment, and 14.9 year posttreatment interval. Little, Riedel and Årtun (1988) further evaluated 31 of the cases in Little, Wallen and Riedel (1981) at a minimum of 20 years posttreatment. This sample had a median age of 13.2 years pretreatment, 15.4 years at the end of active treatment, 30.3 years 10-year posttreatment, and 43.3 years 20-year posttreatment. The Irregularity Index, mandibular arch length, mandibular intercanine width, overbite, and overjet were measured from each dental cast. Variables such as Angle's classification, patient age at the beginning of treatment, sex, overbite, overjet, arch width, arch length were analyzed in both studies. The primary purpose of the studies was to evaluate mandibular anterior alignment. The secondary goal was to describe treatment and posttreatment changes and search for predictors and associations of stability.

Little, Wallen and Riedel (1981) found no significant difference in the end of active treatment or posttreatment crowding index between the various Angle malocclusions, between the sexes, or between the combination of the two. Based on the Irregularity Index, cases were grouped into minor (< 3.5 mm), moderate (3.5 to 6.5 mm), and severe (> 6.5 mm) irregularity at pretreatment and posttreatment stages (Table 2-6).

While more than 70% of the cases were classified as showing moderate to severe crowding pretreatment and posttreatment, pretreatment crowding was not consistent with posttreatment crowding. Although most cases with minor crowding either remained minor or worsened to moderate, 14% became severely crowded posttreatment. In the severely crowded pretreatment group, 60% resulted in moderate crowding posttreatment, and the remaining cases were equally dispersed in both the minimal and severe crowding groups. Patients with moderate pretreatment crowding were evenly distributed in all three groups at the posttreatment examination. Initial pretreatment crowding was a poor predictor of anterior irregularity in the long-term (Table 2-7).

While 60% of the cases showed canine expansion of more than 1 mm during treatment, 92% of the cases exhibited canine constriction posttreatment, averaging 2.0 mm. Arch width change during treatment, change in posttreatment arch width, and net change in intercanine width showed no association with long-term anterior alignment.

Arch length decreased following treatment, with an average change of 2.5 mm. No significant difference was noted between Angle classes or between sexes. The degree of posttreatment arch length reduction and the severity of posttreatment crowding exhibited a weak correlation ($r = 0.52$, $P < 0.001$).

Table 2-6. Incisor Irregularity categories from the study described by Little, Wallen and Riedel (1981).

Posttreatment	Pretreatment status			Pooled
	Minor	Moderate	Severe	
Minor	6	4	7	17 (28%)
Moderate	6	8	20	34 (56%)
Severe	2	2	6	10 (16%)
Pooled	14 (23%)	14 (23%)	33 (54%)	61

Source: Little RM, Wallen TR, Riedel RA. Stability and relapse of mandibular anterior alignment-first premolar extraction cases treated by traditional edgewise orthodontics. Am J Orthod 1981;80:349-65.

Table 2-7. Net change in Incisor Irregularity from pretreatment to posttreatment in the report by Little, Wallen and Riedel (1981).

Pretreatment irregularity	Net change	
	Increased	Decreased
Minor	13	1
Moderate	6	8
Severe	0	33
Pooled	19	42

Source: Little RM, Wallen TR, Riedel RA. Stability and relapse of mandibular anterior alignment-first premolar extraction cases treated by traditional edgewise orthodontics. Am J Orthod 1981;80:349-65.

Overbite increased 0.8 mm during the posttreatment period, but exhibited a 0.5 mm net decrease in overbite. The Class II, division 1 group started with the greatest pretreatment overbite of 5.7 mm compared to 3.5 mm averages for Class I and Class II, division 2 groups. The overbite in the Class II, division 1 group remained constant while the other two groups showed significant improvements. The changes in overbite were not associated with posttreatment crowding.

Overjet decreased significantly during treatment in all three Angle classes. The Class II, division 1 group showed the greatest overjet pretreatment, but no significant difference in overjet was observed between the groups posttreatment. No relationship was observed between the amount of posttreatment crowding and the amount of overjet either during treatment or following treatment.

Little, Wallen and Riedel (1981) reported that no factor, such as sex, age, or Angle class was found to contribute to relapse, as measured by Incisor Irregularity. The extent of pretreatment Incisor Irregularity had no significant correlation with the posttreatment irregularity. In cases exhibiting mild pretreatment Incisor Irregularity, all but one case showed a net increase in Incisor Irregularity from the pretreatment to posttreatment examination. 57% of mildly crowded pretreatment cases became moderate or severely crowded posttreatment. Only 30% of cases exhibited satisfactory posttreatment alignment, while nearly 20% exhibited marked crowding.

Rate of Relapse

To determine whether there is an age of final dental stability, Little, Riedel and Årtun (1988) evaluated 31 cases previously evaluated by Little, Wallen and Riedel (1981) with an additional 20-year recall period. Findings for pretreatment, the end of active treatment, and 10 years posttreatment were similar to the report of Little, Wallen and Riedel (1981) due to similar samples. For both studies, regardless of treatment maintenance of initial arch width, treatment expansion, or treatment constriction, arch length and arch width decreased following treatment with a concomitant increase in crowding. Only slight changes were noted from 10 to 20 years posttreatment with less than a 1 mm increase in Incisor Irregularity (Table 2-8). Reduction of arch length and arch width continued well into the patients 30s and beyond, with the rate of change decreasing after the third decade. While Little, Wallen and Riedel (1981) found 30% satisfactory anterior alignment at 10 years posttreatment, only 10% was considered satisfactory in this sample at 20 years posttreatment. Neither overbite nor overjet showed considerable changes from 10 to 20 years posttreatment.

Table 2-8. Incisor Irregularity (mm) from the study described by Little, Riedel and Årtun (1988).

Incisor Irregularity	Mean	Range
Pretreatment	7.4	1.9 to 18.1
End of treatment	1.7	0.3 to 3.5
10 years posttreatment	5.3	2.0 to 10.1
20 years posttreatment	6.0	2.4 to 11.5

Source: Little RM, Riedel RA, Årtun J. An evaluation of changes in mandibular anterior alignment from 10 to 20 years postretention. Am J Orthod Dentofacial Orthop 1988;93:423-8.

Little, Riedel and Årtun (1988) concluded that from 10 to 20 years posttreatment, most crowding increases are minor, but the degree of malalignment for each individual is unpredictable. The one factor that seems predictable is the continuing decrease in mandibular arch length posttreatment. Little, Riedel, and Årtun concluded that the only way to ensure continued satisfactory alignment posttreatment is by use of fixed or removable retention for life.

Second Premolar Extraction Treatment

McReynolds and Little (1991) evaluated changes in long-term posttreatment records of 32 patients treated with second premolar extracted in the permanent dentition. Records were obtained at the start of treatment, at the end of the active phase of treatment, and at a minimum of 10 years posttreatment. The average posttreatment period was 17 years. The Irregularity Index, mandibular arch length, mandibular intercanine width, overbite, and overjet were measured from each dental cast. The purpose of the study was to compare the posttreatment changes exhibited in patients treated with the extraction of second premolars with previous data on treatment with the extraction of first premolars. Mean dental cast measurements are shown in Table 2-9.

Incisor Irregularity increased 2.6 mm during the posttreatment period. The pretreatment Incisor Irregularity was not correlated with the posttreatment incisor alignment. Males were found to exhibit more Incisor Irregularity posttreatment than females.

Arch length decreased by an average 3.6 mm during the posttreatment period. No correlation was found between the posttreatment change in arch length and change in Incisor Irregularity.

During the posttreatment period, intermolar width decreased an average of 1.0 mm. The intercanine width decreased an average of 1.8 mm during the posttreatment period. No correlation was found between the posttreatment change in intermolar or intercanine width and changes in Incisor Irregularity.

A statistically significant increase in overjet ($\bar{x}$ = 0.8 mm) and overbite ($\bar{x}$ = 1.1 mm) were observed during the posttreatment period. The mean change in overjet measured at the posttreatment examination was associated with an increase in Incisor Irregularity. The change in overjet and overbite was not associated with the change in incisor alignment.

Table 2-9. Mean dental cast measurements (mm) in the study of McReynolds and Little (1991).

Variable	Pretreatment	End of treatment	Posttreatment
Intermolar width	41.8	39.7*	38.7*
Arch length	59.4	48.4*	45.5*
Inter canine width	25.8	26.5*	24.7*
Incisor Irregularity	5.4	1.4*	4.0*
Overbite	4.3	2.4*	3.5*
Overjet	5.7	2.2*	3.0*

*Indicates a statistically significant difference ($P < 0.05$) from the previous examination.

Source: McReynolds DC, Little RM. Mandibular second premolar extraction-postretention evaluation of stability and relapse. *Angle Orthod* 1991;61:133-44.

The decrease in arch length, intermolar width, and intercanine width with an increase in Incisor Irregularity at the posttreatment examination was in agreement with the posttreatment reports on treatment with the extraction of first premolars (Little, Wallen and Riedel 1981; Little, Riedel and Årtun 1988). There was no long-term posttreatment difference when comparing first and second premolar extractions. The posttreatment change in arch length, intermolar width, and intercanine width was not associated with the change in Incisor Irregularity in these studies. McReynolds and Little (1991) concluded that long-term retention is necessary because stability was found to be highly variable and unpredictable for each individual.

Serial Extraction Treatment

In the typical serial extraction treatment, crowding, severe enough to warrant the extraction of permanent premolars, occurs in the mixed dentition. While still in the mixed dentition, a sequence of primary teeth is extracted along with permanent first premolars. The teeth are allowed to drift into the extraction spaces. Serial extraction treatment relieves crowding in the mixed dentition, which raises the question, if crowding never develops or is corrected early, will stability be improved?

Little, Reidel and Engst (1990) evaluated 30 patients treated with a sequence of primary tooth extractions and four first-premolar extractions in the mixed dentition. Records at the start of treatment, at the end of the active phase of treatment, and at a minimum of 10 years posttreatment were analyzed for changes. A subsequent study by Haruki and Little (1998) evaluated 36 patients who initiated active treatment immediately after the extraction of four first premolars in the mixed dentition and 47 patients who underwent orthodontic alignment immediately after four first premolar extractions in the permanent dentition. The purpose of the studies was to compare stability in cases relieved of crowding through early extraction with cases treated with extractions in the permanent dentition.

In the study of Little, Riedel and Engst (1990), the median age was 9.4 years preextraction, 11.8 years pretreatment, 14.3 years at the end of active treatment, and 29.1 years posttreatment. The patients were observed without active treatment for an average of 2.4 years after extractions. There was a statistically significant increase in Irregularity Index ($P < 0.05$) from the end of treatment ($\bar{x} = 1.8$ mm) to the posttreatment examination ($\bar{x} = 4.4$ mm). No difference was found in posttreatment Incisor Irregularity for sex or Angle classification (Table 2-10). Change in overjet, overbite, intercanine width, and arch length had no association with the change in Incisor Irregularity.

Table 2-10. Mean mandibular Incisor Irregularity (mm) based on Angle classification in the report by Little, Riedel and Engst (1990).

Examination	Class I	Class II-1	Class II-2	All classes
Pretreatment	3.3	6.1	5.9	4.1
End of treatment	1.6	2.0	2.6	1.8
Posttreatment	4.5	3.9	4.4	4.4

Source: Little RM, Riedel RA, Engst ED. Serial extraction of first premolars-posttreatment evaluation of stability and relapse. Angle Orthod 1990;60:255-62.

The serial extraction cases of Little, Riedel and Engst (1990) were matched to similar cases treated with the extraction of first premolars after the full eruption of the permanent dentition followed by orthodontic treatment. No significant difference was found in posttreatment Incisor Irregularity between the serial extraction cases and the matched sample.

Arch length and arch width decrease along with increased crowding was the typical finding for this study. These findings are very similar to those of previous studies, continuing to support the hypothesis that posttreatment crowding is inevitable without permanent retention (Little, Wallen and Riedel 1981; Sinclair and Little 1983; Sinclair and Little 1985; Little, Riedel and Årtun 1993). Little, Riedel and Engst (1990) rejected the hypothesis that the serial extraction of first premolars followed by an observation period before orthodontic treatment in the permanent dentition improves long term stability.

Haruki and Little (1998) divided 83 patients into two groups based on whether the orthodontic treatment was initiated in the mixed or permanent dentition (Table 2-11). Cases were categorized at the pretreatment examination into Class I, Class II division 1, and Class II division 2 malocclusions.

There was a statistically significant ($P < 0.01$) difference in posttreatment change in Incisor Irregularity between the mixed and permanent dentition treatment groups (mixed: $\bar{x} = 1.5$ mm; permanent: $\bar{x} = 2.8$ mm; Table 2-12). No significant difference was noted in posttreatment change in Incisor Irregularity based on sex or Angle class.

No statistically significant difference was noted in posttreatment change in arch length between the mixed and permanent dentition treatment groups. There was a statistically significant ($P < 0.01$) difference in posttreatment change in canine width between the mixed and permanent dentition treatment groups (mixed: $\bar{x} = -1.5$ mm; permanent: $\bar{x} = -2.5$ mm). No significant difference was noted in posttreatment change in arch length or canine width based on sex or Angle class (Table 2-13). No difference was noted in posttreatment change in overjet or overbite based on sex, Angle classification, or stage of dentition at the onset of treatment.

In the study of Haruki and Little (1998), the mean posttreatment Incisor Irregularity of the mixed dentition treatment group ($\bar{x} = 3.1$ mm) was significantly better than that of the permanent dentition treatment group ($\bar{x} = 4.2$). The mixed dentition treatment group also exhibited less posttreatment change in Incisor Irregularity (mixed: $\bar{x} = 1.5$ mm; permanent: $\bar{x} = 2.8$ mm).

Table 2-11. Sample sizes in the study of Haruki and Little (1998).

Variable	Mixed dentition	Permanent dentition	Pooled
Sex			
Male	9	10	19
Female	27	37	64
Pooled	36	47	83
Angle class			
Class I	13	23	36
Class II, division 1	20	18	38
Class II, division 2	3	6	9
Mean age			
Pretreatment	11.3	13.3	12.4
End of treatment	12.4	16.3	15.4
Posttreatment	30.6	32.0	31.4
Posttreatment period	16.2	15.8	16.0

Source: Haruki T, Little R. Early versus late treatment of crowded first premolar extraction cases: Postretention evaluation of stability and relapse. Angle Orthod 1998;68:61-8.

Table 2-12. Mean posttreatment changes (mm) for mixed and permanent dentition treatment groups from the study by Haruki and Little (1998).

Variable	Mixed dentition	Permanent dentition
Irregularity Index*	1.5	2.8
Arch length	-3.4	-3.3
Canine width*	-1.5	-2.5

*Statistically significant ($P < 0.01$) intergroup difference.

Source: Haruki T, Little R. Early versus late treatment of crowded first premolar extraction cases: Postretention evaluation of stability and relapse. *Angle Orthod* 1998;68:61-8.

Table 2-13. Mean posttreatment changes (mm) grouped by Angle class in the study of Haruki and Little (1998).

Variable	Class I (n = 36)	Class II-1 (n = 38)	Class II-2 (n = 9)
Irregularity Index	2.0	2.4	2.4
Arch length	-2.9	-3.1	-3.7
Canine width	-2.0	-2.0	-2.2

Source: Haruki T, Little R. Early versus late treatment of crowded first premolar extraction cases: Postretention evaluation of stability and relapse. *Angle Orthod* 1998;68:61-8.

Haruki and Little (1998) concluded that early orthodontic treatment in first premolar extraction cases is more stable than treatment in the permanent dentition. In contrast to the findings of Little, Riedel and Engst (1990), first-premolar extraction in the mixed along with immediate orthodontic treatment exhibited less posttreatment Incisor Irregularity than early extraction with orthodontic treatment delayed until the full eruption of the permanent dentition in the study of Haruki and Little (1998).

Mandibular Incisor Extraction Treatment

Riedel, Little and Bui (1992) evaluated records at the start of treatment, at the end of active treatment, and at the posttreatment examination in 42 patients treated with mandibular incisor extractions (Table 2-14). The sample (Table 2-15) consisted of records of patients treated with the extraction of a single incisor ($n = 24$) and evaluated at a minimum of 7 years posttreatment (Group I). Patients treated with the extraction of two mandibular incisors ($n = 18$) constituted Group II, and they had records at a minimum of 10 years posttreatment. Irregularity Index, intercanine width, intermolar width, arch length, overbite, and overjet were measured on the dental casts.

Groups I and II exhibited statistically significant increases in posttreatment Incisor Irregularity, averaging 0.3 and 0.4 mm, respectively (Table 2-16). Both groups exhibited statistically significant decreases in posttreatment intercanine width (Group I: $\bar{x} = -1.1$ mm, Group II: $\bar{x} = -1.4$ mm). The change in intercanine width during treatment was not significantly correlated with the posttreatment change in intercanine width. The posttreatment change in intermolar width was significant for Group II, but not for Group I (Group I: $\bar{x} = -0.3$ mm, Group II: $\bar{x} = -1.1$ mm). Group II exhibited a statistically significant increase in posttreatment overbite and overjet, while the posttreatment change for Group I was not significant. No difference was noted in posttreatment change in Incisor Irregularity, intercanine width, intermolar width, arch length, overjet, or overbite based on sex or Angle classification.

Almost half (40%) of the patients treated with mandibular incisor extractions exhibited moderate to severe Incisor Irregularity (Incisor Irregularity > 3.5 mm) at the posttreatment examination compared to 70% of patients treated with first premolar extractions (Little, Wallen and Riedel 1981). The mean posttreatment Incisor Irregularity is less than reports on treatment with extraction of four premolars (Little, Wallen and Riedel 1981; Little, Riedel and Årtun 1988). Riedel, Little and Bui (1992) concluded that treatment with the extraction of a mandibular incisor exhibits greater stability than treatment with extraction of four premolars.

Table 2-14. Mean age (years) in the report by Riedel, Little and Bui (1992).

Examination	Group I	Group II	Pooled
Pretreatment	19.8	15.2	17.8
End of treatment	22.3	17.2	20.1
Posttreatment	34.4	36.3	35.3
Posttreatment period	12.1	19.2	15.2

Source: Riedel RA, Little RM, Bui TD. Mandibular incisor extraction-postretention evaluation of stability and relapse. Angle Orthod 1992;62:103-16.

Table 2-15. Sample sizes by Angle class in the study of Riedel, Little and Bui (1992).

Angle class	Group I	Group II	Pooled
Class I	12	9	21
Class II, division 1	6	7	13
Class II, division 2	6	2	8

Source: Riedel RA, Little RM, Bui TD. Mandibular incisor extraction-postretention evaluation of stability and relapse. Angle Orthod 1992;62:103-16.

Table 2-16. Mean posttreatment change (mm) for Groups I and II in the report by Riedel, Little and Bui (1992).

Variable	Group I	Group II
Irregularity Index	+0.3*	+0.4*
Inter canine width	-1.1*	-1.4*
Intermolar width	-0.3	-1.1*
Arch length	-2.4*	-2.5*
Overbite	+0.7	+1.4*
Overjet	+0.1	+1.2*

*Statistically significant ($P < 0.05$) posttreatment change.

Source: Riedel RA, Little RM, Bui TD. Mandibular incisor extraction-postretention evaluation of stability and relapse. *Angle Orthod* 1992;62:103-16.

Treatment by Mandibular Arch Enlargement

Little, Riedel and Stein (1990) evaluated 26 patients, 15 males and 11 females, who had mandibular arch length actively increased at least 1 mm during the mixed dentition. Mandibular arch length was defined as the sum of the left and right distances from mesial anatomic contact points of the first permanent molars to the contact point of the central incisors. Fixed Edgewise appliances, active lingual arches, lip bumpers, and removable appliances were used for lengthening the dental arch during the mixed dentition. Records were collected at the start of treatment, at the end of the active phase of treatment, and at a minimum of 6 years posttreatment. Mean pretreatment age was 10.1 years with average recall age of 25.7 years. Irregularity Index, mandibular arch length, mandibular intercanine width, overbite, and overjet were measured on each dental cast.

Only 11% of lengthened arches exhibited acceptable long-term anterior alignment (Irregularity Index < 3.5 mm) with 20 out of 26 patients showing a net loss of arch length compared with the initial measurement. No significant difference between Angle class or sex was found. Enlarged arches exhibited 6.1 mm mean posttreatment Incisor Irregularity, significantly more than the 4.6 mm posttreatment Incisor Irregularity reported by Little, Wallen and Riedel (1981) on treatment with the extraction of four first premolars.

CHAPTER 3. MATERIALS AND METHODS

Sample Selection

This long-term analysis of posttreatment occlusal stability is based on the study of 52 American white females recalled a minimum of 20 years after their active phase of treatment. These cases were treated with the standard Edgewise “Tweed” orthodontic technique. All brackets have a 0.022” X 0.028” slot size with zero tip and torque. Patients were given a Hawley retainer at debanding for retention.

All patients in the present study were treated during their adolescence by the same practitioner, Dr. James L. Vaden, Cookeville, TN. The sample was of convenience; specifically, inclusion only depended on the patient’s willingness to return for a recall examination. At the recall examination, informed consent was obtained and records, including a lateral cephalogram and full-mouth study casts, were taken. Indeed, the final sample was of 56 people, 52 of whom were women. These few men were excluded from the present study to enhance sample homogeneity, since men’s faces grow more, especially in the vertical axis, and for a longer period of time than women’s (*e.g.*, Behrents 1985a,b; Bishara *et al.* 1998).

The present study reports on data collected at three examinations of each patient, (T0) the start of treatment, (T1) the end of the active phase of treatment, and (T2) the long-term recall examination, though the focus is on how stable the orthodontic result was from T1 to T2. A few of these women had participated in a prior, shorter-term recall analysis (Vaden *et al.* 1997; Gardner *et al.* 1998; Harris *et al.* 1999), but those recall records are not described here. Appendix A contains pictures taken of five cases to provide visual representation of the casts at each examination period.

Extraction Patterns

Cases were treated using standard Edgewise mechanics (*e.g.*, Sandusky and Gramling 1988), and most cases were treated with some pattern of premolar extractions. These can be divided into three categories, (1) 24 cases were treated with first-premolar extractions, (2) 11 cases were treated with maxillary first and mandibular second premolars, and (3) 14 cases were treated with second premolar extractions. Most of the subjects ($n = 39$) exhibited a Class II malocclusion pretreatment (Class I: $n = 12$, Class III: $n = 1$).

Cast Analysis

The maxillary and mandibular casts were occluded in maximum intercuspation, and, as described below, the following variables were measured, (1) incisor overjet, (2) incisor overbite, (3) incisor midline deviation, (4) buccal segment relationship of the first molars, (5) canine relationship, (6) arch width in each arcade, (7) arch chord in each arcade, (8) arch depth in each arcade, and (9) Incisor Irregularity in each arch. These variables were measured on the cases using digital-readout sliding calipers precise to 0.001 mm. Variables are primarily those described by Baume *et al.* (1973), Little (1975), Smith and Bailit (1977), and Harris and Bodford (2007).

Incisor overjet (Baume *et al.* 1973; Smith and Bailit 1977) is the horizontal distance (parallel with the occlusal plane) between the facial surface of the most protrusive maxillary central incisor and the facial of the corresponding mandibular incisor (Figure 3-1). The depth gauge of the calipers was used to obtain this distance.

Incisor overbite (Baume *et al.* 1973) is the distance perpendicular to Downs' occlusal plane that the incisal edge of the maxillary central incisor overlaps the mandibular central incisor (Figure 3-2). A light pencil mark is placed on the facial surface of the mandibular incisor where the incisal limit of the upper incisor occurs, then the maxillary cast is removed and the distance from the pencil mark occlusally to the incisal edge of the tooth is measured in millimeters. If there is left-right asymmetry, the side with greater overbite is measured.

Buccal segment relationship, abbreviated BSR (Grainger 1967) is the horizontal distance (parallel with Downs' occlusal plane) between the mesiobuccal cusp of the maxillary first molar and the buccal groove of the mandibular first molar (Figure 3-3). If there is a Class II relationship, the distance is recorded as negative; if there is a Class III relationship, the distance is positive. A "socked-in" Class I sagittal molar relationship has a BSR of zero.

Canine relationship was measured in a fashion similar to BSR (Figure 3-4). It is the horizontal distance in millimeters from the cusp tip of the maxillary canine to the embrasure between the mandibular canine and first premolar. If there is a Class II (canine) relationship, the distance is negative; if Class III, positive (Harris and Bodford 2007).

Dental midline deviation (Baume *et al.* 1973) was measured as the horizontal deviation of the maxillary and mandibular midline embrasures (Figure 3-5). If the dental midlines are coincident, the deviation is zero. A shift

Figure 3-1. Lateral view of the central incisors, showing the method of measuring overjet, measured parallel with Downs' occlusal plane. The horizontal distance was measured with sliding calipers. If the incisors are in crossbite, the measured value would be negative. (Diagram modified with permission. Harris EF, Corruccini RS. Quantification of dental occlusal variation: A review of methods. Dental Anthropology 2008;21:1-11.)

Figure 3-2. Lateral view of the central incisors, showing the method of measuring overbite, measured perpendicular to Downs' occlusal plane. The vertical distance was measured with sliding calipers as the vertical distance between the maxillary and mandibular incisor's incisal edge. If there was an openbite, the measured value would be negative. (Diagram modified with permission. Harris EF, Bodford K. Bilateral asymmetry in the tooth relationships of orthodontic patients. *Angle Orthod* 2007;77:779-86.)

Figure 3-3. Lateral view of the permanent first molars, showing the method of measuring the buccal segment relationship. This is the horizontal (parasagittal) distance of the maxillary molar's mesiobuccal cusp from the buccal groove of the mandibular molar. The horizontal discrepancy was measured with sliding calipers. If, as diagrammed here, the molars have a Class II relationship, the distance is negative. (Diagram modified with permission. Harris EF, Corruccini RS. Quantification of dental occlusal variation: A review of methods. *Dental Anthropology* 2008;21:1-11.)

Figure 3-4. Lateral view of the canines, showing the method of measuring canine discrepancy, which is the horizontal (parasagittal) deviation of the mandibular canine's cusp tip relative to the canine-first premolar embrasure. The horizontal discrepancy was measured with sliding calipers. If, as diagrammed here, the mandibular canine is mesial (Class III) of its ideal position, the value is defined as positive. (Diagram modified with permission. Harris EF, Bodford K. Bilateral asymmetry in the tooth relationships of orthodontic patients. Angle Orthod 2007;77:779-86.)

Figure 3-5. Diagram of the labial view of the central incisors, showing the method of measuring the deviation of the maxillary and mandibular dental midlines. If the midlines are coincident, the discrepancy is zero. The horizontal discrepancy was measured with sliding calipers. Mandibular shifts to the right were labeled positive. (Diagram modified with permission. Harris EF, Bodford K. Bilateral asymmetry in the tooth relationships of orthodontic patients. *Angle Orthod* 2007;77:779-86.)

of the mandibular dental midline to the person's right is labeled positive; a shift to the left is negative (Harris and Bodford 2007).

Three arch widths (Knott 1971, Smith and Bailit 1977) were measured independently on each dental arch (Figure 3-6). Arch width was measured as the intercanine, interpremolar and intermolar width. The intercanine width is the maximum distance at the buccal surfaces of the canines. The interpremolar width is the maximum distance at the buccal surfaces of the premolars that were not extracted during treatment. The intermolar width is the maximum distance at the buccal surfaces of the first molars. In practice, widths were measured as the maximum attainable distances between buccal surfaces of the teeth, not between cusp tips.

Two arch chords (Moorrees and Reed 1954, Sillman 1964, Knott 1972) were measured on each of the person's four quadrants (Figure 3-7). These are labeled the 1-3 and the 1-6 chords (Cassidy *et al.* 1988). The 1-3 chord is the straight-line distance, measured with sliding calipers, from the central incisor embrasure to the distal aspect of the canine. The 1-6 chord is the distance from the central incisor embrasure and the distal-buccal aspect of the permanent first molar's crown.

Arch depth (*e.g.*, Knott 1971) is measured independently in the two arches as the midsagittal mesiodistal dimension (Figure 3-8) from the labial of the central incisors back to the distal of the permanent first molars. Operationally, a straight-edge is held against the distal heels of the first molars and the depth gauge of the caliper is used to measure the arch depth (Harris 1997).

Incisor Irregularity is measured separately on maxillary and the mandibular casts (Figure 3-9) following Little's method (Little 1975). One locates each anterior tooth's idealized mesial and distal anatomic contact, and then the distances are measured in the occlusal plane. Irregularity is the sum of the five distances (labeled A through E in the figure). If the two idealized contacts are abutted, regardless of each tooth's axioversion, the distance is zero. As such, irregularity is not sensitive to axioversion so long as the contacts are tight.

Tooth Designations

Two tooth-naming systems are used interchangeably. The actual names commonly are written out, but we also use the anatomical coding system (Peck and Peck 1993; Harris 2005), where one letter is used to code for the tooth type and the number designates the tooth's position in the morphogenetic field, either

Figure 3-6. Diagrammatic illustration showing the manner that, with sliding calipers, the intercanine, interpremolar and the intermolar widths were measured. Widths, measured independently on both the maxillary and mandibular arches, are the maximum attainable distances between the buccal surfaces of the teeth, not between cusp tips. (Diagram modified with permission. Harris EF. A longitudinal study of arch size and form in untreated adults. *Am J Orthod Dentofacial Orthop* 1997;111:419-27.)

Figure 3-7. Diagrammatic illustration of a maxillary dental arch, showing the manner that, with sliding calipers, the incisor-to-canine (1-3) and the incisor-to-molar (1-6) arch chords were measured. In practice, both of these chords were measured on the left and right sides of both the maxillary and mandibular arches. (Diagram modified with permission. Harris EF, Bodford K. Bilateral asymmetry in the tooth relationships of orthodontic patients. Angle Orthod 2007;77:779-86.)

Figure 3-8. Diagrammatic illustration of maxillary arch depth. Depth was measured independently on the maxillary and mandibular arches. Operationally, a straight-edge was positioned against the distal heels of the permanent first molars (so there may be some dentoalveolar asymmetry) and the depth was measured from the labial of the central incisors, along the median raphe, to the back of the first molars. (Diagram modified with permission. Harris EF. A longitudinal study of arch size and form in untreated adults. *Am J Orthod Dentofacial Orthop* 1997;111:419-27.)

Figure 3-9. Incisor Irregularity is the summation of the five distances between the anatomic contacts of the anterior six teeth. If the anatomic contacts of two adjacent teeth are approximated, the distance is zero. Incisor Irregularity is, then, the millimetric sum of the five contacts labeled A through E. Incisor Irregularity is measured independently on the maxillary and mandibular casts.

Source: Little RM. The Irregularity Index: A quantitative score of mandibular anterior alignment. *Am J Orthod* 1975;68:554-63.

mesial (1) or distal (2). The codes are:

I1	central incisor
I2	lateral incisor
C	canine (cuspid)
P1	first premolar (bicuspid)
P2	second premolar (bicuspid)
M1	first molar
M2	second molar

Statistical Analyses

Data were collected on custom data-collection forms and then collated into an Excel® spreadsheet (Microsoft®, Seattle, WA). This datafile then was transferred to the statistical package termed JMP 7 (SAS Institute Inc., Cary, NC). Exploratory data analysis (Tukey 1977) was performed, searching for outliers; those due to technical errors were corrected.

Conventional descriptive statistics (*e.g.*, Winer *et al.* 1991; Sokal and Rohlf 1995) were calculated; these (and abbreviations) are sample size (n , taken as counts of individuals, not sides), the arithmetic mean ($\bar{x}$), the sample variance (s^2), the standard deviation (sd), the standard error of the mean (se , calculated as $sd/\sqrt{n}$), and the 95% confidence limits of the distribution (L_1 , L_2), skewness (g_1), kurtosis (g_2), coefficient of variation (cv), number of cases missing, maximum value, median value (50th percentile), and minimum value. Regarding the sample variance and skewness, the significance of these was not tested.

One-sample t-tests were used to assess whether the in-treatment and posttreatment changes were systematically different from zero (two tail tests).

The conventional alpha level of 0.05 was used throughout, and all of the tests were two-tail. No correction was made for multiple comparisons.

CHAPTER 4. RESULTS

Ages at Examinations

The sample consisted of 52 treated females. Mean age at the start of treatment was 13.3 years (Table 4-1), so the cases were treated early in adolescence shortly after all of the permanent teeth (ignoring third molars) had emerged. Comprehensive treatment lasted an average of 2.3 years, completing treatment at an average of 15.7 years. Mean age at the recall examination was 39.4 years, which is 24 years out of the active phase of treatment. Changes over this interval of roughly two-and-a-half decades include whatever relapse was going to occur in combination with aging changes during the 20s and 30s of adulthood (*cf.* Horowitz and Hixon 1969). With the long-term status of these cases, this study captures all of the orthodontic relapse plus the normative age changes of these women during early adulthood (*e.g.*, Harris 1997; Stephens *et al.* 2005).

Descriptive Statistics

The descriptive and inferential statistics are presented in Appendices B through E. This was done to reduce the bulk of the report and for the convenience of the reader in viewing the calculations. Appendix B describes the status of the occlusal variables at the start of treatment, while Appendix C corresponds to the end of treatment. Appendix D presents the in-treatment changes of the occlusal variables, and Appendix E describes the changes observed from the end of treatment to the recall examination. Appendix F plots the change in occlusal variables at the three examinations.

Incisor Irregularity

The alignment of the anterior teeth was quantified by measuring the Incisor Irregularity (Little 1975). Maxillary Incisor Irregularity improved significantly ($P < 0.0001$) during treatment, from an average of 6.8 mm at T1 (Table B-14) to an average of 1.6 mm (Table C-13). Incisor Irregularity relapsed less than one-half millimeter (Table E-13) on average after treatment. This posttreatment change achieved significance statistically ($P = 0.0412$), but 0.5 mm is clinically insignificant, particularly if distributed across the five inter-tooth contacts. Figure F-1 plots the changes in Incisor Irregularity observed over time for the maxillary and mandibular arches.

Table 4-1. Chronological ages (years) for the sample at the examinations.

Examination	Mean	sd	Range
Pretreatment	13.3	2.35	9.5 - 22.9
Treatment interval	2.3	0.41	1.8 - 3.9
End of treatment	15.7	2.28	11.8 - 24.7
Posttreatment	39.4	3.63	32.2 - 46.1
Posttreatment interval	23.7	3.60	16.6 - 31.0

Regression analyses between the in-treatment and posttreatment changes in occlusal variables are described in Appendices G and H. The amount of change in maxillary Incisor Irregularity during treatment is a predictor of the amount of relapse exhibited in Incisor Irregularity during the posttreatment period (Figure H-1). The correlation of $r = -0.39$ is based on only 32 cases. The small number of usable cases for this variable is predominately due to “missing” cases at the pretreatment examination where the canines were not fully erupted. There was a statistically significant ($P = 0.0289$) negative correlation with the posttreatment change in maxillary Incisor Irregularity and the treatment change in Incisor Irregularity (Table G-1). One mm of correction during treatment is associated with about 0.2 mm of relapse. The greater correction in maxillary Incisor Irregularity during treatment is proportional to greater relapse.

Mandibular Incisor Irregularity was significantly reduced during treatment, with an average reduction of 3.1 mm (Table D-19; $P < 0.0001$). The mean change of 1.1 mm (Table E-19) in Incisor Irregularity during the posttreatment period also was statistically significant ($P < 0.0001$), but the result was a net improvement of 2.0 mm from the pretreatment condition. In other terms, one-third of the treatment change (35%) in mandibular Incisor Irregularity was lost during the posttreatment period, but none of the cases exhibited greater than 5.5 mm of mandibular Incisor Irregularity at the recall examination. The mandibular Incisor Irregularity at the recall examination was less than 3.5 mm in 77% of the cases, which is the limit suggested by Little (1975) as being clinically acceptable (Figure 4-1).

The amount of reduction in mandibular Incisor Irregularity during treatment was significantly predictive of the amount of relapse in Incisor Irregularity during the posttreatment period (Figure H-2). The negative correlation ($r = -0.33$) between the in-treatment change in mandibular Incisor Irregularity and the posttreatment change in Incisor Irregularity was statistically significant at $P = 0.0285$ (Table G-2). One mm of correction during treatment is associated with about 0.2 mm of relapse.

Directional asymmetry (Van Valen 1962) occurs when there is a trend for subjects to have left-right differences with systematically larger dimensions on one side (Harris and Bodford 2007). Comparing the left and right canine-lateral incisor and lateral-central incisor contacts for the maxillary and mandibular arches, there was no statistically significant directional asymmetry (Appendix I). The one exception was a significant difference in the in-treatment change for the mandibular lateral-central incisor contact (Table I-4). Although not statistically significant ($P = 0.0693$), the lateral-central incisor contact exhibited a greater irregularity on the right side at the pretreatment examination. As the right and left lateral-central incisor contacts both were corrected to 0.2 mm during

Figure 4-1. Plot of the distribution of mandibular Incisor Irregularity at the recall examination. The X axis represents mandibular Incisor Irregularity in millimeters. The Y axis represents the number of cases that fall within each range.

treatment, the in-treatment period exhibited a statistically significant greater change on the right than the left side.

Arch Widths

Inter canine Width

Mandibular intercanine width increased significantly ($P < 0.0001$), from an average of 30.3 (Table B-34) to 32.5 mm (Table C-34), during treatment, which may be due to the canines being moved back into the premolar extraction space and/or intercanine expansion to alleviate incisor crowding. Intercanine width subsequently decreased to a significant extent ($\bar{x} = 1.2$ mm) during the posttreatment period (Table E-34; $P < 0.0001$). The changes in maxillary and mandibular intercanine width over time are depicted in Figure F-2.

Less than half of the in-treatment increase in mandibular intercanine width was preserved at the recall examination. The amount of expansion of mandibular intercanine width during treatment was predictive ($r = -0.37$) of the amount of narrowing of the intercanine width during the posttreatment period (Figure H-3). A 1 mm in-treatment increase in mandibular intercanine width was associated with a 0.4 mm posttreatment decrease in intercanine width ($P = 0.0068$; Table G-3).

Maxillary intercanine width significantly increased an average of 1.7 mm during treatment (Table D-31; $P < 0.0001$). This intercanine width then decreased 0.7 mm during the posttreatment period, which also was significant (Table E-31; $P < 0.0001$). There was a significant ($P = 0.0306$) association between the in-treatment increase in maxillary intercanine width and the posttreatment decrease in intercanine width ($r = -0.37$; Table G-4). Cases with greater expansion in maxillary intercanine width during treatment exhibited more constriction of the intercanine width during the posttreatment period (Figure H-4).

Inter premolar Width

Cases in the present study were predominately treated with the extraction of premolars. On the pretreatment casts, interpremolar width was measured between the two premolars that were not extracted during treatment. Thus, the interpremolar width measured at the posttreatment examination was between the same premolars measured at the pretreatment examination.

During treatment, the interpremolar width exhibited no systematic change in the maxillary and mandibular arches (Tables D-32 and D-35). However, interpremolar widths in both arches decreased significantly by 0.7 mm each (Tables E-31 and E-35; $P < 0.0001$) during the posttreatment interval. There was no statistically significant association between the in-treatment and posttreatment change in either arch (Tables G-5 and G-6). Figure F-3 plots the changes in interpremolar width observed over time for both the maxillary and mandibular arches.

Intermolar Width

Intermolar widths in both arches significantly ($P < 0.0001$) decreased during treatment, 1.3 (Table D-33) and 2.2 mm (Table D-36), respectively. Such decreases may be attributed to the molars moving forward into a narrower region of the arch, particularly to burn anchorage in premolar extraction cases. Subsequently, during the posttreatment period, neither arch exhibited a significant change in intermolar width (Figure F-4).

The amount of change in intermolar width during treatment was predictive of its posttreatment change (Figures H-7 and H-8). A statistically significant negative correlation ($r = -0.68$ and -0.47) between the in-treatment change in intermolar width and the posttreatment change in intermolar width was observed for both the maxillary and mandibular arches (Tables G-7 and G-8). Intermolar widths, that were either expanded or constricted during treatment, tended to return toward their pretreatment width during the posttreatment period. A 1 mm change in intermolar width during treatment was associated with 0.4 mm and 0.3 mm of relapse in the maxillary and mandibular arches, respectively.

Arch Chords

Incisor-to-Canine Chord

Mandibular incisor-to-canine (1-3) chord increased ($P < 0.0001$) an average of 1.0 mm during treatment, while the increase in maxillary incisor-to-canine chord also achieved statistical significance ($P = 0.05$) but the mean change was smaller ($\bar{x} = 0.5$ mm). During the posttreatment period, mandibular incisor-to-canine chord decreased significantly ($P < 0.0001$), an average of 0.9 mm. The maxillary incisor-to-canine chord decreased an average of 0.4 mm ($P = 0.05$). Figures F-5 and F-6 illustrate the changes in the incisor-to-canine arch chord

observed over time for the maxillary and mandibular arches, respectively. Because chord length was measured from the incisal edge of the central incisor, there is no way of distinguishing in a cast analysis between changes in axial inclination and bodily movement of the incisors in the reduction of arch chord. However, in a long-term cephalometric study evaluating the same sample, Ku *et al.* (2009) found no change in incisor angulation during the posttreatment period.

The amount of increase in incisor-to-canine chord during treatment was predictive ($r = -0.44$) of the amount of decrease incisor-to-canine chord during the posttreatment period in the mandibular arch (Table G-10). Relapse, on the average, was about 20% of the treatment change in the mandibular arch. However, in the maxillary arch, the correlation ($r = -0.20$) between changes during the in-treatment and posttreatment periods failed to achieve statistical significance ($P = 0.5486$; Table G-9).

The mandibular incisor-to-canine chord was greater on the left ($\bar{x} = 17.2$ mm) than the right side ($\bar{x} = 17.0$ mm) at the pretreatment examination. While the difference was statistically significant ($P < 0.05$), it was not clinically significant (Table I-1). This directional asymmetry was removed by the posttreatment examination, and it also was undetectable at the recall examination (Tables I-1 through I-5). No difference was found between the left and right side of the maxillary arch at any examination.

Incisor-to-Molar Chord

Maxillary and mandibular incisor-to-molar chord distances decreased during treatment ($P < 0.0001$) about 5 and 4 mm, respectively, and they continued to decrease significantly following treatment (ca. 1 mm in each arch). The large decrease during treatment was due in part to the extraction of a premolar in each quadrant as part of treatment. However, the arch chord continued to decrease in the posttreatment period. Figures F-7 and F-8 illustrate the changes in the incisor-to-molar chord observed over time for the maxillary and mandibular arches, respectively.

Arches exhibiting larger decreases in incisor-to-molar chord during treatment tended to have a smaller decrease in incisor-to-molar chord during the posttreatment period (Figures H-11 and H-12). This correlation was statistically significant in the maxillary arch ($r = -0.37$; $P = 0.0088$) but not so in the mandible ($r = -0.21$; $P = 0.1595$).

The mandibular left incisor-to-molar chord was significantly longer

($P < 0.05$) than the right side at the pretreatment and posttreatment examinations as tested by repeated-measures ANOVA (Tables I-1 through I-5). The directional asymmetry was obliterated during the posttreatment interval prior to the recall examination (Table I-3). In contrast, no difference was found between the left and right side of the maxillary arch at any examination.

Arch Depth

Maxillary and mandibular arch depths decreased significantly ($P < 0.0001$) during treatment and then decreased farther after treatment. During treatment, maxillary and mandibular arch depths decreased an average of 5 and 4 mm, respectively, which is anticipated since most cases were treated with premolar extractions. Both arch depths decreased farther ($\bar{x} = 1.3$ mm) following treatment. The changes in maxillary and mandibular arch depth over time are plotted in Figure F-9.

A large reduction in maxillary arch depth during treatment was associated with only a minor decrease in arch depth during the posttreatment period (Figure H-13). This statistical association was present in the maxillary arch ($P = 0.0075$) but not in the mandibular arch ($P = 0.4487$).

Overjet

Overjet decreased significantly during treatment, from 6 to 3 mm (Table B-2 and C-2; $P < 0.0001$). Overjet then increased significantly ($P < 0.0001$) from about 3.0 to 3.5 mm during the posttreatment period. Three-quarters (73%) of the treatment correction in overjet was maintained at the recall examination. The change in overjet during treatment was predictive ($r = -0.39$) of the amount of relapse in overjet during the posttreatment period (Figure H-14; $P = 0.0049$; Table G-15). Figure F-10 illustrates the changes in overjet across three examinations.

Overbite

Incisor overbite decreased significantly during treatment ($P < 0.0001$), from a mean of about 4 to 2.5 mm (Tables B-1 and C-1). A statistically significant rebound, averaging 0.7 mm, occurred after treatment. Half (56%) of the treatment correction in overbite was lost during the posttreatment period. The amount of correction in overbite during treatment was predictive ($r = -0.55$) of

the relapse in overbite during the posttreatment period (Figure H-15; $P < 0.0001$). The changes in overbite over time are depicted in Figure F-11.

Midline Deviation

The average dental midline deviated 0.3 mm to the right before treatment (Table B-3). During treatment, the midline deviation was reduced to 0.1 mm (Table C-3). The posttreatment change in midline deviation tended to be back toward the pretreatment condition (Figure H-16). Based on a one sample t-test, no significant directional asymmetry in midline discrepancy was observed. Figure F-12 illustrates the changes in the midline discrepancy observed over time. Since a midline deviation to the left was assigned a positive value while a deviation to the right was assigned a negative value, clinical correction of the midline discrepancy may have occurred during treatment but is not evident as the positive and negative values may have cancelled each other out during calculations.

Using absolute values, the midline deviation decreased significantly during treatment ($P < 0.0001$), from a mean of 1.3 mm to 0.3 mm (Tables B-4 and C-4). Figure F-13 illustrates the changes in the absolute values of the midline discrepancy observed over time. A statistically significant ($P < 0.0001$) posttreatment change, averaging 0.4 mm, occurred after treatment (Table E-4). No significant association was observed between the in-treatment and posttreatment change in midline deviation.

Buccal Segment Relationship

The average buccal segment relationship before treatment was -1.4 mm, meaning that the mesiobuccal cusp tip of the U6 is 1.4 mm ahead of (ventral to) the buccal groove of the L6. The pretreatment range was -5.8 to 1.3 mm, with most (75%) of the subjects exhibited a Class II molar relationship at the start of treatment. The Class II molar correction during treatment was highly significant ($P < 0.0001$), so that the buccal segment relationship averaged 0.2 mm at the end of treatment (range of -2.5 to 3.0 mm). The correction remained stable during the posttreatment period with a -0.2 mm average change that was not statistically significant. Posttreatment change tended back toward the pretreatment condition (Figure H-17), but the association failed to achieve statistical significance ($P = 0.1362$). The changes in the buccal segment relationship over time are depicted in Figure F-14.

When comparing the left and right buccal segment relationship, there was no statistically significant directional asymmetry at any of the three examinations (Tables I-1 through I-5).

Canine Relationship

The average canine relationship was Class II before treatment with an average of -2.7 mm. A significant ($P < 0.0001$) correction occurred during treatment, with an average improvement of 1.8 mm. The canine relationship improved 0.1 mm, but this change was not statistically significant during the course of treatment. There was no significant association found between the in-treatment and posttreatment changes (Table G-19). Figure F-15 illustrates the mean changes in canine relationship over time.

When comparing the left and right canine relationship, there was no detectable directional asymmetry at any of the three examinations (Tables I-1 through I-5).

Bivariate Correlations during the Posttreatment Period

There is, necessarily, redundancy among the several dimensions measured on the casts (1) because the dimensions physically overlap one another but also (2) because the dentition is an interdigitated whole, so spatial changes in one component often affect or are compensated by changes in other components. Moreover, teeth depend on adjacent and occluding elements for physical support, so changes in each tooth affects the force system experienced by the others. Bivariate correlation coefficients were calculated to test for these interdependencies among the teeth within the dentition. The question addressed here is how did the posttreatment changes in one variable influence changes (relapse) of the other dimensions?

A matrix of all correlations of the variables taken pair-wise was compiled of the posttreatment changes, but just those that are highly significant statistically are discussed here (Appendices J and K).

Changes in both the maxillary and mandibular incisor-to-canine chords during the posttreatment period were positively correlated ($r = 0.40$ and 0.53 , respectively) with the posttreatment change in the incisor-to-molar chord (Figures K-1 and K-5). Posttreatment decreases in chord length likely are due to the mesial drift of teeth in the buccal segments probably in combination with changes in incisor position and angulation. However, Ku (2010) found no

posttreatment change in both the inclination and anterior-posterior position of the lower incisors in a long-term cephalometric study on the present sample. Southard *et al.* (1989) attributed the “mesial drift” of teeth to the “anterior component of force in the dentition.” Because of the mesial inclination of the teeth relative to the occlusal plane, occlusal forces have an anterior component of force (Newcomb 1936; Dempster *et al.* 1963). This force is transferred through the contact areas, resulting in a mesial drift of the teeth. Mesial drift tends to shorten both the incisor-to-canine and the incisor-to-molar arch chords because the first is spatially a component of the second.

Posttreatment decreases in lower incisor-to-molar chord were correlated ($r = -0.45$) with increases in posttreatment mandibular Incisor Irregularity (Figure K-4). The decrease in chord length due to mesial drift would cause the lower incisors either to crowd (increasing Incisor Irregularity) or tip labially. However, in a cephalometric study on the present sample, Ku (2010) found no change in the average angulation of the lower incisors posttreatment. That is, the “average” person in the sample experienced no systematic change after treatment, though some individuals in the sample experienced appreciable shifts.

Interpremolar and intermolar widths decreased during treatment due to their more mesial positions in the arch after extraction-space closure. Decreasing arch widths after treatment may reflect the continual mesial migration of the dentition described by Southard *et al.* (1989). Southard *et al.* (1989) found that the anterior contact force applied against the canines could tip them mesially, both crowding the anterior teeth and constricting the intercanine width. Since mesial drift tends to shorten both arch chord lengths and arch widths, an association between these variables would be expected. The posttreatment decrease in lower incisor-to-molar chord length was positively correlated ($r = 0.38$ and 0.43 , respectively) with changes in the maxillary interpremolar and intermolar widths (Figures K-10 and K-12). Similarly, there also was a statistically significant positive association between posttreatment changes in mandibular incisor-to-molar chord length and mandibular intermolar width ($r = 0.43$; Figure K-17).

It is speculated that the significant increase in overjet after treatment is an indirect response to deepening of the overbite (Uhde *et al.* 1983). As overbite increases, the maxillary and mandibular incisors become uncoupled such that the lower incisors occlude against the cingulum of the upper incisors, which tends to increase overjet. A return in the Curve of Spee would also likely affect an increase in overbite and a decrease in mandibular arch length. Since leveling of the Curve of Spee may increase arch length, the return of this curve after treatment results in a shorter arch length (Steadman 1940).

We found that greater increases in overjet after treatment were associated with larger posttreatment decreases in mandibular incisor-to-molar and incisor-to-canine chords ($r = -0.36$ and -0.36 , respectively; Figures K-2 and K-3). These chord lengths decrease as the Curve of Spee increase and the bite deepens posttreatment (Steadman 1940). Uhde *et al.* (1983) found an association between deepening of the bite with an increase in overjet.

Decreases in upper arch depth are influenced by the posttreatment uprighting of the upper incisor. Ku (2010) found that the upper incisor uprighted 1.5° on average during the posttreatment period. The posttreatment uprighting of the upper incisor would explain the correlation ($r = 0.57$) between posttreatment decreases in maxillary incisor-to-molar chord and upper arch depth (Figure K-7). Arch lengths that shorten posttreatment due to the uprighting of the upper incisor tend to have less overjet at the recall examination. This is supported by the positive correlation ($r = 0.35$) in the present study between posttreatment changes in upper arch depth and overjet (Figure K-6).

Arch width is the consequence of the forces of oral musculature (Weinstein 1967). The posttreatment changes in arch width may represent inter-individual variations in the forces of the buccinator complex. The subjects' perioral musculatures are supposed to affect the intercanine, interpremolar, and intermolar widths (Weinstein 1963, Profit 1978). Changes in the maxillary intercanine, interpremolar, and intermolar widths were all positively inter-correlated during the posttreatment period (Figures K-11, K-13, and K-14). Likewise, mandibular intermolar width change was positively correlated ($r = 0.49$) with changes in the mandibular interpremolar width during the posttreatment period (Figure K-19).

Dimensional changes in the maxillary arch directly affect the dimensions in the mandibular arch because the lower arch is contained within the upper arch (Moore 1956; Richardson 1994). As upper intercanine width decreased during the posttreatment period, a positive correlation was observed with both mandibular intercanine width and incisor-to-canine chord length ($r = 0.34$ and 0.40 , respectively; Figures K-8 and K-15). Changes in the maxillary interpremolar width also were positively correlated ($r = 0.41$) with a change in the mandibular intermolar width (Figure K-18).

CHAPTER 5. DISCUSSION

The intent of this study was to quantify the posttreatment dental changes that occurred over approximately a quarter-century in a cohort of women who had received comprehensive orthodontic treatment as teenagers. While the causes of dental relapse remain numerous and hard to specify, knowledge of the associated factors may give rise to a better understanding of the changes to be anticipated after treatment.

When dealing with post-orthodontic changes (relapse), it is important to consider the changes that occurred in the equilibrium of forces acting on the teeth. Prior to treatment, the esthetics and, perhaps, the function of the dentition were compromised, but the teeth were in positions of functional equilibrium. That is, each tooth was in a position where forces of the lips, cheeks, muscles, and the periodontal ligament were balanced – as evidenced by its positional stability. Orthodontic treatment – with its emphasis on ideal inter-tooth relationships – moves teeth into novel positions that may or may not be in equivalently neutral positions. Indeed, there are serious hurdles to understanding what the relevant forces on a tooth are, let alone determining their magnitudes and vectors (Weinstein 1967). The general consensus of events is that (A) teeth are maloccluded before treatment but are in mechanically neutral positions, (B) orthodontic treatment enhances esthetics, but often at the expense of stability, and (C) it is the re-assertion of forces that move teeth back towards their pretreatment positions, which is labeled relapse. In concept, understanding the forces acting on the teeth will eventually permit orthodontists to modulate if not actually overcome these causes of posttreatment instability.

This is hardly a new topic, and numerous orthodontists have, over the past century, spent much time and effort trying (A) to circumvent relapse by judicious treatment and (B) to measure and understand the nature of the forces. Clinically, the summary articles by Riedel (1969) and more recently by Joondeph (2005) have reviewed the clinical literature with the intent of identifying clinical factors that enhance the risk and/or extent of posttreatment relapse. While lengthy lists of citations have been amassed, the actual “rules” that can help guard against relapse are, at best, only broad guidelines – and even strict adherence to these rules is no guarantee of preventing relapse. Joondeph (2005) lists 9 theorems:

1. Teeth that have been moved tend to return to their former positions.
2. Elimination of the cause of malocclusion will prevent recurrence.
3. Malocclusion should be overcorrected as a safety factor.

4. Proper occlusion is a potent factor in holding teeth in their corrected positions.
5. Bone and adjacent tissues must be allowed to reorganize around newly positioned teeth.
6. If the lower incisors are placed upright over basal bone, they are more likely to remain in good alignment.
7. Corrections carried out during periods of growth are less likely to relapse.
8. The farther teeth have been moved, the less likelihood of relapse.
9. Arch form, particularly in the mandible, cannot be altered permanently by appliance therapy.

In addition, Little (1999) has summarized the findings from his career of studying posttreatment changes, but only a few generalities have surfaced:

1. There is so much that we don't know.
2. Expand the mandibular arch at your own risk.
3. Some are the lucky ones.
4. Early stability is a mirage.
5. Rotated teeth tend to relapse, usually toward their initial positions.
6. Lingual versus labial or buccal relapse is unpredictable.
7. Life-long retention equals life-long insurance.
8. Extraction of "wisdom teeth" is not necessarily a wise choice.
9. Younger is not necessarily better.
10. Arch development is the riskiest treatment in terms of stability.
11. Maintain–don't change–the arch form.
12. Constricted maxillary arches are more amenable to expansion than constricted mandibular arches.
13. Alignment stability is improved by maintaining leeway space.
14. Facial growth is not useful in correcting crowded arches.
15. "Return to normal physiology" may be a more correct description of the post-retention process than "relapse."

Improving our knowledge of the biology of the anatomic structures also has been pursued to help identify the biomechanical causes of relapse. Among these, the several studies of Reitan (1959, 1967, 1969), Bowling and Rygh (1988) and others have analyzed the histological outcomes of orthodontic procedures. Weinstein (1967), Proffit (1978), Thüer and Ingervall (1986), and several others have used several technologies – that have become smaller (less invasive) and more sophisticated with time – to measure the forces of the lips, cheeks, muscles, periodontal ligament, and other tissues. The goal is to identify the nature of the forces acting on teeth. There are considerable technical difficulties in this, not the

least of which is the considerable inter-individual variability – and the results to date have not been particularly insightful.

Proffit (1978) organizes forces acting on the teeth into 4 categories, (1) intrinsic forces due to the anatomy, (2) extrinsic forces such as habits, (3) forces of dental occlusion, and (4) forces in the periodontal ligament. Intrinsic forces are due primarily to muscle forces in combination with integumental pressures and tensions such as the lips, cheeks, and tongue. Extrinsic forces compose habits, such as digit-sucking but also respiratory patterns that shift not only during the day but also seasonally. Occlusal forces—such as biting, speaking, and parafunctional habits—can be of short or longer durations, and they involve complicated interactions among muscle, bone, and other tissues. The periodontal ligament may be the hardest to understand because it involves the short-term high-intensity properties of absorbing and dissipating forces of occlusion but also the very long-term low-magnitude forces of eruption. Eruption is obvious when the tooth actively moves into occlusion, but these forces can be reinitiated when a tooth's antagonists are moved (or removed). Overall, when considerable research has been ongoing, we are still far from understanding how a tooth is in dynamic equilibrium from the various forces acting on it. Disturbance of the equilibrium by the orthodontist moving teeth to new relationships remains even less well understood.

Importantly, the sum of these forces—in combination with their durations—should sum to zero as regards a tooth in a stable position. To date, no one has been able to confirm this assumption. Part of the problem is that the forces act over much different intervals of time. Occlusion forces can be powerful but almost instantaneous, while integumental pressures are of low magnitude (including some negative pressures) (Thüer *et al.* 1999) and act over hours.

Sample Description

In the present study, there were 52 women with average pretreatment age of 13 years. Posttreatment records were taken at a mean age of 16 years, and the recall examination was at a mean age of 39 years, which is 24 years out of the active phase of treatment.

Faculty and graduate students at the University of Washington, Seattle, have conducted several similar studies that show that postorthodontic relapse is pervasive and of considerable magnitude (*e.g.*, Little, Wallen and Riedel 1981; Little, Riedel and Årtun 1988; McReynolds and Little 1991). The present study followed a similar (long-term) protocol that allows comparison to these

Washington studies. Table 5-1 provides information on the samples reported in these studies. The study of Little, Wallen and Riedel (1981) reported on subjects an average of 14.9 years out of active treatment. Little, Riedel and Årtun (1988) provided a sequel to that study, observing the same subjects at an average of 27.8 years out of active treatment. McReynolds and Little (1991) reported on subjects with an average posttreatment period of 16.6 years. Since the present study reports on subjects treated in the permanent dentition, only the data for the late extraction group in the study of McReynolds and Little (1991) are compared here. Little, Wallen and Riedel (1981) and Little, Riedel and Årtun (1988) reported on cases treated with the extraction of four first premolars. The sample of McReynolds and Little (1991) was treated by the extraction of four second premolars. The subjects in the present study were treated by four premolar extractions, and these can be divided into three categories, (1) 24 cases were treated with first premolar extractions, (2) 11 cases were treated with maxillary first and mandibular second premolars, and (3) 14 cases were treated with four second premolar extractions.

The present study reports data from the end of treatment and again an average of 24 years after treatment. There is no way to distinguish when the posttreatment changes occurred in the present study. Little, Riedel and Årtun (1988) reported only slight changes from 10 to 20 years after treatment. The posttreatment changes are not age progressive; most of the changes occur soon after treatment.

Incisor Irregularity

The lower Incisor Irregularity improved significantly during treatment with a mean decrease of 3.1 mm. Most (67%) of the correction achieved during treatment was maintained during the posttreatment period. The average posttreatment Incisor Irregularity was 2.5 mm. According to Little (1975), this amount is considered trivial and clinically acceptable (Incisor Irregularity < 3.5 mm). Little (1999) found that about 30% of orthodontic patients exhibit acceptable long-term results. The present study found that 77% of the cases (40/52) were below this cutpoint for Incisor Irregularity. The long-term posttreatment mandibular Incisor Irregularity in the present study (Figure 5-1) is considerably less than that reported in the University of Washington studies (Little, Wallen and Riedel 1981; Little, Riedel and Årtun 1988; McReynolds and Little 1991).

In Figure 5-1, there were highly significant ($P < 0.001$) intergroup differences at all three examinations when evaluated by one-way ANOVA. It

Table 5-1. Sample sizes and durations of follow-up in the present and comparable analyses.

Comparable analyses	Sample size	Pretreatment age	Posttreatment interval
Present study	52	13.3	23.7
Little, Wallen, Riedel (1981)	65	13.0	14.9
Little, Riedel, Årtun (1988)	31	13.2	27.8
McReynolds and Little (1991)	32	12.5	16.6

Sources: Little RM, Riedel RA, Årtun J. An evaluation of changes in mandibular anterior alignment from 10 to 20 years postretention. *Am J Orthod Dentofacial Orthop* 1988;93:423-8.

Little RM, Wallen TR, Riedel RA. Stability and relapse of mandibular anterior alignment-first premolar extraction cases treated by traditional edgewise orthodontics. *Am J Orthod* 1981;80:349-65.

McReynolds DC, Little RM. Mandibular second premolar extraction-postretention evaluation of stability and relapse. *Angle Orthod* 1991;61:133-44.

Figure 5-1. Plot of the average mandibular Incisor Irregularity at pretreatment, the end of active treatment, and the recall examination.

will not go unnoticed that our sample has the smallest average irregularity at the start of treatment ($\bar{x} = 4.5$ mm). This is unexpected since there was no identified selection bias of cases. However, no association ($r = 0.17$; $P = 0.2364$) was found between the Incisor Irregularity at the pretreatment and recall examinations. This is in agreement with Little, Wallen and Riedel (1981) who found that the initial crowding was a very poor predictor of long-term irregularity ($r = 0.20$).

At the end of treatment, Incisor Irregularity was not zero in any of the groups, but we interpret the small measures of irregularity to be due predominately to band spaces, since many of these cases (and all of those in the present study) were treated before the introduction of bonded appliances (and the advent of cements that would reliably adhere the brackets to the teeth). Little's Irregularity Index is sensitive to the open contacts created by bands, though these spaces commonly close during the settling phase.

The increase in Incisor Irregularity observed in the present study also occurs in untreated subjects (Sinclair and Little 1983; Richardson and Gormley 1998; Richardson 1999). In untreated subjects, Richardson (1999) found that lower Incisor Irregularity increased an average of 2.3 mm from the ages of 13 to 18 years, but only exhibited minor increases during the subsequent twenties and thirties. Sinclair and Little (1983) reported that the long-term posttreatment Incisor Irregularity in treated cases was considerably higher than in untreated subjects. This suggests that although the Incisor Irregularity increases with age in treated and in untreated subjects, the extent of these changes is different.

Arch Width

Strang (1949) reported that premolar extraction permits distal movement of the canines into an area of greater arch width, which would allow greater stability following treatment since the teeth are positioned over basal bone. Vaden and Kiser (1996) supported the claims of Strang (1949) in their discussion of the anterior, posterior, transverse and vertical limits of the dentition. Mandibular intercanine width in the present study was increased an average of 2.2 mm due to the retraction of the canines into the extraction spaces during treatment. Although statistically significant, the change in intercanine width is trivial clinically. There is also no way in the present study to distinguish between a change in intercanine width due to tipping or bodily movement.

Figures 5-2 and 5-3 plot the average change in mandibular intercanine width and intermolar width, respectively, for the present study and prior reports. There were highly significant ($P < 0.0001$) intergroup differences at all

Figure 5-2. Plot of the average mandibular intercanine width at pretreatment, the end of active treatment, and the recall examination. Mandibular intercanine width was the maximum distance at the buccal surfaces of the canines in the present study and the Vaden, Harris, and Gardner (1997) study. The intercanine width was the distance between the cusp tips in McReynolds and Little (1991); Paquette *et al.* (1992); and Haruki and Little (1998).

Figure 5-3. Plot of the average mandibular intermolar width at pretreatment, the end of active treatment, and the recall examination. Mandibular intermolar width was the maximum distance at the buccal surfaces of the first molars in the present study and Vaden, Harris, and Gardner (1997). The intermolar width was the distance between the mesiobuccal cusp tips of the first molars in McReynolds and Little (1991) and Paquette *et al.* (1992).

three examinations when evaluated by one-way ANOVA. In Vaden, Harris and Gardner (1997) and the present study, the mandibular intercanine and intermolar widths were significantly larger at all three examinations. The widths were measured as the maximum distance at the buccal surface of the respective teeth in these two reports. McReynolds and Little (1990), Paquette *et al.* (1992), and Haruki and Little (1998) reported the distance between the cusp tips resulting in smaller distances at all examinations.

The intercanine expansion during treatment (roughly 2 mm) was similar to prior reports (Figure 5-2). However, over half of the in-treatment expansion was lost during the posttreatment period. This posttreatment constriction of intercanine width has been noted in treated subjects in the literature (Little, Wallen and Riedel 1981; Little, Riedel and Årtun 1988; McReynolds and Little 1991). However, intercanine width seems to remain unchanged over the long-term in untreated subjects. Harris (1997) reported on the changes in arch widths of untreated subjects observed at an average age of 20 years and again 34 years later; mandibular intercanine width increased 0.1 mm, which was not statistically different from zero.

Steadman (1961) concluded that an expanded intercanine width is not sustained after treatment, but relapse can be avoided by preventing an increase in width during treatment. In the present study, there was a significant ($P = 0.0068$) association between the in-treatment increase in mandibular intercanine width and the posttreatment decrease in intercanine width (Table G-3). However, the intercanine expansion during treatment was not related ($P = 0.1725$) to the relapse observed in lower Incisor Irregularity after treatment.

The studies of McReynolds and Little (1991) and Årtun, Garol and Little (1996) reported intercanine widths at the recall examination that were narrower than the original intercanine width. However, the present study exhibited a net expansion (T1-T3) in intercanine width with about half of the in-treatment intercanine expansion remaining at the recall examination. Because of the decrease in intercanine width following treatment, it seems sensible to minimize treatment expansion. However, the present study did not find that the in-treatment change of the intercanine width affected the stability of the lower incisors after treatment ($r = 0.21$; $P = 0.1725$).

The intermolar width exhibited little average change ($\bar{x} = 0.2$ mm) during the posttreatment period in agreement with Paquette *et al.* (1992) and Vaden, Harris and Gardner (1996) (Figure 5-3). McReynolds and Little (1991) and Årtun, Garol and Little (1996) also reported minor ($\bar{x} = 1.0$ mm) decreases in intermolar width during the posttreatment period in treated cases. Although minor changes in intermolar width are statistically significant, these changes of about 1 mm are

trivial clinically. In agreement with previous findings (McReynolds and Little 1991; Paquette *et al.* 1992; Årtun, Garol and Little 1996; and Haruki and Little 1998), change in intermolar width both during ($P = 0.8090$) and after treatment ($P = 0.4817$) was not correlated with the relapse observed in the lower incisors after treatment.

Intermolar width of treated cases seems to respond differently than in untreated subjects observed long-term. Harris (1997) reported that the intermolar width increased 2.3 mm between 20 and 54 years of age in untreated subjects. The arch form in untreated subjects tended to become more tapered (where intercanine width is much less than intermolar width) over time because intermolar width increased ($\bar{x} = 2.3$ mm) and intercanine width remained unchanged ($\bar{x} = 0.1$ mm). While the arch form in the present study of treated subjects also exhibited tapering over the posttreatment interval, the change in arch shape was due to a decrease in intercanine width ($\bar{x} = -1.2$ mm) rather than a change in intermolar width ($\bar{x} = 0.2$ mm). Both treated and untreated subjects exhibit tapering of the arch over the long-term, but the change in arch form is a result of expansion of the intermolar width in untreated subjects and constriction of the intercanine width in treated cases.

Overjet

In the present study, there was a significant ($P = 0.0049$) association between the treatment change in overjet and the posttreatment relapse in overjet (Table G-15). These findings are consistent with studies by McReynolds and Little (1991), Paquette *et al.* (1992), Årtun, Garol and Little (1996), Vaden, Harris and Gardner (1996), and Haruki and Little (1998) (Figure 5-4). The studies in Figure 5-4 exhibited highly significant ($P < 0.0001$) intergroup differences at all three examinations when evaluated by one-way ANOVA. The relapse in overjet observed by Paquette *et al.* (1992) was nearly twice that of the other studies in Figure 5-4, but the treatment change in overjet also was considerably greater. This is supported by the association of in-treatment and posttreatment change in overjet observed in the present study. However, in agreement with Little, Wallen and Riedel (1981), the change in overjet both during ($r = 0.11$) and after treatment ($r = 0.28$) was not associated with the posttreatment relapse in lower Incisor Irregularity.

The increase in overjet over the posttreatment period does not seem to be a normal function of aging. Harris (1997) reported only minor changes ($\bar{x} = 0.1$ mm) in overjet between 20 and 54 years of age in untreated subjects. The lack of change in overjet is in contrast to the increases noted in posttreatment subjects (McReynolds and Little 1991; Paquette *et al.* 1992; Årtun, Garol, and Little 1996;

Figure 5-4. Plot of the average overjet at pretreatment, the end of active treatment, and the recall examination.

Vaden, Harris, and Gardner 1996; Haruki and Little 1998). Overjet in treated cases tends to return toward the pretreatment condition evidenced by the association ($P = 0.0049$) of the in-treatment and posttreatment change in overjet observed in the present study (Table G-15).

Overbite

In agreement with the literature (McReynolds and Little 1991; Paquette *et al.* 1992; Årtun, Garol and Little 1996; Vaden, Harris and Gardner 1996; Haruki and Little 1998), the present study discloses a significant association between the treatment change in overbite and its posttreatment relapse (Table G-15, Figure 5-5). According to one-way ANOVA measures, the studies on Figure 5-5 did not differ significantly in overbite at any of the three examinations. Paquette *et al.* (1992) reported a significantly greater mean treatment change in overbite than the other studies, but the overbite relapsed twice as much afterwards (Figure 5-5), which is consistent with findings that the in-treatment and posttreatment changes are associated. However, in agreement with Little, Wallen and Riedel (1981), the in-treatment ($r = 0.18$) and posttreatment ($r = 0.15$) change in overbite in the present study was not associated with the posttreatment relapse in lower Incisor Irregularity.

Harris (1997) reported that overbite decreased an average of 0.3 mm in untreated subjects between 20 and 54 years of age. These changes are in contrast to the present study exhibiting a 0.7 mm increase in overbite after treatment. The present study found that overbite in treated cases tends to return toward the pretreatment condition evidenced by the association ($r = 0.54$; $P < 0.0001$) of the in-treatment and posttreatment change in overbite (Table G-16). Also, the “settling” of the occlusion after treatment, allowing the dentition to obtain better cusp-fossa relationships, may be reflected in an increase in the overbite in treated subjects. Magill (1960) reported that the average degree of overbite settling was approximately 1 mm, supporting the inference that treated subjects tend to exhibit a greater increase in overbite over time.

Arch Length

Both mandibular arch depth and arch chord decreased during the posttreatment period. The reduction in arch length is consistent with reports on treated subjects (Little, Wallen, and Riedel 1981; Little, Riedel, and Årtun 1988; McReynolds and Little 1991). This also agrees with the maturation of untreated subjects (DeKock 1972; Sinclair and Little 1983). Uprighting of the lower incisors over time could account for the decrease in arch length (Siatkowski 1974).

Figure 5-5. Plot of the average overbite at pretreatment, the end of active treatment, and the recall examination.

However, Ku (2010) found no systematic posttreatment change in either the inclination or the anterior-posterior position of the lower incisors in the present sample. A similar maturational process for both treated and untreated groups could be explained by the “mesial drift” due to the “anterior component of force” (Southard *et al.* 1989, 1990). The mesial inclination of the teeth combined with occlusal forces cause an anterior component of force (Newcomb 1936; Dempster *et al.* 1963). This force is transferred through the contact areas, resulting in a mesial drift of the dentition. However, in agreement with the literature (Little, Wallen, and Riedel 1981; Little, Riedel, and Årtun 1988; McReynolds and Little 1991), the posttreatment decrease in arch chord ($r = 0.15$) and depth ($r = 0.19$) in the present study was not associated and with the posttreatment relapse in lower Incisor Irregularity.

Tests of Theorems

Riedel (1960) and, more recently, Joondeph (2005) have collected several “theorems” of retention and relapse which include the etiology and management of orthodontic relapse. These guidelines are intended to be orthodontic treatment options to enhance posttreatment stability. The validity of some of the theorems can be tested with the data from the present cast analysis.

Theorem 1

Teeth that have been moved in or through bone by mechanical appliances have a tendency to return to their former positions. To test this hypothesis, six variables were analyzed and the amount of in-treatment change was compared to the amount of posttreatment relapse. The variables tested were: Incisor Irregularity, overbite, overjet, buccal segment relationship, mandibular intercanine width, and mandibular intermolar width. The results from regressing the posttreatment change on the in-treatment change of these variables are summarized in Table 5-2.

The negative regression coefficients for all variables in Table 5-2 support the Theorem 1 argument. The posttreatment change related to the amount of treatment change achieved statistical significance ($P < 0.05$) for Incisor Irregularity, overbite, overjet, mandibular intercanine width, and mandibular intermolar width. The buccal segment relationship failed to achieve statistical significance ($P = 0.1362$), but the direction of change supports this generality that the vector (amount and direction) of relapse is predicted by the vector of in-treatment change.

Table 5-2. Correlation coefficients between the in-treatment changes and the posttreatment changes for six variables.¹

Variable	Regression coefficient	P-value
Incisor Irregularity	-0.182	0.0285
Overbite	-0.408	<0.0001
Overjet	-0.937	0.0049
Buccal segment relationship	-0.081	0.1362
Md intercanine width	-0.372	0.0068
Md intermolar width	-0.277	0.0007

¹Because of the way in-treatment and posttreatment changes were calculated, a negative correlation indicates that greater treatment change tends to be associated with greater relapse and vice versa.

Theorem 2

Elimination of the cause of the malocclusion will prevent recurrence.
Diagnosing and treating such habits as thumb-sucking, lip-biting, tongue-thrusting, and mouth-breathing was not measured in the present study; so this hypothesis cannot be tested using the present data.

Theorem 3

Malocclusion should be overcorrected as a safety factor. Overcorrection involves greater tooth movement than correction alone, there is no support in the present data that suggests more movement is associated with greater stability.

Theorem 4

Proper occlusion is a potent factor in holding teeth in their corrected positions. Buccal segment and canine relationship can be used to assess a proper occlusion. The buccal segment and canine relationship in an ideal Class I occlusion would have be zero. However, there is minor variation in buccal segment and canine relationship at the end of active treatment because all subjects were treated to near ideal relationships during treatment.

Theorem 5

Bone and adjacent tissues must be allowed to reorganize around newly positioned teeth. Testing this theorem would require histological analyses, which falls outside the scope of our data and cannot be tested.

Theorem 6

If the mandibular incisors are placed upright over the basal bone, they are more likely to remain in good alignment. The present study was solely a cast analysis; therefore, the measurements provide no information on the position of the incisors within the bone. Thus, Theorem 6 could not be tested with the present data.

Theorem 7

Corrections carried out during periods of growth are less likely to relapse. The pretreatment age of the subjects in the present study exhibited little variation. In particular, there were few patients (5/52) who had initiated treatment after 14 years of age. Using a sample with a greater range of pretreatment ages, Dyer (1989) compared the relapse of adult versus adolescent patients and found no significant difference between the two age groups.

Theorem 8

The farther the teeth are moved, the less likelihood there is of relapse. To test this hypothesis, six variables were analyzed and the absolute value of the amount of in-treatment change was compared to the absolute value of the amount of posttreatment relapse. The absolute value of change was used because Theorem 8 relates the total distance the teeth are moved during treatment to the amount of movement after treatment. The variables tested were: Incisor Irregularity, overbite, overjet, buccal segment relationship, mandibular intercanine width, and mandibular intermolar width. The results from regressing the posttreatment change on the in-treatment change of these variables are summarized in Table 5-3.

The amount of posttreatment change based on the amount of pretreatment change did not achieve statistical significance (Table 5-3) for Incisor Irregularity, buccal segment relationship, mandibular intercanine width, or mandibular intermolar width. Theorem 8 claims that there should be a statistically significant association; so the present study does not support Theorem 8 for these four variables.

A statistically significant association was found between the amount of posttreatment change based on the amount of pretreatment change for overbite ($P < 0.0001$) and overjet ($P = 0.0022$). However, those patients who had a greater in-treatment change in overbite and overjet tended to have more relapse than those who had less in-treatment change (Table 5-3). The greater the correction in overjet and overbite, the less likely they were to stay stable. The suggestion in Theorem 8 is that a lot of movement will break the transseptal fibers and will cause more bone remodeling, so that elastic properties of the dental system are regenerated anew. In fact, we find no support for this intuitive suggestion. Theorem 8 is refuted by these data.

Table 5-3. Regression coefficients calculated between the treatment changes (predictor variable) and the posttreatment changes (outcome variable).¹

Variable	Regression coefficient	P-value
Incisor Irregularity	0.484	0.1151
Overbite	0.685	<0.0001
Overjet	1.172	0.0022
Buccal segment relationship	0.402	0.3653
Md intercanine width	0.298	0.0924
Md intermolar width	0.481	0.0672

¹The absolute values of the changes were used throughout, so a statistically significant association means that bigger changes during treatment are associated with greater changes following treatment.

Theorem 9

Arch form, particularly in the mandibular arch, cannot be permanently altered by appliance therapy. Arch form was measured by devising a ratio, where the intercanine width was divided by the intermolar width. A smaller ratio indicates a more tapered arch, accomplished either by constricting the intercanine width or by expanding the intermolar width. When assessing changes over time, a negative value indicates that the arch form became smaller or more tapered. The in-treatment change in the mandibular arch form ratio ($\bar{x} = 0.070$) was significant as compared to zero ($P < 0.0001$). The mean posttreatment arch form relapse ($\bar{x} = -0.027$) also was significant ($P < 0.0001$). The mandibular arch form became less tapered during treatment and relapsed back to a more tapered arch form after treatment. There was a significant association ($r = 0.33$; $P < 0.0001$) between the in-treatment and posttreatment change in arch form ratio. The data of our sample supports Theorem 9; arch form changes during treatment relapsed back toward the arch form present before treatment.

CHAPTER 6. SUMMARY AND CONCLUSIONS

This longitudinal cast analysis examined 52 females treated comprehensively by a single experienced orthodontist. Cases were treated with conventional edgewise mechanics, and most cases (47/52) were treated with premolar extractions. The purpose of the present investigation was to evaluate the long-term posttreatment changes of orthodontic cases. Dental casts were made at the start of treatment, at the end of active treatment, and at the long-term recall examination. The average recall interval for these subjects is 24 years out of the active phase of treatment. Major findings were:

- The amount of in-treatment change is one of the few identifiable predictors of the vectors of posttreatment relapse.
- The maxillary and mandibular arches became shorter and narrower with age.
- Arch depth decreased 1.3 mm during the posttreatment interval, perhaps as mesial drift consolidating the dentition.
- Inter canine width was increased (2.2 mm) during treatment, but decreased (1.2 mm) towards the initial dimension after treatment. About half (1.0 mm) of the in-treatment inter canine expansion persisted at the recall examination.
- Intermolar width did not change significantly after treatment.
- Overjet increased (0.9 mm) after treatment.
- Overbite deepened after treatment. Half (0.6 mm) of the treatment correction in overbite was lost during the posttreatment period.
- Buccal segment and canine relationship both remained stable after treatment. This suggests that, once established, cusp-fossa relationships tend to persist with time.
- Correction of the maxillary Incisor Irregularity remained stable with age (1% relapse).
- 65% of the correction in mandibular Incisor Irregularity persisted over the long-term period. The mandibular Incisor Irregularity at the recall examination was less than 3.5 mm in 77% of the cases, which is the upper limit suggested as being clinically acceptable. The University of Washington studies reported that less than 30% of their cases exhibited clinically acceptable long-term mandibular Incisor Irregularity.
- The present results seem more stable than those reported in most long-term recall studies.

It is likely that posttreatment changes will continue to perplex the orthodontic specialty. The orthodontist cannot assume that stability will occur after treatment, but should assume that posttreatment changes will likely be the norm. The specialist must relay to the patient the expected changes of the

dentition that are likely to occur over time so that they may better appreciate their roles in the maintenance of the treatment results.

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APPENDIX A.

**CASTS AT THE PRETREATMENT, END OF ACTIVE TREATMENT, AND
POSTTREATMENT EXAMINATIONS**

Figure A-1. Picture illustrations of example casts at pretreatment, the end of active treatment, and posttreatment examinations. Casts are arranged chronologically from left-to-right.

Figure A-2. Picture illustrations of example casts at pretreatment, the end of active treatment, and posttreatment examinations. Casts are arranged chronologically from left-to-right.

Figure A-3. Picture illustrations of example casts at pretreatment, the end of active treatment, and posttreatment examinations. Casts are arranged chronologically from left-to-right.

Figure A-4. Picture illustrations of example casts at pretreatment, the end of active treatment, and posttreatment examinations. Casts are arranged chronologically from left-to-right.

Figure A-5. Picture illustrations of example casts at pretreatment, the end of active treatment, and posttreatment examinations. Casts are arranged chronologically from left-to-right.

Figure A-6. Picture illustrations of example casts at pretreatment, the end of active treatment, and posttreatment examinations. Casts are arranged chronologically from left-to-right.

Figure A-7. Picture illustrations of example casts at pretreatment, the end of active treatment, and posttreatment examinations. Casts are arranged chronologically from left-to-right.

Figure A-8. Picture illustrations of example casts at pretreatment, the end of active treatment, and posttreatment examinations. Casts are arranged chronologically from left-to-right.

Figure A-9. Picture illustrations of example casts at pretreatment, the end of active treatment, and posttreatment examinations. Casts are arranged chronologically from left-to-right.

Figure A-10. Picture illustrations of example casts at pretreatment, the end of active treatment, and posttreatment examinations. Casts are arranged chronologically from left-to-right.

APPENDIX B.

**STATISTICAL TABLES DESCRIBING THE STATUS OF THE OCCLUSAL
VARIABLES AT THE START OF TREATMENT**

Table B-1. Status at start of treatment for overbite.

Variable	Statistic
Arithmetic mean	3.88
Standard deviation	1.57
Standard error mean	0.22
Upper 95% CL	4.31
Lower 95% CL	3.44
Sample size	52
Variance	2.48
Skewness	-0.57
Kurtosis	1.20
Coefficient variation	40.61
Number missing	0
Maximum	7.97
Median	4.01
Minimum	-0.62

Table B-2. Status at start of treatment for overjet.

Variable	Statistic
Arithmetic mean	5.89
Standard deviation	2.03
Standard error mean	0.28
Upper 95% CL	6.46
Lower 95% CL	5.33
Sample size	52
Variance	4.12
Skewness	0.70
Kurtosis	0.09
Coefficient variation	34.44
Number missing	0
Maximum	11.52
Median	5.66
Minimum	2.90

Table B-3. Status at start of treatment for dental midline.

Variable	Statistic
Arithmetic mean	0.31
Standard deviation	1.56
Standard error mean	0.22
Upper 95% CL	0.75
Lower 95% CL	-0.12
Sample size	52
Variance	2.44
Skewness	0.02
Kurtosis	-0.37
Coefficient variation	497.77
Number missing	0
Maximum	3.67
Median	0.23
Minimum	-2.82

Table B-4. Status at start of treatment for the absolute value of the dental midline.

Variable	Statistic
Arithmetic mean	1.25
Standard deviation	0.96
Standard error mean	0.12
Upper 95% CL	1.51
Lower 95% CL	0.99
Sample size	56
Variance	0.92
Skewness	0.58
Kurtosis	-0.36
Coefficient variation	76.88
Number missing	0
Maximum	3.67
Median	1.10
Minimum	0

Table B-5. Status at start of treatment for buccal segment relationship (right).

Variable	Statistic
Arithmetic mean	-1.51
Standard deviation	1.78
Standard error mean	0.25
Upper 95% CL	-1.01
Lower 95% CL	-2.02
Sample size	50
Variance	3.15
Skewness	-0.72
Kurtosis	0.03
Coefficient variation	-117.49
Number missing	2
Maximum	1.13
Median	-1.26
Minimum	-5.82

Table B-6. Status at start of treatment for canine relationship (right).

Variable	Statistic
Arithmetic mean	-3.02
Standard deviation	2.22
Standard error mean	0.35
Upper 95% CL	-2.31
Lower 95% CL	-3.73
Sample size	40
Variance	4.92
Skewness	-0.18
Kurtosis	-0.19
Coefficient variation	-73.38
Number missing	12
Maximum	1.76
Median	-3.23
Minimum	-8.17

Table B-7. Status at start of treatment for buccal segment relationship (left).

Variable	Statistic
Arithmetic mean	-1.21
Standard deviation	1.65
Standard error mean	0.23
Upper 95% CL	-0.75
Lower 95% CL	-1.66
Sample size	52
Variance	2.71
Skewness	-0.38
Kurtosis	0.40
Coefficient variation	-136.45
Number missing	0
Maximum	3.05
Median	-0.85
Minimum	-5.41

Table B-8. Status at start of treatment for canine relationship (left).

Variable	Statistic
Arithmetic mean	-2.27
Standard deviation	2.56
Standard error mean	0.41
Upper 95% CL	-1.43
Lower 95% CL	-3.11
Sample size	38
Variance	6.53
Skewness	-0.28
Kurtosis	-0.67
Coefficient variation	-112.80
Number missing	14
Maximum	2.30
Median	-1.74
Minimum	-7.67

Table B-9. Status at start of treatment for maxillary Incisor Irregularity (site A).

Variable	Statistic
Arithmetic mean	1.75
Standard deviation	1.46
Standard error mean	0.25
Upper 95% CL	2.27
Lower 95% CL	1.23
Sample size	33
Variance	2.15
Skewness	1.26
Kurtosis	1.25
Coefficient variation	83.77
Number missing	19
Maximum	5.91
Median	1.35
Minimum	0.00

Table B-10. Status at start of treatment for maxillary Incisor Irregularity (site B).

Variable	Statistic
Arithmetic mean	1.60
Standard deviation	1.70
Standard error mean	0.30
Upper 95% CL	2.21
Lower 95% CL	1.00
Sample size	33
Variance	2.90
Skewness	1.52
Kurtosis	1.56
Coefficient variation	106.26
Number missing	19
Maximum	6.08
Median	1.06
Minimum	0.00

Table B-11. Status at start of treatment for maxillary Incisor Irregularity (site C).

Variable	Statistic
Arithmetic mean	0.64
Standard deviation	0.60
Standard error mean	0.11
Upper 95% CL	0.85
Lower 95% CL	0.42
Sample size	33
Variance	0.36
Skewness	0.60
Kurtosis	-0.78
Coefficient variation	94.95
Number missing	19
Maximum	2.00
Median	0.45
Minimum	0.00

Table B-12. Status at start of treatment for maxillary Incisor Irregularity (site D).

Variable	Statistic
Arithmetic mean	1.32
Standard deviation	1.24
Standard error mean	0.22
Upper 95% CL	1.76
Lower 95% CL	0.88
Sample size	33
Variance	1.54
Skewness	1.40
Kurtosis	1.10
Coefficient variation	93.91
Number missing	19
Maximum	4.35
Median	0.87
Minimum	0.00

Table B-13. Status at start of treatment for maxillary Incisor Irregularity (site E).

Variable	Statistic
Arithmetic mean	1.45
Standard deviation	1.06
Standard error mean	0.19
Upper 95% CL	1.83
Lower 95% CL	1.08
Sample size	33
Variance	1.13
Skewness	1.50
Kurtosis	3.96
Coefficient variation	73.10
Number missing	19
Maximum	5.30
Median	1.35
Minimum	0.00

Table B-14. Status at start of treatment for maxillary Incisor Irregularity.

Variable	Statistic
Arithmetic mean	6.76
Standard deviation	3.62
Standard error mean	0.63
Upper 95% CL	8.04
Lower 95% CL	5.48
Sample size	33
Variance	13.09
Skewness	0.80
Kurtosis	-0.42
Coefficient variation	53.50
Number missing	19
Maximum	15.38
Median	5.30
Minimum	1.82

Table B-15. Status at start of treatment for mandibular Incisor Irregularity (site A).

Variable	Statistic
Arithmetic mean	1.12
Standard deviation	0.91
Standard error mean	0.13
Upper 95% CL	1.38
Lower 95% CL	0.86
Sample size	51
Variance	0.84
Skewness	0.99
Kurtosis	0.99
Coefficient variation	81.63
Number missing	1
Maximum	3.81
Median	0.96
Minimum	0.00

Table B-16. Status at start of treatment for mandibular Incisor Irregularity (site B).

Variable	Statistic
Arithmetic mean	0.94
Standard deviation	0.80
Standard error mean	0.11
Upper 95% CL	1.17
Lower 95% CL	0.72
Sample size	51
Variance	0.64
Skewness	0.77
Kurtosis	0.16
Coefficient variation	84.61
Number missing	1
Maximum	3.14
Median	0.76
Minimum	0.00

Table B-17. Status at start of treatment for mandibular Incisor Irregularity (site C).

Variable	Statistic
Arithmetic mean	0.56
Standard deviation	0.61
Standard error mean	0.09
Upper 95% CL	0.73
Lower 95% CL	0.38
Sample size	51
Variance	0.38
Skewness	1.10
Kurtosis	0.92
Coefficient variation	110.14
Number missing	1
Maximum	2.34
Median	0.50
Minimum	0.00

Table B-18. Status at start of treatment for mandibular Incisor Irregularity (site D).

Variable	Statistic
Arithmetic mean	0.72
Standard deviation	0.65
Standard error mean	0.09
Upper 95% CL	0.90
Lower 95% CL	0.53
Sample size	51
Variance	0.43
Skewness	1.34
Kurtosis	2.02
Coefficient variation	91.08
Number missing	1
Maximum	2.86
Median	0.58
Minimum	0.00

Table B-19. Status at start of treatment for mandibular Incisor Irregularity (site E).

Variable	Statistic
Arithmetic mean	1.17
Standard deviation	0.95
Standard error mean	0.13
Upper 95% CL	1.44
Lower 95% CL	0.91
Sample size	51
Variance	0.90
Skewness	0.85
Kurtosis	0.51
Coefficient variation	80.87
Number missing	1
Maximum	4.06
Median	1.00
Minimum	0.00

Table B-20. Status at start of treatment for mandibular Incisor Irregularity.

Variable	Statistic
Arithmetic mean	4.51
Standard deviation	2.38
Standard error mean	0.33
Upper 95% CL	5.18
Lower 95% CL	3.84
Sample size	51
Variance	5.67
Skewness	0.88
Kurtosis	0.69
Coefficient variation	52.77
Number missing	1
Maximum	12.11
Median	4.03
Minimum	1.08

Table B-21. Status at start of treatment for maxillary 1-3 chord (right).

Variable	Statistic
Arithmetic mean	23.00
Standard deviation	1.54
Standard error mean	0.25
Upper 95% CL	23.51
Lower 95% CL	22.49
Sample size	38
Variance	2.39
Skewness	-1.27
Kurtosis	2.76
Coefficient variation	6.72
Number missing	14
Maximum	25.58
Median	23.06
Minimum	18.28

Table B-22. Status at start of treatment for maxillary 1-6 chord (right).

Variable	Statistic
Arithmetic mean	44.92
Standard deviation	3.00
Standard error mean	0.42
Upper 95% CL	45.77
Lower 95% CL	44.08
Sample size	51
Variance	9.02
Skewness	-0.19
Kurtosis	0.31
Coefficient variation	6.68
Number missing	1
Maximum	52.18
Median	44.89
Minimum	37.33

Table B-23. Status at start of treatment for maxillary 1-3 chord (left).

Variable	Statistic
Arithmetic mean	22.81
Standard deviation	1.14
Standard error mean	0.19
Upper 95% CL	23.19
Lower 95% CL	22.42
Sample size	36
Variance	1.29
Skewness	-0.63
Kurtosis	1.00
Coefficient variation	4.98
Number missing	16
Maximum	24.88
Median	22.90
Minimum	19.42

Table B-24. Status at start of treatment for maxillary 1-6 chord (left).

Variable	Statistic
Arithmetic mean	44.93
Standard deviation	2.47
Standard error mean	0.34
Upper 95% CL	45.62
Lower 95% CL	44.25
Sample size	52
Variance	6.12
Skewness	-0.33
Kurtosis	-0.43
Coefficient variation	5.51
Number missing	0
Maximum	49.17
Median	45.10
Minimum	38.97

Table B-25. Status at start of treatment for mandibular 1-3 chord (right).

Variable	Statistic
Arithmetic mean	17.02
Standard deviation	1.35
Standard error mean	0.19
Upper 95% CL	17.40
Lower 95% CL	16.64
Sample size	51
Variance	1.81
Skewness	0.37
Kurtosis	-0.92
Coefficient variation	7.91
Number missing	1
Maximum	19.96
Median	16.73
Minimum	14.53

Table B-26. Status at start of treatment for mandibular 1-6 chord (right).

Variable	Statistic
Arithmetic mean	40.00
Standard deviation	2.09
Standard error mean	0.30
Upper 95% CL	40.60
Lower 95% CL	39.41
Sample size	50
Variance	4.38
Skewness	0.18
Kurtosis	-0.28
Coefficient variation	5.23
Number missing	2
Maximum	45.17
Median	40.16
Minimum	35.94

Table B-27. Status at start of treatment for mandibular 1-3 chord (left).

Variable	Statistic
Arithmetic mean	17.24
Standard deviation	1.19
Standard error mean	0.17
Upper 95% CL	17.57
Lower 95% CL	16.91
Sample size	51
Variance	1.40
Skewness	0.02
Kurtosis	-0.93
Coefficient variation	6.87
Number missing	1
Maximum	19.60
Median	17.32
Minimum	15.14

Table B-28. Status at start of treatment for mandibular 1-6 chord (left).

Variable	Statistic
Arithmetic mean	40.34
Standard deviation	2.07
Standard error mean	0.29
Upper 95% CL	40.92
Lower 95% CL	39.77
Sample size	52
Variance	4.28
Skewness	0.03
Kurtosis	0.89
Coefficient variation	5.13
Number missing	0
Maximum	46.30
Median	40.37
Minimum	35.57

Table B-29. Status at start of treatment for maxillary arch depth.

Variable	Statistic
Arithmetic mean	39.71
Standard deviation	2.79
Standard error mean	0.39
Upper 95% CL	40.49
Lower 95% CL	38.93
Sample size	52
Variance	7.77
Skewness	-0.11
Kurtosis	-0.47
Coefficient variation	7.02
Number missing	0
Maximum	45.57
Median	39.35
Minimum	33.28

Table B-30. Status at start of treatment for mandibular arch depth.

Variable	Statistic
Arithmetic mean	33.65
Standard deviation	2.00
Standard error mean	0.28
Upper 95% CL	34.22
Lower 95% CL	33.08
Sample size	50
Variance	4.00
Skewness	0.48
Kurtosis	-0.16
Coefficient variation	5.95
Number missing	2
Maximum	38.30
Median	33.49
Minimum	29.68

Table B-31. Status at start of treatment for maxillary intercanine width.

Variable	Statistic
Arithmetic mean	37.39
Standard deviation	2.19
Standard error mean	0.37
Upper 95% CL	38.13
Lower 95% CL	36.65
Sample size	36
Variance	4.81
Skewness	-0.73
Kurtosis	0.25
Coefficient variation	5.87
Number missing	16
Maximum	40.62
Median	37.47
Minimum	31.37

Table B-32. Status at start of treatment for maxillary interpremolar width.

Variable	Statistic
Arithmetic mean	45.76
Standard deviation	2.61
Standard error mean	0.42
Upper 95% CL	46.61
Lower 95% CL	44.90
Sample size	38
Variance	6.81
Skewness	-0.56
Kurtosis	-0.09
Coefficient variation	5.70
Number missing	14
Maximum	49.94
Median	46.14
Minimum	39.09

Table B-33. Status at start of treatment for maxillary intermolar width.

Variable	Statistic
Arithmetic mean	53.74
Standard deviation	3.05
Standard error mean	0.42
Upper 95% CL	54.59
Lower 95% CL	52.89
Sample size	52
Variance	9.29
Skewness	0.49
Kurtosis	2.09
Coefficient variation	5.67
Number missing	0
Maximum	64.09
Median	53.87
Minimum	46.91

Table B-34. Status at start of treatment for mandibular intercanine width.

Variable	Statistic
Arithmetic mean	30.31
Standard deviation	1.68
Standard error mean	0.24
Upper 95% CL	30.79
Lower 95% CL	29.84
Sample size	51
Variance	2.82
Skewness	0.08
Kurtosis	0.21
Coefficient variation	5.54
Number missing	1
Maximum	35.02
Median	30.60
Minimum	26.52

Table B-35. Status at start of treatment for mandibular interpremolar width.

Variable	Statistic
Arithmetic mean	40.97
Standard deviation	3.63
Standard error mean	0.55
Upper 95% CL	42.09
Lower 95% CL	39.85
Sample size	43
Variance	13.15
Skewness	0.03
Kurtosis	-0.97
Coefficient variation	8.85
Number missing	9
Maximum	46.91
Median	40.69
Minimum	33.81

Table B-36. Status at start of treatment for mandibular intermolar width.

Variable	Statistic
Arithmetic mean	51.87
Standard deviation	2.85
Standard error mean	0.40
Upper 95% CL	52.68
Lower 95% CL	51.06
Sample size	50
Variance	8.11
Skewness	-0.57
Kurtosis	4.66
Coefficient variation	5.49
Number missing	2
Maximum	59.76
Median	51.92
Minimum	40.70

APPENDIX C.

**STATISTICAL TABLES DESCRIBING THE STATUS OF THE OCCLUSAL
VARIABLES AT THE END OF TREATMENT**

Table C-1. Status at the end of treatment for overbite.

Variable	Statistic
Arithmetic mean	2.50
Standard deviation	0.79
Standard error mean	0.11
Upper 95% mean	2.73
Lower 95% mean	2.28
Sample size	50
Variance	0.63
Skewness	0.36
Kurtosis	-0.41
Coefficient variation	31.70
Number missing	2.00
Maximum	4.29
Median	2.40
Minimum	1.11

Table C-2. Status at the end of treatment for overjet.

Variable	Statistic
Arithmetic mean	2.67
Standard deviation	0.62
Standard error mean	0.09
Upper 95% mean	2.84
Lower 95% mean	2.49
Sample size	50
Variance	0.38
Skewness	0.32
Kurtosis	0.41
Coefficient variation	23.12
Number missing	2
Maximum	4.41
Median	2.64
Minimum	1.38

Table C-3. Status at the end of treatment for dental midline.

Variable	Statistic
Arithmetic mean	0.08
Standard deviation	0.53
Standard error mean	0.08
Upper 95% mean	0.23
Lower 95% mean	-0.08
Sample size	50
Variance	0.29
Skewness	0.12
Kurtosis	0.56
Coefficient variation	696.43
Number missing	2
Maximum	1.39
Median	0.00
Minimum	-1.27

Table C-4. Status at the end of treatment for the absolute value of the dental midline.

Variable	Statistic
Arithmetic mean	0.33
Standard deviation	0.41
Standard error mean	0.06
Upper 95% mean	0.45
Lower 95% mean	0.23
Sample size	54
Variance	0.17
Skewness	0.86
Kurtosis	-0.40
Coefficient variation	121.39
Number missing	2
Maximum	1.39
Median	0.00
Minimum	0.00

Table C-5. Status at the end of treatment for buccal segment relationship (right).

Variable	Statistic
Arithmetic mean	0.13
Standard deviation	0.82
Standard error mean	0.12
Upper 95% mean	0.37
Lower 95% mean	-0.11
Sample size	46
Variance	0.67
Skewness	0.65
Kurtosis	5.23
Coefficient variation	626.54
Number missing	6
Maximum	2.97
Median	0.00
Minimum	-2.53

Table C-6. Status at the end of treatment for canine relationship (right).

Variable	Statistic
Arithmetic mean	-0.90
Standard deviation	1.07
Standard error mean	0.15
Upper 95% mean	-0.60
Lower 95% mean	-1.21
Sample size	51
Variance	1.15
Skewness	-0.50
Kurtosis	0.96
Coefficient variation	-118.68
Number missing	1
Maximum	1.46
Median	-0.84
Minimum	-4.26

Table C-7. Status at the end of treatment for buccal segment relationship (left).

Variable	Statistic
Arithmetic mean	0.21
Standard deviation	0.53
Standard error mean	0.08
Upper 95% mean	0.37
Lower 95% mean	0.06
Sample size	48
Variance	0.29
Skewness	1.17
Kurtosis	1.66
Coefficient variation	253.61
Number missing	4
Maximum	1.83
Median	0.00
Minimum	-0.86

Table C-8. Status at the end of treatment for canine relationship (left).

Variable	Statistic
Arithmetic mean	-0.60
Standard deviation	1.04
Standard error mean	0.15
Upper 95% mean	-0.31
Lower 95% mean	-0.89
Sample size	51
Variance	1.08
Skewness	0.37
Kurtosis	1.12
Coefficient variation	-173.48
Number missing	1
Maximum	2.55
Median	-0.63
Minimum	-2.74

Table C-9. Status at the end of treatment for maxillary Incisor Irregularity (site A).

Variable	Statistic
Arithmetic mean	0.46
Standard deviation	0.49
Standard error mean	0.07
Upper 95% mean	0.60
Lower 95% mean	0.32
Sample size	50
Variance	0.24
Skewness	-0.33
Kurtosis	1.57
Coefficient variation	106.76
Number missing	2
Maximum	1.58
Median	0.53
Minimum	-1.20

Table C-10. Status at the end of treatment for maxillary Incisor Irregularity (site B).

Variable	Statistic
Arithmetic mean	0.22
Standard deviation	0.33
Standard error mean	0.05
Upper 95% mean	0.31
Lower 95% mean	0.12
Sample size	50
Variance	0.11
Skewness	2.40
Kurtosis	8.43
Coefficient variation	152.57
Number missing	2
Maximum	1.76
Median	0.00
Minimum	0.00

Table C-11. Status at the end of treatment for maxillary Incisor Irregularity (site C).

Variable	Statistic
Arithmetic mean	0.18
Standard deviation	0.25
Standard error mean	0.04
Upper 95% mean	0.25
Lower 95% mean	0.11
Sample size	50
Variance	0.06
Skewness	1.54
Kurtosis	2.34
Coefficient variation	137.76
Number missing	2
Maximum	1.04
Median	0.00
Minimum	0.00

Table C-12. Status at the end of treatment for maxillary Incisor Irregularity (site D).

Variable	Statistic
Arithmetic mean	0.30
Standard deviation	0.34
Standard error mean	0.05
Upper 95% mean	0.40
Lower 95% mean	0.21
Sample size	50
Variance	0.11
Skewness	1.29
Kurtosis	2.48
Coefficient variation	110.81
Number missing	2
Maximum	1.55
Median	0.29
Minimum	0.00

Table C-13. Status at the end of treatment for maxillary Incisor Irregularity (site E).

Variable	Statistic
Arithmetic mean	0.43
Standard deviation	0.33
Standard error mean	0.05
Upper 95% mean	0.53
Lower 95% mean	0.34
Sample size	50
Variance	0.11
Skewness	0.39
Kurtosis	-0.50
Coefficient variation	77.68
Number missing	2
Maximum	1.21
Median	0.42
Minimum	0.00

Table C-14. Status at the end of treatment for maxillary Incisor Irregularity.

Variable	Statistic
Arithmetic mean	1.59
Standard deviation	1.11
Standard error mean	0.16
Upper 95% mean	1.91
Lower 95% mean	1.28
Sample size	50
Variance	1.23
Skewness	0.61
Kurtosis	1.09
Coefficient variation	69.74
Number missing	2
Maximum	5.22
Median	1.50
Minimum	-0.77

Table C-15. Status at the end of treatment for mandibular Incisor Irregularity (site A).

Variable	Statistic
Arithmetic mean	0.47
Standard deviation	0.45
Standard error mean	0.07
Upper 95% mean	0.60
Lower 95% mean	0.33
Sample size	45
Variance	0.20
Skewness	1.05
Kurtosis	1.38
Coefficient variation	96.20
Number missing	7
Maximum	1.90
Median	0.44
Minimum	0.00

Table C-16. Status at the end of treatment for mandibular Incisor Irregularity (site B).

Variable	Statistic
Arithmetic mean	0.21
Standard deviation	0.28
Standard error mean	0.04
Upper 95% mean	0.29
Lower 95% mean	0.12
Sample size	45
Variance	0.08
Skewness	1.53
Kurtosis	2.94
Coefficient variation	132.80
Number missing	7
Maximum	1.24
Median	0.00
Minimum	0.00

Table C-17. Status at the end of treatment for mandibular Incisor Irregularity (site C).

Variable	Statistic
Arithmetic mean	0.14
Standard deviation	0.24
Standard error mean	0.04
Upper 95% mean	0.21
Lower 95% mean	0.06
Sample size	45
Variance	0.06
Skewness	1.52
Kurtosis	0.96
Coefficient variation	175.31
Number missing	7
Maximum	0.79
Median	0.00
Minimum	0.00

Table C-18. Status at the end of treatment for mandibular Incisor Irregularity (site D).

Variable	Statistic
Arithmetic mean	0.23
Standard deviation	0.27
Standard error mean	0.04
Upper 95% mean	0.31
Lower 95% mean	0.15
Sample size	45
Variance	0.07
Skewness	1.45
Kurtosis	3.10
Coefficient variation	119.35
Number missing	7
Maximum	1.25
Median	0.21
Minimum	0.00

Table C-19. Status at the end of treatment for mandibular Incisor Irregularity (site E).

Variable	Statistic
Arithmetic mean	0.41
Standard deviation	0.40
Standard error mean	0.06
Upper 95% mean	0.53
Lower 95% mean	0.29
Sample size	45
Variance	0.16
Skewness	0.67
Kurtosis	-0.33
Coefficient variation	97.52
Number missing	7
Maximum	1.49
Median	0.36
Minimum	0.00

Table C-20. Status at the end of treatment for mandibular Incisor Irregularity.

Variable	Statistic
Arithmetic mean	1.45
Standard deviation	0.83
Standard error mean	0.12
Upper 95% mean	1.70
Lower 95% mean	1.20
Sample size	45
Variance	0.69
Skewness	0.23
Kurtosis	-0.50
Coefficient variation	57.44
Number missing	7
Maximum	3.19
Median	1.45
Minimum	0.00

Table C-21. Status at the end of treatment for maxillary 1-3 chord (right).

Variable	Statistic
Arithmetic mean	23.49
Standard deviation	1.11
Standard error mean	0.15
Upper 95% mean	23.80
Lower 95% mean	23.18
Sample size	51
Variance	1.22
Skewness	0.13
Kurtosis	0.32
Coefficient variation	4.71
Number missing	1
Maximum	26.11
Median	23.37
Minimum	20.47

Table C-22. Status at the end of treatment for maxillary 1-6 chord (right).

Variable	Statistic
Arithmetic mean	40.40
Standard deviation	2.22
Standard error mean	0.31
Upper 95% mean	41.03
Lower 95% mean	39.78
Sample size	51
Variance	4.95
Skewness	0.58
Kurtosis	0.09
Coefficient variation	5.50
Number missing	1
Maximum	46.00
Median	39.91
Minimum	35.73

Table C-23. Status at the end of treatment for maxillary 1-3 chord (left).

Variable	Statistic
Arithmetic mean	23.39
Standard deviation	1.09
Standard error mean	0.15
Upper 95% mean	23.70
Lower 95% mean	23.08
Sample size	51
Variance	1.19
Skewness	0.26
Kurtosis	-0.12
Coefficient variation	4.67
Number missing	1
Maximum	25.94
Median	23.39
Minimum	21.25

Table C-24. Status at the end of treatment for maxillary 1-6 chord (left).

Variable	Statistic
Arithmetic mean	40.26
Standard deviation	2.00
Standard error mean	0.28
Upper 95% mean	40.83
Lower 95% mean	39.69
Sample size	50
Variance	3.99
Skewness	0.39
Kurtosis	-0.12
Coefficient variation	4.96
Number missing	2
Maximum	45.16
Median	39.94
Minimum	36.13

Table C-25. Status at the end of treatment for mandibular 1-3 chord (right).

Variable	Statistic
Arithmetic mean	18.17
Standard deviation	1.01
Standard error mean	0.14
Upper 95% mean	18.45
Lower 95% mean	17.88
Sample size	50
Variance	1.01
Skewness	-0.42
Kurtosis	0.38
Coefficient variation	5.53
Number missing	2
Maximum	20.10
Median	18.19
Minimum	15.44

Table C-26. Status at the end of treatment for mandibular 1-6 chord (right).

Variable	Statistic
Arithmetic mean	36.26
Standard deviation	2.16
Standard error mean	0.31
Upper 95% mean	36.88
Lower 95% mean	35.63
Sample size	48
Variance	4.68
Skewness	0.69
Kurtosis	0.87
Coefficient variation	5.97
Number missing	4
Maximum	41.85
Median	35.83
Minimum	31.37

Table C-27. Status at the end of treatment for mandibular 1-3 chord (left).

Variable	Statistic
Arithmetic mean	18.20
Standard deviation	0.91
Standard error mean	0.13
Upper 95% mean	18.47
Lower 95% mean	17.94
Sample size	48
Variance	0.83
Skewness	-0.07
Kurtosis	0.07
Coefficient variation	5.02
Number missing	4
Maximum	20.32
Median	18.22
Minimum	15.94

Table C-28. Status at the end of treatment for mandibular 1-6 chord (left).

Variable	Statistic
Arithmetic mean	36.63
Standard deviation	2.15
Standard error mean	0.31
Upper 95% mean	37.26
Lower 95% mean	36.00
Sample size	47
Variance	4.61
Skewness	0.61
Kurtosis	0.33
Coefficient variation	5.86
Number missing	5
Maximum	42.02
Median	36.26
Minimum	32.25

Table C-29. Status at the end of treatment for maxillary arch depth.

Variable	Statistic
Arithmetic mean	34.44
Standard deviation	2.06
Standard error mean	0.29
Upper 95% mean	35.03
Lower 95% mean	33.86
Sample size	50
Variance	4.24
Skewness	0.44
Kurtosis	0.12
Coefficient variation	5.98
Number missing	2
Maximum	39.80
Median	34.35
Minimum	30.32

Table C-30. Status at the end of treatment for mandibular arch depth.

Variable	Statistic
Arithmetic mean	29.64
Standard deviation	2.24
Standard error mean	0.32
Upper 95% mean	30.29
Lower 95% mean	28.99
Sample size	48
Variance	5.04
Skewness	0.60
Kurtosis	0.57
Coefficient variation	7.57
Number missing	4
Maximum	34.95
Median	29.51
Minimum	24.69

Table C-31. Status at the end of treatment for maxillary intercanine width.

Variable	Statistic
Arithmetic mean	39.07
Standard deviation	1.56
Standard error mean	0.22
Upper 95% mean	39.51
Lower 95% mean	38.63
Sample size	51
Variance	2.44
Skewness	0.38
Kurtosis	-0.03
Coefficient variation	4.00
Number missing	1
Maximum	42.78
Median	38.76
Minimum	35.41

Table C-32. Status at the end of treatment for maxillary interpremolar width.

Variable	Statistic
Arithmetic mean	45.45
Standard deviation	1.70
Standard error mean	0.24
Upper 95% mean	45.93
Lower 95% mean	44.98
Sample size	51
Variance	2.89
Skewness	0.18
Kurtosis	-0.71
Coefficient variation	3.74
Number missing	1
Maximum	49.11
Median	45.31
Minimum	42.38

Table C-33. Status at the end of treatment for maxillary intermolar width.

Variable	Statistic
Arithmetic mean	52.47
Standard deviation	2.27
Standard error mean	0.32
Upper 95% mean	53.11
Lower 95% mean	51.82
Sample size	50
Variance	5.14
Skewness	0.35
Kurtosis	0.51
Coefficient variation	4.32
Number missing	2
Maximum	59.29
Median	52.54
Minimum	47.38

Table C-34. Status at the end of treatment for mandibular intercanine width.

Variable	Statistic
Arithmetic mean	32.50
Standard deviation	1.47
Standard error mean	0.21
Upper 95% mean	32.91
Lower 95% mean	32.09
Sample size	51
Variance	2.16
Skewness	-0.36
Kurtosis	-0.08
Coefficient variation	4.53
Number missing	1
Maximum	35.72
Median	32.58
Minimum	29.16

Table C-35. Status at the end of treatment for mandibular interpremolar width.

Variable	Statistic
Arithmetic mean	40.95
Standard deviation	2.03
Standard error mean	0.28
Upper 95% mean	41.52
Lower 95% mean	40.38
Sample size	51
Variance	4.11
Skewness	0.49
Kurtosis	0.05
Coefficient variation	4.95
Number missing	1
Maximum	46.58
Median	40.96
Minimum	36.90

Table C-36. Status at the end of treatment for mandibular intermolar width.

Variable	Statistic
Arithmetic mean	49.71
Standard deviation	2.11
Standard error mean	0.30
Upper 95% mean	50.32
Lower 95% mean	49.11
Sample size	49
Variance	4.43
Skewness	-0.24
Kurtosis	-0.94
Coefficient variation	4.23
Number missing	3
Maximum	52.88
Median	49.90
Minimum	45.39

APPENDIX D.

**STATISTICAL TABLES DESCRIBING THE IN-TREATMENT CHANGES OF
THE OCCLUSAL VARIABLES**

Table D-1. Status for the in-treatment change of overbite.

Variable	Statistic
Arithmetic mean	-1.33
Standard deviation	1.51
Standard error mean	0.21
Upper 95% mean	-0.90
Lower 95% mean	-1.76
Sample size	50
Variance	2.28
Skewness	0.31
Kurtosis	0.29
Coefficient variation	-113.54
Number missing	2
Maximum	2.56
Median	-1.34
Minimum	-4.26
One-sample t-test	-6.23
P-value	<0.0001

Table D-2. Status for the in-treatment change of overjet.

Variable	Statistic
Arithmetic mean	-3.19
Standard deviation	1.96
Standard error mean	0.28
Upper 95% mean	-2.63
Lower 95% mean	-3.75
Sample size	50
Variance	3.84
Skewness	-0.99
Kurtosis	0.38
Coefficient variation	-61.44
Number missing	2
Maximum	-0.33
Median	-2.52
Minimum	-8.87
One-sample t-test	-11.51
P-value	<0.0001

Table D-3. Status for the in-treatment change of dental midline.

Variable	Statistic
Arithmetic mean	-0.30
Standard deviation	1.59
Standard error mean	0.23
Upper 95% mean	0.15
Lower 95% mean	-0.76
Sample size	50
Variance	2.53
Skewness	0.30
Kurtosis	-0.30
Coefficient variation	-524.12
Number missing	2
Maximum	2.96
Median	-0.24
Minimum	-3.40
One-sample t-test	-1.35
P-value	0.1835

Table D-4. Status for the in-treatment change of the absolute value of the dental midline.

Variable	Statistic
Arithmetic mean	1.26
Standard deviation	0.97
Standard error mean	0.13
Upper 95% mean	1.53
Lower 95% mean	0.99
Sample size	54
Variance	0.95
Skewness	0.49
Kurtosis	-0.76
Coefficient variation	77.26
Number missing	2
Maximum	3.40
Median	1.13
Minimum	0.00
One-sample t-test	9.51
P-value	<0.0001

Table D-5. Status for the in-treatment change of buccal segment relationship (right).

Variable	Statistic
Arithmetic mean	1.54
Standard deviation	1.82
Standard error mean	0.27
Upper 95% mean	2.07
Lower 95% mean	1.00
Sample size	46
Variance	3.30
Skewness	1.16
Kurtosis	0.63
Coefficient variation	118.34
Number missing	6
Maximum	6.74
Median	0.89
Minimum	-1.01
One-sample t-test	5.73
P-value	<0.0001

Table D-6. Status for the in-treatment change of canine relationship (right).

Variable	Statistic
Arithmetic mean	2.09
Standard deviation	1.98
Standard error mean	0.32
Upper 95% mean	2.73
Lower 95% mean	1.45
Sample size	39
Variance	3.94
Skewness	0.71
Kurtosis	0.19
Coefficient variation	94.94
Number missing	13
Maximum	6.69
Median	1.58
Minimum	-1.76
One-sample t-test	6.58
P-value	<0.0001

Table D-7. Status for the in-treatment change of buccal segment relationship (left).

Variable	Statistic
Arithmetic mean	1.39
Standard deviation	1.74
Standard error mean	0.25
Upper 95% mean	1.90
Lower 95% mean	0.89
Sample size	48
Variance	3.04
Skewness	0.54
Kurtosis	-0.08
Coefficient variation	125.03
Number missing	4
Maximum	5.41
Median	1.11
Minimum	-2.17
One-sample t-test	5.54
P-value	<0.0001

Table D-8. Status for the in-treatment change of canine relationship (left).

Variable	Statistic
Arithmetic mean	1.46
Standard deviation	2.51
Standard error mean	0.41
Upper 95% mean	2.29
Lower 95% mean	0.62
Sample size	37
Variance	6.30
Skewness	0.67
Kurtosis	0.22
Coefficient variation	172.20
Number missing	15
Maximum	7.51
Median	1.30
Minimum	-2.86
One-sample t-test	3.53
P-value	0.0000

Table D-9. Status for the in-treatment change of maxillary Incisor Irregularity (site A).

Variable	Statistic
Arithmetic mean	-1.30
Standard deviation	1.61
Standard error mean	0.29
Upper 95% mean	-0.72
Lower 95% mean	-1.88
Sample size	32
Variance	2.61
Skewness	-1.54
Kurtosis	2.37
Coefficient variation	-123.89
Number missing	20
Maximum	0.52
Median	-0.80
Minimum	-6.09
One-sample t-test	-4.57
P-value	<0.0001

Table D-10. Status for the in-treatment change of maxillary Incisor Irregularity (site B).

Variable	Statistic
Arithmetic mean	-1.20
Standard deviation	1.61
Standard error mean	0.28
Upper 95% mean	-0.62
Lower 95% mean	-1.78
Sample size	32
Variance	2.58
Skewness	-1.51
Kurtosis	1.91
Coefficient variation	-133.70
Number missing	20
Maximum	0.76
Median	-0.76
Minimum	-5.76
One-sample t-test	-4.23
P-value	0.0000

Table D-11. Status for the in-treatment change of maxillary Incisor Irregularity (site C).

Variable	Statistic
Arithmetic mean	-0.46
Standard deviation	0.60
Standard error mean	0.11
Upper 95% mean	-0.24
Lower 95% mean	-0.68
Sample size	32
Variance	0.36
Skewness	-0.70
Kurtosis	0.01
Coefficient variation	-130.31
Number missing	20
Maximum	0.53
Median	-0.37
Minimum	-2.00
One-sample t-test	-4.34
P-value	0.0000

Table D-12. Status for the in-treatment change of maxillary Incisor Irregularity (site D).

Variable	Statistic
Arithmetic mean	-1.02
Standard deviation	1.15
Standard error mean	0.20
Upper 95% mean	-0.60
Lower 95% mean	-1.43
Sample size	32
Variance	1.32
Skewness	-1.33
Kurtosis	1.08
Coefficient variation	-112.98
Number missing	20
Maximum	0.47
Median	-0.69
Minimum	-3.81
One-sample t-test	-5.01
P-value	<0.0001

Table D-13. Status for the in-treatment change of maxillary Incisor Irregularity (site E).

Variable	Statistic
Arithmetic mean	-1.04
Standard deviation	1.20
Standard error mean	0.21
Upper 95% mean	-0.60
Lower 95% mean	-1.47
Sample size	32
Variance	1.44
Skewness	-1.38
Kurtosis	3.70
Coefficient variation	-115.78
Number missing	20
Maximum	0.64
Median	-0.92
Minimum	-5.30
One-sample t-test	-4.89
P-value	<0.0001

Table D-14. Status for the in-treatment change of maxillary Incisor Irregularity.

Variable	Statistic
Arithmetic mean	-5.02
Standard deviation	3.61
Standard error mean	0.64
Upper 95% mean	-3.72
Lower 95% mean	-6.32
Sample size	32
Variance	13.01
Skewness	-1.07
Kurtosis	0.52
Coefficient variation	-71.88
Number missing	20
Maximum	0.57
Median	-3.93
Minimum	-13.39
One-sample t-test	-7.87
P-value	<0.0001

Table D-15. Status for the in-treatment change of mandibular Incisor Irregularity (site A).

Variable	Statistic
Arithmetic mean	-0.64
Standard deviation	0.89
Standard error mean	0.13
Upper 95% mean	-0.36
Lower 95% mean	-0.91
Sample size	44
Variance	0.80
Skewness	-1.26
Kurtosis	3.05
Coefficient variation	-140.86
Number missing	8
Maximum	0.71
Median	-0.51
Minimum	-3.81
One-sample t-test	-4.71
P-value	<0.0001

Table D-16. Status for the in-treatment change of mandibular Incisor Irregularity (site B).

Variable	Statistic
Arithmetic mean	-0.78
Standard deviation	0.87
Standard error mean	0.13
Upper 95% mean	-0.52
Lower 95% mean	-1.04
Sample size	44
Variance	0.75
Skewness	-0.17
Kurtosis	-0.83
Coefficient variation	-111.33
Number missing	8
Maximum	0.67
Median	-0.72
Minimum	-2.68
One-sample t-test	-5.96
P-value	<0.0001

Table D-17. Status for the in-treatment change of mandibular Incisor Irregularity (site C).

Variable	Statistic
Arithmetic mean	-0.40
Standard deviation	0.64
Standard error mean	0.10
Upper 95% mean	-0.20
Lower 95% mean	-0.59
Sample size	44
Variance	0.41
Skewness	-1.20
Kurtosis	1.76
Coefficient variation	-161.11
Number missing	8
Maximum	0.79
Median	-0.11
Minimum	-2.34
One-sample t-test	-4.12
P-value	0.00

Table D-18. Status for the in-treatment change of mandibular Incisor Irregularity (site D).

Variable	Statistic
Arithmetic mean	-0.47
Standard deviation	0.66
Standard error mean	0.10
Upper 95% mean	-0.27
Lower 95% mean	-0.67
Sample size	44
Variance	0.43
Skewness	-0.92
Kurtosis	0.88
Coefficient variation	-141.35
Number missing	8
Maximum	0.67
Median	-0.47
Minimum	-2.42
One-sample t-test	-4.69
P-value	<0.0001

Table D-19. Status for the in-treatment change of mandibular Incisor Irregularity (site E).

Variable	Statistic
Arithmetic mean	-0.80
Standard deviation	1.06
Standard error mean	0.16
Upper 95% mean	-0.48
Lower 95% mean	-1.13
Sample size	44
Variance	1.12
Skewness	-0.71
Kurtosis	0.82
Coefficient variation	-131.76
Number missing	8
Maximum	0.93
Median	-0.67
Minimum	-4.06
One-sample t-test	-5.03
P-value	<0.0001

Table D-20. Status for the in-treatment change of mandibular Incisor Irregularity.

Variable	Statistic
Arithmetic mean	-3.08
Standard deviation	2.55
Standard error mean	0.38
Upper 95% mean	-2.31
Lower 95% mean	-3.86
Sample size	44
Variance	6.51
Skewness	-0.82
Kurtosis	1.14
Coefficient variation	-82.82
Number missing	8
Maximum	1.09
Median	-2.80
Minimum	-11.36
One-sample t-test	-8.01
P-value	<0.0001

Table D-21. Status for the in-treatment change of maxillary 1-3 chord (right).

Variable	Statistic
Arithmetic mean	0.46
Standard deviation	1.12
Standard error mean	0.18
Upper 95% mean	0.83
Lower 95% mean	0.09
Sample size	38
Variance	1.26
Skewness	1.35
Kurtosis	2.23
Coefficient variation	242.24
Number missing	14
Maximum	4.21
Median	0.19
Minimum	-1.46
One-sample t-test	2.54
P-value	0.02

Table D-22. Status for the in-treatment change of maxillary 1-6 chord (right).

Variable	Statistic
Arithmetic mean	-4.52
Standard deviation	2.85
Standard error mean	0.40
Upper 95% mean	-3.72
Lower 95% mean	-5.32
Sample size	51
Variance	8.12
Skewness	0.12
Kurtosis	-0.70
Coefficient variation	-63.02
Number missing	1
Maximum	1.06
Median	-4.67
Minimum	-10.24
One-sample t-test	-11.33
P-value	<0.0001

Table D-23. Status for the in-treatment change of maxillary 1-3 chord (left).

Variable	Statistic
Arithmetic mean	0.55
Standard deviation	0.97
Standard error mean	0.16
Upper 95% mean	0.88
Lower 95% mean	0.22
Sample size	36
Variance	0.95
Skewness	-0.21
Kurtosis	-0.86
Coefficient variation	177.83
Number missing	16
Maximum	2.18
Median	0.38
Minimum	-1.44
One-sample t-test	3.37
P-value	0.00

Table D-24. Status for the in-treatment change of maxillary 1-6 chord (left).

Variable	Statistic
Arithmetic mean	-4.77
Standard deviation	2.52
Standard error mean	0.36
Upper 95% mean	-4.05
Lower 95% mean	-5.49
Sample size	50
Variance	6.37
Skewness	0.70
Kurtosis	0.18
Coefficient variation	-52.90
Number missing	2
Maximum	1.88
Median	-5.32
Minimum	-9.54
One-sample t-test	-13.37
P-value	<0.0001

Table D-25. Status for the in-treatment change of mandibular 1-3 chord (right).

Variable	Statistic
Arithmetic mean	1.13
Standard deviation	1.24
Standard error mean	0.18
Upper 95% mean	1.48
Lower 95% mean	0.77
Sample size	49
Variance	1.55
Skewness	0.15
Kurtosis	-0.49
Coefficient variation	110.24
Number missing	3
Maximum	3.74
Median	1.11
Minimum	-1.85
One-sample t-test	6.35
P-value	<0.0001

Table D-26. Status for the in-treatment change of mandibular 1-6 chord (right).

Variable	Statistic
Arithmetic mean	-3.78
Standard deviation	2.17
Standard error mean	0.31
Upper 95% mean	-3.15
Lower 95% mean	-4.41
Sample size	48
Variance	4.69
Skewness	1.07
Kurtosis	0.73
Coefficient variation	-57.38
Number missing	4
Maximum	2.29
Median	-4.26
Minimum	-7.48
One-sample t-test	-12.08
P-value	<0.0001

Table D-27. Status for the in-treatment change of mandibular 1-3 chord (left).

Variable	Statistic
Arithmetic mean	0.88
Standard deviation	0.98
Standard error mean	0.14
Upper 95% mean	1.16
Lower 95% mean	0.59
Sample size	47
Variance	0.96
Skewness	0.56
Kurtosis	0.71
Coefficient variation	112.03
Number missing	5
Maximum	3.34
Median	0.67
Minimum	-1.49
One-sample t-test	6.12
P-value	<0.0001

Table D-28. Status for the in-treatment change of mandibular 1-6 chord (left).

Variable	Statistic
Arithmetic mean	-3.96
Standard deviation	2.32
Standard error mean	0.34
Upper 95% mean	-3.28
Lower 95% mean	-4.64
Sample size	47
Variance	5.36
Skewness	0.89
Kurtosis	1.20
Coefficient variation	-58.51
Number missing	5
Maximum	2.70
Median	-4.25
Minimum	-8.69
One-sample t-test	-11.72
P-value	<0.0001

Table D-29. Status for the in-treatment change of maxillary arch depth.

Variable	Statistic
Arithmetic mean	-5.35
Standard deviation	2.91
Standard error mean	0.41
Upper 95% mean	-4.52
Lower 95% mean	-6.17
Sample size	50
Variance	8.50
Skewness	0.01
Kurtosis	-0.62
Coefficient variation	-54.52
Number missing	2
Maximum	0.57
Median	-5.18
Minimum	-11.12
One-sample t-test	-12.97
P-value	<0.0001

Table D-30. Status for the in-treatment change of mandibular arch depth.

Variable	Statistic
Arithmetic mean	-4.04
Standard deviation	2.31
Standard error mean	0.33
Upper 95% mean	-3.37
Lower 95% mean	-4.71
Sample size	48
Variance	5.32
Skewness	0.98
Kurtosis	0.81
Coefficient variation	-57.08
Number missing	4
Maximum	2.31
Median	-4.37
Minimum	-7.79
One-sample t-test	-12.14
P-value	<0.0001

Table D-31. Status for the in-treatment change of maxillary intercanine width.

Variable	Statistic
Arithmetic mean	1.68
Standard deviation	1.63
Standard error mean	0.28
Upper 95% mean	2.23
Lower 95% mean	1.12
Sample size	35
Variance	2.66
Skewness	-0.16
Kurtosis	-1.18
Coefficient variation	97.29
Number missing	17
Maximum	4.49
Median	2.10
Minimum	-1.21
One-sample t-test	6.08
P-value	<0.0001

Table D-32. Status for the in-treatment change of maxillary interpremolar width.

Variable	Statistic
Arithmetic mean	-0.40
Standard deviation	2.29
Standard error mean	0.38
Upper 95% mean	0.36
Lower 95% mean	-1.17
Sample size	37
Variance	5.27
Skewness	0.01
Kurtosis	-0.80
Coefficient variation	-569.89
Number missing	15
Maximum	4.27
Median	0.04
Minimum	-4.77
One-sample t-test	-1.07
P-value	0.29

Table D-33. Status for the in-treatment change of maxillary intermolar width.

Variable	Statistic
Arithmetic mean	-1.27
Standard deviation	2.74
Standard error mean	0.39
Upper 95% mean	-0.49
Lower 95% mean	-2.05
Sample size	50
Variance	7.52
Skewness	-0.57
Kurtosis	2.76
Coefficient variation	-216.18
Number missing	2
Maximum	5.81
Median	-1.18
Minimum	-11.01
One-sample t-test	-3.27
P-value	0.00

Table D-34. Status for the in-treatment change of mandibular intercanine width.

Variable	Statistic
Arithmetic mean	2.15
Standard deviation	1.47
Standard error mean	0.21
Upper 95% mean	2.56
Lower 95% mean	1.73
Sample size	50
Variance	2.16
Skewness	-0.09
Kurtosis	0.42
Coefficient variation	68.55
Number missing	2
Maximum	5.63
Median	2.06
Minimum	-1.85
One-sample t-test	10.32
P-value	<0.0001

Table D-35. Status for the in-treatment change of mandibular interpremolar width.

Variable	Statistic
Arithmetic mean	-0.11
Standard deviation	3.07
Standard error mean	0.47
Upper 95% mean	0.84
Lower 95% mean	-1.07
Sample size	42
Variance	9.41
Skewness	-0.56
Kurtosis	-0.23
Coefficient variation	-2723.97
Number missing	10
Maximum	5.41
Median	0.39
Minimum	-7.81
One-sample t-test	-0.24
P-value	0.81

Table D-36. Status for the in-treatment change of mandibular intermolar width.

Variable	Statistic
Arithmetic mean	-2.18
Standard deviation	2.45
Standard error mean	0.35
Upper 95% mean	-1.48
Lower 95% mean	-2.88
Sample size	49
Variance	5.99
Skewness	0.29
Kurtosis	1.16
Coefficient variation	-112.13
Number missing	3
Maximum	4.69
Median	-2.20
Minimum	-8.70
One-sample t-test	-6.24
P-value	<0.0001

APPENDIX E.

**STATISTICAL TABLES DESCRIBING CHANGES OF THE OCCLUSAL
VARIABLES FROM THE END OF TREATMENT TO THE RECALL
EXAMINATION**

Table E-1. Post-treatment changes in overbite.

Variable	Statistic
Arithmetic mean	0.74
Standard deviation	1.13
Standard error mean	0.16
Upper 95% mean	1.06
Lower 95% mean	0.42
Sample size	50
Variance	1.28
Skewness	0.13
Kurtosis	-0.20
Coefficient variation	153.05
Number missing	2
Maximum	3.40
Median	0.61
Minimum	-1.63
One-sample t-test	4.62
P-value	<0.0001

Table E-2. Post-treatment changes in overjet.

Variable	Statistic
Arithmetic mean	0.85
Standard deviation	0.82
Standard error mean	0.12
Upper 95% mean	1.08
Lower 95% mean	0.62
Sample size	50
Variance	0.67
Skewness	0.38
Kurtosis	-0.11
Coefficient variation	96.43
Number missing	2
Maximum	2.65
Median	
Minimum	-0.76
One-sample t-test	7.33
P-value	<0.0001

Table E-3. Post-treatment changes in dental midline.

Variable	Statistic
Arithmetic mean	0.12
Standard deviation	0.58
Standard error mean	0.08
Upper 95% mean	0.28
Lower 95% mean	-0.05
Sample size	50
Variance	0.34
Skewness	-0.64
Kurtosis	0.72
Coefficient variation	502.68
Number missing	2
Maximum	1.35
Median	0.06
Minimum	-1.63
One-sample t-test	1.41
P-value	0.1658

Table E-4. Post-treatment changes in the absolute value of the dental midline.

Variable	Statistic
Arithmetic mean	0.43
Standard deviation	0.38
Standard error mean	0.05
Upper 95% mean	0.53
Lower 95% mean	0.32
Sample size	54
Variance	0.15
Skewness	0.76
Kurtosis	0.56
Coefficient variation	88.83
Number missing	2
Maximum	1.63
Median	0.43
Minimum	0.00
One-sample t-test	8.27
P-value	<0.0001

Table E-5. Post-treatment changes in buccal segment relationship (right).

Variable	Statistic
Arithmetic mean	-0.17
Standard deviation	0.98
Standard error mean	0.15
Upper 95% mean	0.12
Lower 95% mean	-0.47
Sample size	45
Variance	0.97
Skewness	0.49
Kurtosis	5.86
Coefficient variation	-572.89
Number missing	7
Maximum	3.67
Median	0.00
Minimum	-3.01
One-sample t-test	-1.17
P-value	0.2479

Table E-6. Post-treatment changes in canine relationship (right).

Variable	Statistic
Arithmetic mean	0.17
Standard deviation	1.16
Standard error mean	0.16
Upper 95% mean	0.50
Lower 95% mean	-0.16
Sample size	51
Variance	1.35
Skewness	-0.37
Kurtosis	2.05
Coefficient variation	685.15
Number missing	1
Maximum	3.07
Median	0.07
Minimum	-3.71
One-sample t-test	1.04
P-value	0.3023

Table E-7. Post-treatment changes in buccal segment relationship (left).

Variable	Statistic
Arithmetic mean	-0.25
Standard deviation	0.65
Standard error mean	0.09
Upper 95% mean	-0.06
Lower 95% mean	-0.43
Sample size	48
Variance	0.42
Skewness	0.21
Kurtosis	1.44
Coefficient variation	-261.57
Number missing	4
Maximum	1.78
Median	0.00
Minimum	-1.78
One-sample t-test	-2.65
P-value	0.011

Table E-8. Post-treatment changes in canine relationship (left).

Variable	Statistic
Arithmetic mean	0.00
Standard deviation	1.08
Standard error mean	0.15
Upper 95% mean	0.31
Lower 95% mean	-0.30
Sample size	51
Variance	1.17
Skewness	-1.10
Kurtosis	0.84
Coefficient variation	39448.84
Number missing	1
Maximum	1.45
Median	0.00
Minimum	-3.14
One-sample t-test	0.02
P-value	0.9856

Table E-9. Post-treatment changes in maxillary Incisor Irregularity (site A).

Variable	Statistic
Arithmetic mean	-0.04
Standard deviation	0.59
Standard error mean	0.08
Upper 95% mean	0.13
Lower 95% mean	-0.20
Sample size	50
Variance	0.35
Skewness	0.41
Kurtosis	1.73
Coefficient variation	-1614.11
Number missing	2
Maximum	1.86
Median	0.00
Minimum	-1.48
One-sample t-test	-0.44
P-value	0.6633

Table E-10. Post-treatment changes in maxillary Incisor Irregularity (site B).

Variable	Statistic
Arithmetic mean	0.08
Standard deviation	0.54
Standard error mean	0.08
Upper 95% mean	0.24
Lower 95% mean	-0.07
Sample size	50
Variance	0.29
Skewness	-0.47
Kurtosis	1.75
Coefficient variation	646.14
Number missing	2
Maximum	1.29
Median	0.00
Minimum	-1.76
One-sample t-test	1.09
P-value	0.2791

Table E-11. Post-treatment changes in maxillary Incisor Irregularity (site C).

Variable	Statistic
Arithmetic mean	0.20
Standard deviation	0.57
Standard error mean	0.08
Upper 95% mean	0.37
Lower 95% mean	0.04
Sample size	50
Variance	0.32
Skewness	0.99
Kurtosis	1.58
Coefficient variation	279.16
Number missing	2
Maximum	1.97
Median	0.00
Minimum	-0.86
One-sample t-test	2.53
P-value	0.0146

Table E-12. Post-treatment changes in maxillary Incisor Irregularity (site D).

Variable	Statistic
Arithmetic mean	0.18
Standard deviation	0.45
Standard error mean	0.06
Upper 95% mean	0.31
Lower 95% mean	0.05
Sample size	50
Variance	0.20
Skewness	0.49
Kurtosis	0.40
Coefficient variation	249.02
Number missing	2
Maximum	1.34
Median	0.05
Minimum	-0.80
One-sample t-test	2.84
P-value	0.0066

Table E-13. Post-treatment changes in maxillary Incisor Irregularity (site E).

Variable	Statistic
Arithmetic mean	-0.02
Standard deviation	0.53
Standard error mean	0.07
Upper 95% mean	0.13
Lower 95% mean	-0.17
Sample size	50
Variance	0.28
Skewness	-0.11
Kurtosis	-0.65
Coefficient variation	-3215.31
Number missing	2
Maximum	1.11
Median	0.02
Minimum	-1.11
One-sample t-test	-0.22
P-value	0.8268

Table E-14. Post-treatment changes in maxillary Incisor Irregularity.

Variable	Statistic
Arithmetic mean	0.41
Standard deviation	1.39
Standard error mean	0.20
Upper 95% mean	0.81
Lower 95% mean	0.02
Sample size	50
Variance	1.94
Skewness	-0.12
Kurtosis	-0.74
Coefficient variation	337.30
Number missing	2
Maximum	3.09
Median	0.52
Minimum	-2.53
One-sample t-test	2.10
P-value	0.0412

Table E-15. Post-treatment changes in mandibular Incisor Irregularity (site A).

Variable	Statistic
Arithmetic mean	0.13
Standard deviation	0.74
Standard error mean	0.11
Upper 95% mean	0.35
Lower 95% mean	-0.09
Sample size	45
Variance	0.54
Skewness	1.11
Kurtosis	2.65
Coefficient variation	552.38
Number missing	7
Maximum	2.72
Median	0.00
Minimum	-1.18
One-sample t-test	1.21
P-value	0.2311

Table E-16. Post-treatment changes in mandibular Incisor Irregularity (site B).

Variable	Statistic
Arithmetic mean	0.27
Standard deviation	0.51
Standard error mean	0.08
Upper 95% mean	0.42
Lower 95% mean	0.12
Sample size	45
Variance	0.26
Skewness	1.02
Kurtosis	2.26
Coefficient variation	186.33
Number missing	7
Maximum	1.87
Median	0.25
Minimum	-0.67
One-sample t-test	3.60
P-value	0.0008

Table E-17. Post-treatment changes in mandibular Incisor Irregularity (site C).

Variable	Statistic
Arithmetic mean	0.38
Standard deviation	0.49
Standard error mean	0.07
Upper 95% mean	0.53
Lower 95% mean	0.23
Sample size	45
Variance	0.24
Skewness	2.07
Kurtosis	5.72
Coefficient variation	128.73
Number missing	7
Maximum	2.25
Median	0.31
Minimum	-0.45
One-sample t-test	5.21
P-value	<0.0001

Table E-18. Post-treatment changes in mandibular Incisor Irregularity (site D).

Variable	Statistic
Arithmetic mean	0.17
Standard deviation	0.43
Standard error mean	0.06
Upper 95% mean	0.30
Lower 95% mean	0.04
Sample size	45
Variance	0.18
Skewness	0.35
Kurtosis	-0.37
Coefficient variation	249.03
Number missing	7
Maximum	1.20
Median	0.01
Minimum	-0.67
One-sample t-test	2.69
P-value	0.0100

Table E-19. Post-treatment changes in mandibular Incisor Irregularity (site E).

Variable	Statistic
Arithmetic mean	0.13
Standard deviation	0.48
Standard error mean	0.07
Upper 95% mean	0.28
Lower 95% mean	-0.01
Sample size	45
Variance	0.23
Skewness	0.19
Kurtosis	-0.46
Coefficient variation	366.36
Number missing	7
Maximum	1.17
Median	0.00
Minimum	-0.78
One-sample t-test	1.83
P-value	0.0739

Table E-20. Post-treatment changes in mandibular Incisor Irregularity.

Variable	Statistic
Arithmetic mean	1.09
Standard deviation	1.40
Standard error mean	0.21
Upper 95% mean	1.51
Lower 95% mean	0.67
Sample size	45
Variance	1.95
Skewness	0.88
Kurtosis	0.42
Coefficient variation	128.43
Number missing	7
Maximum	4.74
Median	0.75
Minimum	-0.99
One-sample t-test	5.22
P-value	<0.0001

Table E-21. Post-treatment changes in maxillary 1-3 chord (right).

Variable	Statistic
Arithmetic mean	-0.38
Standard deviation	0.65
Standard error mean	0.09
Upper 95% mean	-0.20
Lower 95% mean	-0.56
Sample size	51
Variance	0.42
Skewness	-0.34
Kurtosis	0.59
Coefficient variation	-168.97
Number missing	1
Maximum	0.99
Median	-0.29
Minimum	-2.12
One-sample t-test	-4.23
P-value	0.0001

Table E-22. Post-treatment changes in maxillary 1-6 chord (right).

Variable	Statistic
Arithmetic mean	-0.91
Standard deviation	0.94
Standard error mean	0.13
Upper 95% mean	-0.65
Lower 95% mean	-1.18
Sample size	50
Variance	0.89
Skewness	-0.05
Kurtosis	1.16
Coefficient variation	-103.18
Number missing	2
Maximum	1.42
Median	-1.12
Minimum	-3.76
One-sample t-test	-6.85
P-value	<0.0001

Table E-23. Post-treatment changes in maxillary 1-3 chord (left).

Variable	Statistic
Arithmetic mean	-0.35
Standard deviation	0.95
Standard error mean	0.13
Upper 95% mean	-0.08
Lower 95% mean	-0.61
Sample size	51
Variance	0.89
Skewness	2.22
Kurtosis	9.45
Coefficient variation	-271.26
Number missing	1
Maximum	4.13
Median	-0.35
Minimum	-2.00
One-sample t-test	-2.63
P-value	0.0112

Table E-24. Post-treatment changes in maxillary 1-6 chord (left).

Variable	Statistic
Arithmetic mean	-1.07
Standard deviation	0.78
Standard error mean	0.11
Upper 95% mean	-0.85
Lower 95% mean	-1.30
Sample size	50
Variance	0.61
Skewness	-0.34
Kurtosis	0.47
Coefficient variation	-72.46
Number missing	2
Maximum	0.32
Median	-1.05
Minimum	-3.49
One-sample t-test	-9.76
P-value	<0.0001

Table E-25. Post-treatment changes in mandibular 1-3 chord (right).

Variable	Statistic
Arithmetic mean	-0.87
Standard deviation	0.54
Standard error mean	0.08
Upper 95% mean	-0.71
Lower 95% mean	-1.02
Sample size	50
Variance	0.29
Skewness	-0.25
Kurtosis	-0.78
Coefficient variation	-62.47
Number missing	2
Maximum	0.15
Median	-0.74
Minimum	-2.00
One-sample t-test	-11.32
P-value	<0.0001

Table E-26. Post-treatment changes in mandibular 1-6 chord (right).

Variable	Statistic
Arithmetic mean	-1.23
Standard deviation	0.76
Standard error mean	0.11
Upper 95% mean	-1.01
Lower 95% mean	-1.45
Sample size	48
Variance	0.58
Skewness	-0.17
Kurtosis	0.39
Coefficient variation	-61.67
Number missing	4
Maximum	0.42
Median	-1.07
Minimum	-3.29
One-sample t-test	-11.23
P-value	<0.0001

Table E-27. Post-treatment changes in mandibular 1-3 chord (left).

Variable	Statistic
Arithmetic mean	-0.82
Standard deviation	0.54
Standard error mean	0.08
Upper 95% mean	-0.67
Lower 95% mean	-0.98
Sample size	48
Variance	0.29
Skewness	-0.27
Kurtosis	0.04
Coefficient variation	-64.91
Number missing	4
Maximum	0.46
Median	-0.74
Minimum	-2.12
One-sample t-test	-10.67
P-value	<0.0001

Table E-28. Post-treatment changes in mandibular 1-6 chord (left).

Variable	Statistic
Arithmetic mean	-1.32
Standard deviation	0.74
Standard error mean	0.11
Upper 95% mean	-1.10
Lower 95% mean	-1.53
Sample size	47
Variance	0.55
Skewness	-0.33
Kurtosis	0.90
Coefficient variation	-56.41
Number missing	5
Maximum	0.65
Median	-1.24
Minimum	-3.13
One-sample t-test	-12.15
P-value	<0.0001

Table E-29. Post-treatment changes in maxillary arch depth.

Variable	Statistic
Arithmetic mean	-1.31
Standard deviation	1.13
Standard error mean	0.16
Upper 95% mean	-0.98
Lower 95% mean	-1.64
Sample size	49
Variance	1.28
Skewness	0.78
Kurtosis	1.64
Coefficient variation	-86.52
Number missing	3
Maximum	2.20
Median	-1.42
Minimum	-3.77
One-sample t-test	-8.09
P-value	<0.0001

Table E-30. Post-treatment changes in mandibular arch depth.

Variable	Statistic
Arithmetic mean	-1.32
Standard deviation	1.83
Standard error mean	0.26
Upper 95% mean	-0.79
Lower 95% mean	-1.85
Sample size	48
Variance	3.33
Skewness	4.23
Kurtosis	24.21
Coefficient variation	-138.63
Number missing	4
Maximum	9.25
Median	-1.55
Minimum	-3.84
One-sample t-test	-5.00
P-value	<0.0001

Table E-31. Post-treatment changes in maxillary intercanine width.

Variable	Statistic
Arithmetic mean	-0.74
Standard deviation	0.87
Standard error mean	0.12
Upper 95% mean	-0.50
Lower 95% mean	-0.99
Sample size	51
Variance	0.76
Skewness	0.01
Kurtosis	2.18
Coefficient variation	-117.73
Number missing	1
Maximum	1.85
Median	-0.67
Minimum	-3.45
One-sample t-test	-6.07
P-value	<0.0001

Table E-32. Post-treatment changes in maxillary interpremolar width.

Variable	Statistic
Arithmetic mean	-0.70
Standard deviation	1.02
Standard error mean	0.14
Upper 95% mean	-0.41
Lower 95% mean	-0.98
Sample size	51
Variance	1.04
Skewness	0.01
Kurtosis	-0.38
Coefficient variation	-145.87
Number missing	1
Maximum	1.76
Median	-0.67
Minimum	-2.70
One-sample t-test	-4.90
P-value	<0.0001

Table E-33. Post-treatment changes in maxillary intermolar width.

Variable	Statistic
Arithmetic mean	-0.29
Standard deviation	1.72
Standard error mean	0.25
Upper 95% mean	0.21
Lower 95% mean	-0.78
Sample size	49
Variance	2.95
Skewness	-1.46
Kurtosis	4.94
Coefficient variation	-600.22
Number missing	3
Maximum	2.83
Median	-0.23
Minimum	-7.37
One-sample t-test	-1.17
P-value	0.2493

Table E-34. Post-treatment changes in mandibular intercanine width.

Variable	Statistic
Arithmetic mean	-1.19
Standard deviation	1.43
Standard error mean	0.20
Upper 95% mean	-0.78
Lower 95% mean	-1.59
Sample size	51
Variance	2.06
Skewness	1.83
Kurtosis	8.10
Coefficient variation	-121.03
Number missing	1
Maximum	5.39
Median	-1.36
Minimum	-4.33
One-sample t-test	-5.90
P-value	<0.0001

Table E-35. Post-treatment changes in mandibular interpremolar width.

Variable	Statistic
Arithmetic mean	-0.69
Standard deviation	1.28
Standard error mean	0.18
Upper 95% mean	-0.33
Lower 95% mean	-1.05
Sample size	51
Variance	1.64
Skewness	0.69
Kurtosis	1.00
Coefficient variation	-185.09
Number missing	1
Maximum	3.46
Median	-0.83
Minimum	-3.29
One-sample t-test	-3.86
P-value	0.0003

Table E-36. Post-treatment changes in mandibular intermolar width.

Variable	Statistic
Arithmetic mean	0.21
Standard deviation	1.45
Standard error mean	0.21
Upper 95% mean	0.62
Lower 95% mean	-0.21
Sample size	49
Variance	2.09
Skewness	0.75
Kurtosis	2.19
Coefficient variation	697.22
Number missing	3
Maximum	5.32
Median	-0.04
Minimum	-3.18
One-sample t-test	1.00
P-value	0.3204

APPENDIX F.

**FIGURES PLOTTING THE CHANGE IN OCCLUSAL VARIABLES AT THE
THREE EXAMINATIONS**

Figure F-1. Plot of the maxillary and mandibular change in Incisor Irregularity at all three examinations. Error bars are $\pm$ one standard deviation.

Figure F-2. Plot of the maxillary and mandibular change in intercanine width at all three examinations. Error bars are $\pm$ one standard deviation.

Figure F-3. Plot of the maxillary and mandibular change in interpremolar width at all three examinations. Error bars are $\pm$ one standard deviation.

Figure F-4. Plot of the maxillary and mandibular change in intermolar width at all three examinations. Error bars are $\pm$ one standard deviation.

Figure F-5. Plot of the left and right change in maxillary incisor-to-canine arch chord at all three examinations. Error bars are $\pm$ one standard deviation.

Figure F-6. Plot of the left and right change in mandibular incisor-to-canine arch chord at all three examinations. Error bars are $\pm$ one standard deviation.

Figure F-7. Plot of the left and right change in maxillary incisor-to-molar arch chord at all three examinations. Error bars are $\pm$ one standard deviation.

Figure F-8. Plot of the left and right change in mandibular incisor-to-molar arch chord at all three examinations. Error bars are $\pm$ one standard deviation.

Figure F-9. Plot of the maxillary and mandibular change in arch depth at all three examinations. Error bars are $\pm$ one standard deviation.

Figure F-10. Plot of the change in overjet at all three examinations. Error bars are $\pm$ one standard deviation.

Figure F-11. Plot of the change in overbite at all three examinations. Error bars are $\pm$ one standard deviation.

Figure F-12. Plot of the change in midline discrepancy at all three examinations. Error bars are $\pm$ one standard deviation.

Figure F-13. Plot of the change in the absolute value of the midline discrepancy at all three examinations. Error bars are $\pm$ one standard deviation.

Figure F-14. Plot of the left and right change in buccal segment relationship at all three examinations. Error bars are $\pm$ one standard deviation.

Figure F-15. Plot of the left and right change in canine relationship at all three examinations. Error bars are $\pm$ one standard deviation.

APPENDIX G.

**TABLES OF REGRESSION ANALYSES BETWEEN THE IN-TREATMENT
AND POSTTREATMENT CHANGES IN OCCLUSAL VARIABLES**

Table G-1. Results of regressing the posttreatment change in maxillary Incisor Irregularity on the treatment change in maxillary Incisor Irregularity.

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	9.198	9.198	5.27	
Error	30	52.387	1.746		
Corr. total	31	61.585			0.0289

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	-0.476	0.404	-1.18	0.2486
Max inc irreg tx	-0.151	0.066	-2.30	0.0289

Table G-2. Results of regressing the posttreatment change in mandibular Incisor Irregularity on the treatment change in mandibular Incisor Irregularity.

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	9.283	9.283	5.15	
Error	42	75.712	1.803		
Corr. total	43	84.995			0.0285

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	0.506	0.320	1.58	0.1209
Mand inc irreg tx	-0.182	0.080	-2.27	0.0285

Table G-3. Results of regressing the posttreatment change in mandibular intercanine width on the treatment change in mandibular intercanine width.

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	14.661	14.661	8.01	
Error	48	87.881	1.831		
Corr. total	47	102.541			0.0068

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	-0.375	0.341	-1.10	0.2760
Mand intermolar tx	-0.372	0.131	-2.83	0.0068

Table G-4. Results of regressing the posttreatment change in maxillary intercanine width on the treatment change in maxillary intercanine width.

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	2.195	2.195	5.11	
Error	33	14.186	0.430		
Corr. total	34	16.381			0.0306

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	-0.544	0.160	-3.40	0.0018
Max intercanine tx	-0.156	0.069	-2.26	0.0306

Table G-5. Results of regressing the posttreatment change in maxillary interpremolar width on the treatment change in maxillary interpremolar width.

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	0.906	0.906	0.96	
Error	35	33.121	0.946		
Corr. total	36	34.027			0.3346

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	-0.645	0.162	-3.97	0.0003
Max interpremolar tx	-0.069	0.071	-0.98	0.3346

Table G-6. Results of regressing the posttreatment change in mandibular interpremolar width on the treatment change in mandibular interpremolar width.

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	1.380	1.380	0.79	
Error	40	69.458	1.736		
Corr. total	41	70.838			0.3780

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	-0.623	0.203	-3.06	0.0039
Mand interpremolar tx	-0.060	0.067	-0.89	0.3780

Table G-7. Results of regressing the posttreatment change in maxillary intermolar width on the treatment change in maxillary intermolar width.

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	64.428	64.428	39.26	
Error	47	77.139	1.641		
Corr. total	48	141.567			<0.0001

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	-0.812	0.201	-4.03	0.0002
Max intermolar tx	-0.418	0.067	-6.27	<0.0001

Table G-8. Results of regressing the posttreatment change in mandibular intermolar width on the treatment change in mandibular intermolar width.

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	22.113	22.113	13.29	
Error	47	78.203	1.664		
Corr. total	48	100.316			0.0007

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	-0.398	0.248	-1.60	0.1153
Mand intermolar tx	-0.277	0.076	-3.65	0.0007

Table G-9. Results of regressing the posttreatment change in maxillary chord 1-3 (left) on the treatment change in maxillary chord 1-3 (left).

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	0.421	0.421	0.37	
Error	34	38.942	1.145		
Corr. total	35	39.363			0.5486

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	-0.336	0.205	-1.64	0.1109
Max chord 1-3 tx	-0.113	0.186	-0.61	0.5486

Table G-10. Results of regressing the posttreatment change in mandibular chord 1-3 (left) on the treatment change in mandibular chord 1-3 (left).

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	1.794	1.794	6.92	
Error	45	11.661	0.259		
Corr. total	46	13.455			0.0116

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	-0.650	0.100	-6.50	<0.0001
Mand chord 1-3 tx	-0.201	0.076	-2.63	0.0116

Table G-11. Results of regressing the posttreatment change in maxillary chord 1-6 (left) on the treatment change in maxillary chord 1-6 (left).

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	3.987	3.987	7.45	
Error	48	25.685	0.535		
Corr. total	49	29.673			0.0088

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	-1.613	0.223	-7.23	<0.0001
Max chord 1-6 tx	-0.113	0.041	-2.73	0.0088

Table G-12. Results of regressing the posttreatment change in mandibular chord 1-6 (left) on the treatment change in mandibular chord 1-6 (left).

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	1.101	1.101	2.05	
Error	45	24.213	0.538		
Corr. total	46	25.314			0.1595

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	-1.580	0.214	-7.40	<0.0001
Mand chord 1-6 tx	-0.067	0.047	-1.43	0.1595

Table G-13. Results of regressing the posttreatment change in maxillary arch depth on the treatment change in maxillary arch depth.

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	8.787	8.787	7.81	
Error	47	52.878	1.125		
Corr. total	48	61.665			0.0075

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	-2.084	0.316	-6.60	<0.0001
Max arch depth tx	-0.146	0.052	-2.79	0.0075

Table G-14. Results of regressing the posttreatment change in mandibular arch depth on the treatment change in mandibular arch depth.

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	1.962	1.962	0.58	
Error	46	154.584	3.360		
Corr. total	47	156.546			0.4487

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	-1.674	0.538	-3.11	0.0032
Max arch depth tx	-0.089	0.116	-0.76	0.4487

Table G-15. Results of regressing the posttreatment change in overjet on the treatment change in overjet.

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	5.041	5.041	8.69	
Error	48	27.849	0.580		
Corr. total	49	32.889			0.0049

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	0.328	0.207	1.58	0.1207
Overjet tx	0.164	0.056	-2.95	0.0049

Table G-16. Results of regressing the posttreatment change in overbite on the treatment change in overbite.

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	18.619	18.619	20.26	
Error	48	44.102	0.919		
Corr. total	49	62.720			<0.0001

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	0.196	0.181	1.08	0.2847
Overbite tx	-0.408	0.091	-4.50	<0.0001

Table G-17. Results of regressing the posttreatment change in midline deviation on the treatment change in midline deviation using absolute values.

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	0.213	0.213	1.47	
Error	52	7.53	0.145		
Corr. total	53	7.740			0.2311

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	0.512	0.085	6.01	<0.0001
Midline tx	-0.065	0.054	-1.21	0.2311

Table G-18. Results of regressing the posttreatment change in buccal segment relationship (left) on the treatment change in buccal segment relationship (left).

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	0.935	0.935	2.30	
Error	46	18.697	0.406		
Corr. total	47	19.632			0.1362

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	-0.134	0.118	-1.13	0.2623
BSR tx	-0.081	0.053	-1.52	0.1362

Table G-19. Results of regressing the posttreatment change in canine relationship (left) on the treatment change in canine relationship (left).

Source	df	SSQ	Mean square	F-ratio	P-value
Model	1	2.185	2.185	2.19	
Error	35	34.849	0.996		
Corr. total	36	37.033			0.1475

Parameter Estimates

Term	Estimate	St error	t-test	P-value
Intercept	0.246	0.190	1.29	0.2047
Canine tx	-0.098	0.066	-1.48	0.1475

APPENDIX H.

FIGURES OF REGRESSION ANALYSES BETWEEN THE IN-TREATMENT AND POSTTREATMENT CHANGES IN OCCLUSAL VARIABLES

Figure H-1. Plot of the association between the posttreatment change in maxillary Incisor Irregularity on the treatment change in maxillary Incisor Irregularity.

Figure H-2. Plot of the association between the posttreatment change in mandibular Incisor Irregularity on the treatment change in mandibular Incisor Irregularity.

Figure H-3. Plot of the association between the posttreatment change in mandibular intercanine width on the treatment change in mandibular intercanine width.

Figure H-4. Plot of the association between the posttreatment change in maxillary intercanine width on the treatment change in maxillary intercanine width.

Figure H-5. Plot of the association between the posttreatment change in maxillary interpremolar width on the treatment change in maxillary interpremolar width.

Figure H-6. Plot of the association between the posttreatment change in mandibular interpremolar width on the treatment change in mandibular interpremolar width.

Figure H-7. Plot of the association between the posttreatment change in maxillary intermolar width on the treatment change in maxillary intermolar width.

Figure H-8. Plot of the association between the posttreatment change in mandibular intermolar width on the treatment change in mandibular intermolar width.

Figure H-9. Plot of the association between the posttreatment change in maxillary incisor-to-canine chord on the treatment change in maxillary incisor-to-canine chord.

Figure H-10. Plot of the association between the posttreatment change in mandibular incisor-to-canine chord on the treatment change in mandibular incisor-to-canine chord.

Figure H-11. Plot of the association between the posttreatment change in maxillary incisor-to-molar chord on the treatment change in maxillary incisor-to-molar chord.

Figure H-12. Plot of the association between the posttreatment change in mandibular incisor-to-molar chord on the treatment change in mandibular incisor-to-molar chord.

Figure H-13. Plot of the association between the posttreatment change in maxillary arch depth on the treatment change in maxillary arch depth.

Figure H-14. Plot of the association between the posttreatment change in overjet on the treatment change in overjet.

Figure H-15. Plot of the association between the posttreatment change in overbite on the treatment change in overbite.

Figure H-16. Plot of the association between the posttreatment change in midline deviation on the treatment change in midline deviation.

Figure H-17. Plot of the association between the posttreatment change in buccal segment relationship on the treatment change in buccal segment relationship.

Figure H-18. Plot of the association between the posttreatment change in canine relationship on the treatment change in canine relationship.

APPENDIX I.

**TABLES OF PAIRED T-TESTS EVALUATING DIRECTIONAL
ASYMMETRY AT EACH EXAMINATION**

Table I-1. Results of paired t-tests of whether there is evidence of directional asymmetry in the extent of malocclusion at the pretreatment examination.

Variable	Left side	Right side	Side difference	se _d	n	t-test	P-value
Buccal segment relationship	-1.25	-1.51	0.26	0.216	50	1.19	0.2404
Canine relationship	-2.27	-2.91	0.64	0.383	36	1.67	0.1048
Canine-lateral incisor contact (Mx)	1.45	1.75	-0.29	0.297	33	-0.99	0.3283
Lateral-central incisor contact (Mx)	1.32	1.60	-0.28	0.297	33	-0.95	0.3494
Canine-lateral incisor contact (Md)	1.17	1.12	0.05	0.157	51	0.34	0.7359
Lateral-central incisor contact (Md)	0.72	0.94	-0.22	0.121	51	-1.86	0.0693
Chord distance 1-3 (Mx)	22.85	23.01	-0.16	0.184	34	-0.88	0.3868
Chord distance 1-6 (Mx)	44.99	44.92	0.06	0.229	51	0.28	0.7785
Chord distance 1-3 (Md)	17.24	17.02	0.22	0.111	51	2.01	0.0499
Chord distance 1-6 (Md)	40.41	40.00	0.41	0.193	50	2.11	0.0402

Table I-2. Results of paired t-tests of whether there is evidence of directional asymmetry in the extent of malocclusion at the posttreatment examination.

Variable	Left side	Right side	Side difference	se _d	n	t-test	P-value
Buccal segment relationship	0.18	0.13	0.05	0.099	46	0.50	0.6225
Canine relationship	-0.60	-0.90	0.31	0.163	51	1.87	0.0671
Canine-lateral incisor contact (Mx)	0.43	0.46	-0.03	0.069	50	-0.44	0.6637
Lateral-central incisor contact (Mx)	0.30	0.22	0.09	0.056	50	1.54	0.1308
Canine-lateral incisor contact (Md)	0.41	0.47	-0.06	0.086	45	-0.69	0.4962
Lateral-central incisor contact (Md)	0.23	0.21	0.02	0.046	45	0.41	0.6820
Chord distance 1-3 (Mx)	23.39	23.49	-0.10	0.063	51	-1.61	0.1147
Chord distance 1-6 (Mx)	40.26	40.38	-0.13	0.182	50	-0.69	0.4909
Chord distance 1-3 (Md)	18.20	18.24	-0.04	0.060	48	-0.60	0.5518
Chord distance 1-6 (Md)	36.65	36.42	0.23	0.107	46	2.14	0.0377

Table I-3. Results of paired t-tests of whether there is evidence of directional asymmetry in the extent of malocclusion at the recall examination.

Variable	Left side	Right side	Side difference	se _d	n	t-test	P-value
Buccal segment relationship	-0.06	-0.05	-0.01	0.122	46	-0.05	0.9590
Canine relationship	-0.58	-0.75	0.17	0.162	52	1.04	0.3018
Canine-lateral incisor contact (Mx)	0.43	0.42	0.01	0.076	52	0.12	0.9023
Lateral-central incisor contact (Mx)	0.48	0.35	0.13	0.076	52	1.76	0.0846
Canine-lateral incisor contact (Md)	0.55	0.63	-0.08	0.117	52	-0.67	0.5035
Lateral-central incisor contact (Md)	0.40	0.49	-0.09	0.072	52	-1.30	0.2010
Chord distance 1-3 (Mx)	23.01	23.08	-0.07	0.125	52	-0.53	0.6014
Chord distance 1-6 (Mx)	39.11	39.42	-0.31	0.168	50	-1.85	0.0709
Chord distance 1-3 (Md)	17.28	17.28	0.00	0.089	52	0.00	1.0000
Chord distance 1-6 (Md)	35.09	34.97	0.12	0.139	50	0.86	0.3945

Table I-4. Results of paired t-tests of whether there is evidence of directional asymmetry in the extent of malocclusion for the in-treatment changes.

Variable	Left side	Right side	Side difference	se _d	n	t-test	P-value
Buccal segment relationship	1.34	1.54	-0.20	0.236	46	-0.83	0.4084
Canine relationship	1.51	2.05	-0.54	0.422	35	-1.28	0.2097
Canine-lateral incisor contact (Mx)	-1.04	-1.30	0.27	0.317	32	0.84	0.4086
Lateral-central incisor contact (Mx)	-1.02	-1.20	0.18	0.285	32	0.64	0.5256
Canine-lateral incisor contact (Md)	-0.80	-0.64	-0.17	0.178	44	-0.95	0.3487
Lateral-central incisor contact (Md)	-0.47	-0.78	0.31	0.137	44	2.28	0.0276
Chord distance 1-3 (Mx)	0.50	0.49	0.01	0.173	34	0.07	0.9450
Chord distance 1-6 (Mx)	-4.77	-4.51	-0.26	0.249	50	-1.04	0.3055
Chord distance 1-3 (Md)	0.88	1.13	-0.25	0.132	47	-1.92	0.0612
Chord distance 1-6 (Md)	-3.96	-3.78	-0.19	0.192	46	-0.98	0.3322

Table I-5. Results of paired t-tests of whether there is evidence of directional asymmetry in the extent of malocclusion for the posttreatment changes.

Variable	Left side	Right side	Side difference	se _d	n	t-test	P-value
Buccal segment relationship	-0.25	-0.17	-0.07	0.156	45	-0.48	0.6356
Canine relationship	0.00	0.17	-0.17	0.181	51	-0.92	0.3609
Canine-lateral incisor contact (Mx)	-0.02	-0.04	0.02	0.097	50	0.21	0.8360
Lateral-central incisor contact (Mx)	0.18	0.08	0.10	0.094	50	1.01	0.3161
Canine-lateral incisor contact (Md)	0.13	0.13	0.00	0.116	45	-0.01	0.9924
Lateral-central incisor contact (Md)	0.17	0.27	-0.10	0.086	45	-1.16	0.2507
Chord distance 1-3 (Mx)	-0.35	-0.38	0.03	0.132	51	0.26	0.7973
Chord distance 1-6 (Mx)	-1.09	-0.91	-0.19	0.107	49	-1.74	0.0889
Chord distance 1-3 (Md)	-0.82	-0.89	0.06	0.086	48	0.74	0.4623
Chord distance 1-6 (Md)	-1.32	-1.24	-0.08	0.130	46	-0.63	0.5324

APPENDIX J.

**TABLE OF BIVARIATE CORRELATIONS BETWEEN THE AMOUNTS OF
POSTTREATMENT CHANGE**

Table J-1. Listing of bivariate correlations between the amounts of posttreatment change of the variables taken pair-wise.

Bivariate correlation		Correlation	n	P-value
Variable 1	Variable 2			
Overjet	Overbite	0.2739	50	0.0542
Overjet	Overbite	0.2739	50	0.0542
Midline	Overbite	0.1648	50	0.2527
Midline	Overjet	0.1016	50	0.4828
BSR L	Overbite	-0.2972	47	0.0425
BSR L	Overjet	-0.2310	47	0.1182
BSR L	Midline	0.1061	47	0.4780
Canine L	Overbite	-0.1863	50	0.1952
Canine L	Overjet	0.0035	50	0.9809
Canine L	Midline	0.0398	50	0.7840
Canine L	BSR L	0.2797	48	0.0541
U IncIrreg	Overbite	0.0398	49	0.7860
U IncIrreg	Overjet	0.2524	49	0.0802
U IncIrreg	Midline	0.1186	49	0.4168
U IncIrreg	BSR L	0.0132	47	0.9299
U IncIrreg	Canine L	-0.0465	50	0.7483
L IncIrreg	Overbite	0.0013	45	0.9932
L IncIrreg	Overjet	0.2801	45	0.0624
L IncIrreg	Midline	0.0626	45	0.6829
L IncIrreg	BSR L	0.0383	43	0.8076
L IncIrreg	Canine L	0.1238	45	0.4179
L IncIrreg	U IncIrreg	0.1071	44	0.4891
UChord L 1-3	Overbite	-0.0264	50	0.8559
UChord L 1-3	Overjet	-0.1240	50	0.3909
UChord L 1-3	Midline	0.1464	50	0.3102
UChord L 1-3	BSR L	0.0695	48	0.6389
UChord L 1-3	Canine L	0.2395	51	0.0905
UChord L 1-3	U IncIrreg	-0.0324	50	0.8231
UChord L 1-3	L IncIrreg	-0.0294	45	0.8481
UChord L 1-6	Overbite	-0.1456	49	0.3183
UChord L 1-6	Overjet	0.0766	49	0.6007
UChord L 1-6	Midline	0.0697	49	0.6340
UChord L 1-6	BSR L	0.2391	48	0.1017
UChord L 1-6	Canine L	0.2387	50	0.0950

Continued

Table J-1. *Continued.*

Bivariate correlation		Correlation	n	P-value
Variable 1	Variable 2			
UChord L 1-6	U InclIrreg	-0.1634	49	0.2618
UChord L 1-6	L InclIrreg	-0.0353	45	0.8177
UChord L 1-6	UChord L 1-3	0.4003	50	0.0040
LChord L 1-3	Overbite	-0.0647	48	0.6624
LChord L 1-3	Overjet	-0.3570	48	0.0127
LChord L 1-3	Midline	0.1784	48	0.2251
LChord L 1-3	BSR L	-0.0760	45	0.6196
LChord L 1-3	Canine L	-0.2624	48	0.0715
LChord L 1-3	U InclIrreg	-0.1895	47	0.2021
LChord L 1-3	L InclIrreg	-0.3252	45	0.0293
LChord L 1-3	UChord L 1-3	0.1226	48	0.4064
LChord L 1-3	UChord L 1-6	0.0911	47	0.5427
LChord L 1-6	Overbite	-0.0371	47	0.8043
LChord L 1-6	Overjet	-0.3574	47	0.0137
LChord L 1-6	Midline	0.1618	47	0.2772
LChord L 1-6	BSR L	0.1426	45	0.3501
LChord L 1-6	Canine L	-0.2762	47	0.0602
LChord L 1-6	U InclIrreg	0.0472	46	0.7554
LChord L 1-6	L InclIrreg	-0.4548	45	0.0017
LChord L 1-6	UChord L 1-3	0.0869	47	0.5612
LChord L 1-6	UChord L 1-6	0.1534	47	0.3032
LChord L 1-6	LChord L 1-3	0.5282	47	0.0001
U ArchDepth	Overbite	-0.1430	48	0.3322
U ArchDepth	Overjet	0.3511	48	0.0144
U ArchDepth	Midline	0.2476	48	0.0898
U ArchDepth	BSR L	0.1863	47	0.2100
U ArchDepth	Canine L	0.2843	49	0.0477
U ArchDepth	U InclIrreg	0.2204	48	0.1322
U ArchDepth	L InclIrreg	0.0330	44	0.8317
U ArchDepth	UChord L 1-3	0.2359	49	0.1028
U ArchDepth	UChord L 1-6	0.5720	49	0.0000
U ArchDepth	LChord L 1-3	0.0371	46	0.8064
U ArchDepth	LChord L 1-6	-0.0432	46	0.7757

Continued

Table J-1. *Continued.*

Bivariate correlation		Correlation	n	P-value
Variable 1	Variable 2			
L ArchDepth	Overbite	-0.1523	48	0.3015
L ArchDepth	Overjet	-0.0379	48	0.7979
L ArchDepth	Midline	0.0626	48	0.6724
L ArchDepth	BSR L	0.3272	46	0.0265
L ArchDepth	Canine L	0.0456	48	0.7581
L ArchDepth	U InclIrreg	0.1670	47	0.2618
L ArchDepth	L InclIrreg	0.0937	44	0.5266
L ArchDepth	UChord L 1-3	0.0495	48	0.7383
L ArchDepth	UChord L 1-6	0.2453	48	0.0929
L ArchDepth	LChord L 1-3	-0.0186	46	0.9024
L ArchDepth	LChord L 1-6	0.0856	46	0.5715
L ArchDepth	U ArchDepth	0.1923	47	0.1952
Mx 3-3	Overbite	0.0603	50	0.6775
Mx 3-3	Overjet	-0.1541	50	0.2852
Mx 3-3	Midline	0.2236	50	0.1185
Mx 3-3	BSR L	0.1109	48	0.4530
Mx 3-3	Canine L	-0.0008	51	0.9958
Mx 3-3	U InclIrreg	-0.0414	50	0.7750
Mx 3-3	L InclIrreg	-0.2192	45	0.1480
Mx 3-3	UChord L 1-3	0.2926	51	0.0372
Mx 3-3	UChord L 1-6	0.3126	50	0.0271
Mx 3-3	LChord L 1-3	0.4029	48	0.0045
Mx 3-3	LChord L 1-6	0.3048	47	0.0372
Mx 3-3	U ArchDepth	0.2359	49	0.1027
Mx 3-3	L ArchDepth	-0.0570	48	0.7005
Mx 5-5	Overbite	0.0956	50	0.5089
Mx 5-5	Overjet	-0.5389	50	0.0001
Mx 5-5	Midline	0.0401	50	0.7822
Mx 5-5	BSR L	-0.0904	48	0.5411
Mx 5-5	Canine L	0.0469	51	0.7437
Mx 5-5	U InclIrreg	-0.0699	50	0.6296
Mx 5-5	L InclIrreg	-0.1371	45	0.3692
Mx 5-5	UChord L 1-3	0.2472	51	0.0804
Mx 5-5	UChord L 1-6	0.2736	50	0.0545

Continued

Table J-1. *Continued.*

Bivariate correlation		Correlation	n	P-value
Variable 1	Variable 2			
Mx 5-5	LChord L 1-3	0.2128	48	0.1465
Mx 5-5	LChord L 1-6	0.3844	47	0.0076
Mx 5-5	U ArchDepth	-0.1373	49	0.3467
Mx 5-5	L ArchDepth	-0.0977	48	0.5090
Mx 5-5	Mx 3-3	0.4661	51	0.0006
Mx 6-6	Overbite	0.2357	48	0.1068
Mx 6-6	Overjet	-0.2904	48	0.0453
Mx 6-6	Midline	0.2480	48	0.0893
Mx 6-6	BSR L	-0.0716	47	0.6324
Mx 6-6	Canine L	-0.1673	49	0.2505
Mx 6-6	U InclIrreg	-0.0465	48	0.7534
Mx 6-6	L InclIrreg	-0.2221	44	0.1474
Mx 6-6	UChord L 1-3	0.2329	49	0.1073
Mx 6-6	UChord L 1-6	0.2081	49	0.1514
Mx 6-6	LChord L 1-3	0.1871	46	0.2131
Mx 6-6	LChord L 1-6	0.4277	46	0.0030
Mx 6-6	U ArchDepth	-0.0669	49	0.6477
Mx 6-6	L ArchDepth	0.1463	47	0.3263
Mx 6-6	Mx 3-3	0.4224	49	0.0025
Mx 6-6	Mx 5-5	0.6355	49	0.0000
Md 3-3	Overbite	0.1204	50	0.4049
Md 3-3	Overjet	-0.2672	50	0.0607
Md 3-3	Midline	-0.0201	50	0.8896
Md 3-3	BSR L	0.0500	48	0.7359
Md 3-3	Canine L	-0.0806	51	0.5740
Md 3-3	U InclIrreg	-0.0177	50	0.9030
Md 3-3	L InclIrreg	-0.2216	45	0.1436
Md 3-3	UChord L 1-3	0.1109	51	0.4384
Md 3-3	UChord L 1-6	-0.1199	50	0.4069
Md 3-3	LChord L 1-3	0.1824	48	0.2146
Md 3-3	LChord L 1-6	-0.0389	47	0.7954
Md 3-3	U ArchDepth	-0.1071	49	0.4638
Md 3-3	L ArchDepth	-0.0997	48	0.5004

Continued

Table J-1. *Continued.*

Bivariate correlation		Correlation	n	P-value
Variable 1	Variable 2			
Md 3-3	Mx 3-3	0.3452	51	0.0131
Md 3-3	Mx 5-5	0.2822	51	0.0449
Md 3-3	Mx 6-6	0.0808	49	0.5812
Md 5-5	Overbite	-0.0687	50	0.6355
Md 5-5	Overjet	-0.4486	50	0.0011
Md 5-5	Midline	-0.2833	50	0.0462
Md 5-5	BSR L	0.0216	48	0.8843
Md 5-5	Canine L	-0.1748	51	0.2199
Md 5-5	U InclIrreg	-0.0102	50	0.9439
Md 5-5	L InclIrreg	-0.2191	45	0.1481
Md 5-5	UChord L 1-3	-0.1520	51	0.2871
Md 5-5	UChord L 1-6	-0.1769	50	0.2192
Md 5-5	LChord L 1-3	0.0397	48	0.7888
Md 5-5	LChord L 1-6	0.1261	47	0.3985
Md 5-5	U ArchDepth	-0.2955	49	0.0393
Md 5-5	L ArchDepth	-0.3257	48	0.0239
Md 5-5	Mx 3-3	-0.0836	51	0.5596
Md 5-5	Mx 5-5	0.3148	51	0.0245
Md 5-5	Mx 6-6	-0.0551	49	0.7069
Md 5-5	Md 3-3	0.3915	51	0.0045
Md 6-6	Overbite	0.0396	48	0.7894
Md 6-6	Overjet	-0.2641	48	0.0697
Md 6-6	Midline	-0.1377	48	0.3506
Md 6-6	BSR L	-0.0933	47	0.5327
Md 6-6	Canine L	-0.1318	49	0.3669
Md 6-6	U InclIrreg	0.0489	48	0.7415
Md 6-6	L InclIrreg	-0.1851	44	0.2291
Md 6-6	UChord L 1-3	-0.0885	49	0.5454
Md 6-6	UChord L 1-6	-0.1602	49	0.2716
Md 6-6	LChord L 1-3	-0.0627	46	0.6789
Md 6-6	LChord L 1-6	0.4292	46	0.0029
Md 6-6	U ArchDepth	-0.3337	48	0.0205

Continued

Table J-1. *Continued.*

Bivariate correlation		Correlation	n	P-value
Variable 1	Variable 2			
Md 6-6	L ArchDepth	-0.2094	48	0.1531
Md 6-6	Mx 3-3	0.0434	49	0.7669
Md 6-6	Mx 5-5	0.4117	49	0.0033
Md 6-6	Mx 6-6	0.2219	48	0.1296
Md 6-6	Md 3-3	-0.0033	49	0.9821
Md 6-6	Md 5-5	0.4931	49	0.0003

APPENDIX K.

**FIGURES OF BIVARIATE CORRELATIONS ACHIEVING STATISTICAL
SIGNIFICANCE IN THE AMOUNTS OF POSTTREATMENT CHANGE**

Figure K-1. Plot of the association between the posttreatment change of upper 1-3 chord distance and the upper 1-6 chord distance.

Figure K-2. Plot of the association between the posttreatment change of lower 1-3 chord distance and overjet.

Figure K-3. Plot of the association between the posttreatment change of lower 1-6 chord distance and overjet.

Figure K-4. Plot of the association between the posttreatment change of lower 1-6 chord distance and lower Incisor Irregularity.

Figure K-5. Plot of the association between the posttreatment change of lower 1-6 chord distance and lower 1-3 chord distance.

Figure K-6. Plot of the association between the posttreatment change of upper arch depth and overjet.

Figure K-7. Plot of the association between the posttreatment change of upper arch depth and upper 1-6 chord distance.

Figure K-8. Plot of the association between the posttreatment change of lower 1-3 chord distance and maxillary intercanine width.

Figure K-9. Plot of the association between the posttreatment change of upper interpremolar width and overjet.

Figure K-10. Plot of the association between the posttreatment change of upper interpremolar width and lower 1-6 chord distance.

Figure K-11. Plot of the association between the posttreatment change of upper interpremolar width and upper intercanine width.

Figure K-12. Plot of the association between the posttreatment change of upper intermolar width and lower 1-6 chord distance.

Figure K-13. Plot of the association between the posttreatment change of upper intermolar width and upper intercanine width.

Figure K-14. Plot of the association between the posttreatment change of upper intermolar width and upper interpremolar width.

Figure K-15. Plot of the association between the posttreatment change of lower intercanine width and upper intercanine width.

Figure K-16. Plot of the association between the posttreatment change of lower interpremolar width and overjet.

Figure K-17. Plot of the association between the posttreatment change of lower intermolar width and lower 1-6 chord distance.

Figure K-18. Plot of the association between the posttreatment change of lower intermolar width and upper interpremolar width.

Figure K-19. Plot of the association between the posttreatment change of lower intermolar width and lower interpremolar width.

VITA

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