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Longitudinal Cephalometric Changes of Orthodontic Patients Evaluated Long-Term

Abstract

Posttreatment changes are further complicated by the slow continued growth that occurs after treatment into adulthood. The purpose of this study was to examine long term posttreatment changes. The lateral cephalograms of 51 Caucasian females treated in the standard Edgewise practice of one private practitioner in Cookeville, TN were examined to investigate changes in the cranial base, nasomaxillary complex, mandible, interarch relationships, dental relationships, and the soft tissue integumental profile that occurred an average of 23 years posttreatment. Two tailed t-tests ($\alpha = 0.05$) were run to see whether the posttreatment changes was statistically significantly different from zero. Craniofacial growth continued after treatment, though subtle compared to that seen in other studies, which is probably because this study was exclusively females. Dentally, there was a remarkable stability with no clinically significant orthodontic relapse.

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**LONGITUDINAL CEPHALOMETRIC CHANGES OF ORTHODONTIC
PATIENTS EVALUATED LONG-TERM**

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
Lisa Ku, D.D.S.
May 2010

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ABSTRACT

Posttreatment changes are further complicated by the slow continued growth that occurs after treatment into adulthood. The purpose of this study was to examine long term posttreatment changes. The lateral cephalograms of 51 Caucasian females treated in the standard Edgewise practice of one private practitioner in Cookeville, TN were examined to investigate changes in the cranial base, nasomaxillary complex, mandible, interarch relationships, dental relationships, and the soft tissue integumental profile that occurred an average of 23 years posttreatment. Two tailed t-tests ($\alpha = 0.05$) were run to see whether the posttreatment changes was statistically significantly different from zero. Craniofacial growth continued after treatment, though subtle compared to that seen in other studies, which is probably because this study was exclusively females. Dentally, there was a remarkable stability with no clinically significant orthodontic relapse.

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CHAPTER 1. INTRODUCTION

It should be the determination of every orthodontist to make a continuous study of the stability of his finished treatment results, to follow his cases clinically as long as possible, and to evaluate honestly the reason for success or failure of each case (Jones 1956:588).

Orthodontic treatment consists of directed dentoskeletal changes, but these changes may not be stable after the appliances are removed because of forces acting on the teeth. Additionally, the typical patient, treated in the early teens, can experience years of posttreatment growth (Little 1983). Posttreatment relapse occurs when the teeth return towards their pretreatment positions.

Prior to orthodontic treatment, a person's teeth are not in ideal functional and esthetic positions, but they are in biomechanically neutral positions (Weinstein *et al.* 1963). During treatment, tooth and jaw positions are altered into commonly non-neutral states, so there is the potential for relapse (Reitan 1969). It is a popular public perception that orthodontic results should be stable and the orthodontic correction will persist forever, but studies show that relapse can be a serious problem in orthodontics.

Reports on the likelihood and extent of post-orthodontic relapse extend throughout the 20th century, and various types of orthodontic corrections have been shown to be more or less stable with time (Joondeph 2005). Of note, many of the studies of posttreatment stability during the past two decades are from a single source, the graduate orthodontic program of the University of Washington. Their results suggest that most cases are destined to undergo appreciable relapse (Little, Riedel and Årtun 1988; Little, Riedel and Stein 1990). The question arises whether these university-based studies are representative of orthodontic outcomes generally or specific to their treatment protocols. The central goal of the present study – based on cases treated by a single, experienced orthodontist in private practice – is to see whether the high degree of relapse commonly reported in the literature is exhibited elsewhere. In addition, few studies have analyzed posttreatment changes over a long term. Consequently, the second purpose of the present study is to cephalometrically evaluate the long-term changes that have occurred after about two decades of time out of treatment.

CHAPTER 2. REVIEW OF THE LITEARTURE

The etiology of post-orthodontic relapse is complex and multifactorial. Studies have been undertaken investigating the issues of stability, normative changes, and numerous aspects of posttreatment orthodontic changes (Blake and Bibby 1998).

Posttreatment Stability

Post-orthodontic stability is the retention of teeth in their ideal esthetic and functional position as accomplished through orthodontic treatment. However, teeth have a tendency to return to their pretreatment position. Reitan (1967) defined relapse as when the teeth move back toward their original positions shortly after orthodontic appliances are removed. Horowitz and Hixon (1969) stated that orthodontics temporarily alters the course of the normal dental developmental maturation process and that, following treatment and retention, the developmental maturation process resumes. A problem is the inability to determine whether the posttreatment changes are a result of orthodontic treatment or part of the normal dental developmental maturation process. Horowitz and Hixon argued that when there are unanticipated posttreatment changes to an otherwise well-diagnosed and well-treated case, there are factors at work that are beyond the orthodontist's control.

Hellman (1940) stated long ago that, "We are in almost complete ignorance of the specific factors causing relapses and failures." The problem of orthodontic relapse is certainly not a new one, but it persists today. Over the years, there have been various schools of thought regarding techniques that will enhance stable orthodontic results and thereby decrease the extent of orthodontic relapse (Joondeph 2005).

Occlusion

Kingsley (1880) stated that occlusion of the teeth is the most potent factor in determining their stability in their new posttreatment positions. Edward H. Angle (1903) stated, "It is that the best balance, the best harmony, the best proportions of the mouth in its relations to the other features require that there shall be the full complement of teeth, and that each tooth shall be made to occupy its normal position—normal occlusion." Blake and Bibby (1998) found that adequate interincisal contact angles may prevent overbite relapse and good posterior intercuspation prevents relapse of both transverse and anteroposterior

corrections. They also found that a perfect molar relationship is a significant factor in maxillary incisor alignment. Harris and Behrents (1988) studied stability of the buccal sagittal molar relationship in untreated persons with full dentitions who had been followed from approximately 20 years of age to 55 years of age in the Bolton study of Cleveland, Ohio. Class I cases were indeed the most stable, with 100% maintaining this relationship 30 years later whereas both the Class II and Class III progressively worsened with time. Pancherz (1991) found that a well-interdigitating occlusion inhibits tooth migration. These studies support the idea that a good occlusion helps maintain a stable orthodontic result.

Equilibrium

Weinstein *et al.* (1963) defined equilibrium as the state in which the resultant of all forces is zero; the consequence is a state of rest or uniform motion. The dentition is in equilibrium with its surroundings, which include the adjacent teeth, tongue, musculature, and periodontium; other forces that must be taken into account in orthodontics include external ones such as habits and orthodontic appliances. Weinstein *et al.* explained that each tooth is in equilibrium with its surroundings at any moment irrespective of its equilibrium position. Equilibrium positions are not necessarily stable ones. A stable position is one in which minimal energy exists in the surrounding environment of the tooth. There may be more than one position in which there is a minimum potential energy and, as such, there may be more than one stable position.

Proffit (1978) viewed malocclusion as a result of a combination of genetic as well as environmental factors. Conflicting forces and pressures affect tooth position. Opposing forces must be balanced for equilibrium to exist. Orthodontic treatment changes the natural situation and thereby alters the equilibrium situation.

Proffit (1978) described primary factors that contribute to the equilibrium of the dentition. First, since the teeth are between the tongue on one side and the lips and cheeks on the other, these opposing forces are a major determinant of dental equilibrium. Weinstein *et al.* (1963) felt that stability was associated with minimal potential energy and that this energy was largely stored in the musculature or soft tissues. Proffit explained that the dental apparatus is well adapted to resist short acting forces. But, the resting pressures of the tongue and lips are of longer duration and thus are primary factors in equilibrium. Secondly, extrinsic forces such as habits or orthodontic appliances affect the equilibrium. Orthodontics is based on altering force equilibriums to move the teeth. The duration of force is more important than the magnitude of force. This also holds

true for habits such as thumb sucking and tongue thrusting. Equilibrium in the vertical position also is influential. Proffit explained that the forces that oppose eruption and those that promote it determine the vertical equilibrium. Though the cause of eruption is unknown, it has been found that eruption continues after a tooth has come into occlusion as does vertical growth of the face. Forces from the periodontal membrane may be important in stabilizing teeth after they have come into occlusion. It probably is the source of forces that maintain teeth in stable positions amongst an imbalance of resting tongue and lip pressures. Proffit felt that it is not one, but rather a combination of these primary factors that constitute equilibrium of the dental apparatus.

Periodontium

Reitan (1969) found that if remodeling of the periodontium had not been completed by the time orthodontic retention devices were removed, teeth tend to return to their preorthodontic positions. However, there is individual variation as seen in the different behavior of cases treated and stabilized similarly. Variation is attributed to the highly individual reaction of the fibrous supporting structures. The principal fibers of the periodontal ligament rearrange themselves in eight to nine weeks based on experiments conducted on dogs, but the supra-alveolar structures, which are considered important in maintaining tooth position, have a slower turnover as shown by the scarcity of new cells. The supra-alveolar fibers rearranged themselves more slowly than the principal fibers. If the dentition is released immediately after movement, all the fibers of the periodontal ligament tend to contract and rearrange themselves. Thus, immediate retention after removal of the appliances can avoid relapse and allow time for remodeling of the periodontium.

Thilander (2000) stated that the relapse that occurs soon after treatment might be associated with the slow remodeling process of the periodontium. This may be due to the quality of the supra-alveolar fiber groups whose main role is to protect and conserve the interproximal tooth contact. Removal of the original interproximal contacts allows the transseptal fibers to contract and approximate the adjacent teeth and may lead to long term crowding.

Arch Form and Arch Width

McCauley (1944) suggested that the mandibular intercanine width and intermolar width should be maintained as originally presented in order to minimize retention problems. He disagreed with attempting to move all the teeth into alignment according to an "ideal" arch form. McCauley felt that the

there was no such thing as a predetermined ideal, but rather that the lateral dimensions of the mandible should be respected and that the upper arch should be built on the foundation of the lower arch. The tongue has a certain width, and the muscular structure prevents the maintenance of expansion after the removal of appliances. So the existing intermolar width is a stable area. The lower cuspid region is among the first to show signs of collapse and its dimensions must be protected; the intercanine width is of utmost importance for retention. These two areas serve as the framework of the mandible. The upper teeth overlap the lowers and the upper arch contracts more easily than the lower due to the less dense bone. Thus, the lower arch stability will determine the upper arch stability.

Reitan (1967) found that expansion of the dental arches was followed by relapse due to the contraction of the periodontium. However, Little, Riedel and Årtun (1988) found that, 10 years posttreatment, cases exhibited diminished arch width and length and increased crowding despite maintenance of initial intercanine width, treatment expansion, or arch constriction. The above conclusions were drawn from a cast study consisting of 31 four-premolar extraction cases from the University of Washington files. Little, Riedel and Stein (1990) reported on 26 mixed dentition patients from the University of Washington files who had received enlargement of arch width due to inadequate pretreatment mandibular arch length. Casts and cephalograms were examined ranging from 6 to 23 years after treatment. Their results agreed with the Little, Riedel and Årtun (1988) study. There was a trend toward decrease in arch length, constriction in arch width, and increased mandibular anterior crowding. Most of this change took place before the age of 30, but continued thereafter at a slower rate. When compared to other studies, they concluded that the enlargement of mandibular arch length in the mixed dentition showed a greater relapse tendency than other directions of treatment.

Kahl-Nieke, Fischbach and Schwarze (1996) studied the casts of 226 cases from the University of Cologne Department of Orthodontics files at an average of 15.7 years out of treatment (sd = 4.4 years). 14% showed an upper arch width constriction of 2 mm or more whereas 24% showed a lower intercanine width decrease of more than 2 mm. Posterior arch width relapse was 26% in the upper arch and 19% in the lower arch. Maxillary intermolar width was maintained to a significantly higher frequency in the nonextraction group. An intermolar expansion during treatment of 4 mm or more and an intercanine arch width increase of 2.5 mm or more were significantly correlated with arch width relapse. The degree of arch expansion was positively correlated with the degree of arch width relapse.

De La Cruz *et al.* (1995) studied the casts of 45 Class I and 42 Class II division 1 malocclusion patients who had received premolar extractions; recall

examinations averaged 10 years out of treatment. The patients were largely from the private practice of two ABO certified orthodontists, while a minority of the cases came from the University of Washington files. Computer generated arch forms were used to assess the changes in arch shape over time. The upper and lower arches were not significantly different at the posttreatment examination in the Class I group, whereas they were significantly different in the Class II group, with the maxillary arch form being more tapered. Arch form tended to return toward pretreatment shape. Smaller treatment changes resulted in minor posttreatment changes whereas larger treatment changes resulted in larger posttreatment changes. Changes in arch width and length were not associated with changes in arch form. However, even minimally altering the patient's pretreatment arch form did not ensure long term stability. They concluded that the patient's pretreatment arch form appeared to be the best guide to future stability.

Boundaries

Vaden and Kiser (1996) conveyed the importance of understanding the anterior, posterior, vertical, and transverse limitations of the dentition and its supporting structures. The anterior dimension was evaluated using a diagnostic facial triangle to evaluate the facial balance and the position of the anterior teeth over basal bone. The patient with a low Frankfort mandibular plane angle might not need as much mandibular incisor uprighting as the patient with the higher Frankfort mandibular plane angle. Sometimes extractions are necessary to respect the anterior limit in the presence of significant anterior crowding or protrusion. The posterior dimension of the mouth can be evaluated on cephalograms. There is a limit to which the teeth can be driven back, for example to preclude the impaction of unerupted second molars. Vaden and Kiser stressed the importance of knowing how much space is available in the posterior of the dental arches; there are limits of available bone. If the vertical dimension is increased in the posterior, a longer face results and there may be more gingival display when smiling. If maxillary posterior teeth are distalized to correct a Class II molar relationship when no space is available, there is an anterior "wedging open" effect. When patients who need extractions are expanded vertically, B Point drops down and back and a poor facial profile may result. Every patient is unique, and the spacial dimensions must be considered to provide an esthetic, healthy, functional, and stable result.

Changes in Untreated Patients

When evaluating orthodontic relapse, it is important to differentiate relapse *per se* from the long-term changes resulting from the natural maturation of the untreated normal occlusion, dentofacial maturation of untreated normals, and growth.

Maturation of Untreated Normal Occlusions

Sinclair and Little (1983) studied the developmental maturation process of the normal dentition. They looked at arch length, intercanine width, intermolar width, overjet, overbite, and incisor irregularity in the mixed dentition (9 to 10 years), early permanent dentition (12 to 13 years), and early adulthood (19 to 20 years) of 65 untreated normal occlusions. The sample was from the Burlington Growth Center Study in Ontario, Canada. The mixed dentition stage (T1) was defined as when the mandibular permanent incisors and first molars had erupted; this corresponded to the time when early orthodontic therapy might be initiated. The early permanent dentition stage (T2) was defined as when all permanent teeth were present except the third molars. The adult dentition stage (T3) was defined as when males were at least 18 years of age and females at least 17 years of age. There was a consistent trend towards a decrease in arch length from T1 to T2 ($\bar{x} = -4.8$ mm; $sd = 1.9$). More change was seen in the female group during T1 to T2 while the male arch length decreased at a constant rate. 61 of the 65 cases exhibited some decrease in arch length from T1 to T3. There were small, but statistically significant decreases in intercanine width from T1 to T2 ($\bar{x} = 0.8$; $sd = 1.5$). The females had the majority of the change during T2 while the males were gradual over the entire period. From T2 to T3, 48 of 65 cases decreased in intercanine width. Statistically significant differences in intermolar width were seen for males and females from T1 to T3. Males showed small, insignificant increases in intermolar width while females showed statistically significant loss in intermolar width ($\bar{x} = -0.9$ mm; $sd = 1.5$) with the majority of the decrease occurring between T2 and T3, where 22 of the 32 cases decreased. Overjet increased from T1 to T2 ($\bar{x} = 0.4$ mm; $sd = 0.9$) and then decreased from T2 to T3 ($\bar{x} = -0.5$ mm; $sd = 0.9$). Overbite increased from T1 to T2 ($\bar{x} = 0.4$ mm; $sd = 1.0$) then decreased from T2 to T3 ($\bar{x} = -0.6$ mm; $sd = 0.9$). Incisor irregularity showed a statistically significant increase during T2. Females showed significantly greater crowding than males at T1 ($\bar{x} = 2.6$ mm; $sd = 1.4$ vs. $\bar{x} = 1.9$; $sd = 1.0$) and at T3 ($\bar{x} = 3.1$ mm; $sd = 1.8$ vs. $\bar{x} = 2.3$ mm; $sd = 1.4$).

In summary, there was a consistent trend towards a decrease in arch length from the mixed dentition into early adulthood. There were small decreases in intercanine width with the most change seen in females from 13 to

20 years of age. Intermolar width was generally stable, but with a small but significant decrease from 13 to 20 years among females. Overjet and overbite typically increased from 9 to 13 years of age then decreased from 13 to 20 years, resulting in trivial overall changes. Incisor irregularity increased from 13 to 20 years, with females showing more incisor irregularity than males at the adult stage.

Sinclair and Little (1985) also performed a cephalometric study on the same sample from the above cast study. Their aim was to evaluate the skeletal and dental changes that occur in untreated normal persons during the active growth years and beyond. 28 anatomic landmarks were located on each tracing, and 12 angular and 14 linear parameters were used for interpretation. 3 angular and 6 linear parameters were chosen for interpretation of the mandible. A statistically significant ($P < 0.05$) correlation of $r = 0.70$ to 0.79 was defined as “closely correlated” and correlation above 0.80 were defined as “very closely correlated.”

In the anteroposterior direction, Sinclair and Little found that the changes in SNA angle were relatively small with only males showing a statistically significant increase from T1 to T2 and from T2 to T3. The amount of forward maxillary growth from T2 to T3 was closely correlated with the degree of forward movement of the mandible as measured by the SNB angle. The SNB angle increased from T1 to T3 with larger changes in males. This change was very closely correlated with the amount of posterior facial height growth as measured from Sella to Gonion and from Articulare to Gonion. The forward movement of the mandible was closely correlated with a decrease in the mandibular plane to Se-Na angle with a decrease in the Y axis to Sella-Nasion angle, which are measurements of mandibular rotation. As a whole, the ANB change showed a small but statistically significant decrease from T1 to T3. At T2 the males had a significantly higher ANB angle than the females and from T2 to T3 they showed a significant decrease in the ANB angle.

From T1 to T3, the Sella-Nasion distance increased significantly, with males showing significantly greater dimensions at T2 and T3 and significantly greater growth from T2 to T3 than the females. From T1 to T3, there was a small but statistically significant increase in the distance from Sella to the cranial base, which was more noticeable in males. The amount of growth from Sella to the cranial base was less than one fifth of that from Sella to Nasion. The cranial base angle showed a statistically significant overall increase with the majority of the change from T2 to T3.

There was a statistically significant increase in the Sella-Gonion distance, which occurred largely from T2 to T3. The male increase was significantly

greater. There were close correlations with changes in SNB and MP-SeNa, growth of Se-Na, and vertical development of Nasion-Menton. The amount of eruption of the mandibular first molar was very closely correlated with the amount of vertical posterior facial growth and closely correlated with changes in the gonial angle.

Incisor angulation showed stability especially for the upper incisors, which showed no statistically significant changes. Females exhibited proclination of the lower incisors from T2 to T3 whereas the males showed incisor uprighting. However, the males showed proclination of the lower incisors as measured to the mandibular plane from T1 to T2. However, the only statistically significant change in the interincisal angle was an increase from T2 to T3, with males showing a greater value than females. There was a statistically significant eruption of the mandibular incisors from T1 to T3, with the changes in males greater than in females; the amount of eruption was closely correlated with the amount of mandibular growth. There was a statistically significant forward movement of the mandibular molar and incisor from T1 to T3.

Upper face height (Na-ANS) increased throughout T1 to T3 with a slower rate of increase from T2 to T3. Males showed greater increases in UFH than females. The increases in UFH were very closely correlated with posterior facial height. The amount of molar eruption was also very closely correlated with the increase in the proportions of UFH as was growth of the anterior cranial base. Lower face height (ANS-Me) increased from T1 to T3, with males showing greater increases than females from T2 to T3. Males showed an increase in upper dental height (UDH) from T1 to T3 whereas females did not. Lower dental height (LDH) was significantly greater in males than females from T1 to T3.

There was a statistically significant degree of maxillary molar eruption relative to the palatal plane from T1 to T3, with males showing greater eruption from T2 to T3. The majority of the eruption occurred from T2 to T3. There was a mesial tipping as well as movement of the molar from T1 to T3.

There was a statistically significant amount of mandibular growth, as measured at Articulare, from T1 to T3, with males showing more growth from T2 to T3 than females. The amount of mandibular growth, as measured at Articulare was correlated very closely with the amount of eruption of the mandibular incisor and molar. There were close correlations to UFH, LFH, and LDH. There was a change to a more vertical growth direction from T1 to T3, more so in males from T2 to T3. The amount of mandibular incisor proclination and molar eruption was closely correlated with changes in growth direction.

To summarize, the amount and direction of maxillary growth were associated with the degree of anteroposterior mandibular growth. The degree of anteroposterior mandibular growth was closely correlated with the direction of condylar growth, while the degree of vertical mandibular growth was closely correlated with the total amount of condylar growth. Postpubertally, there is an upward and forward (bite-closing) rotation of the mandible, which is influenced by the vertical eruption of the molars. The relationship between skeletal and dental changes in both the vertical and sagittal planes influences the sagittal jaw relations. Incisor angulation to the cranial base was fairly stable with compensations to skeletal changes, which resulted in the maintenance of occlusal relationships. In addition, Sinclair and Little found that there was a natural sexual dimorphism in the extents of growth. Males showed larger dimensions, more growth postpubertally, and greater late skeletal and dental changes. These findings of the natural maturation of the dentofacial complex can be kept in mind when trying to determine whether posttreatment changes are due to orthodontic relapse or are simply a part of the natural maturation. The above results are shown in Table 2-1.

Bishara and Jakobsen (1988) studied the longitudinal changes in three normal facial types (long, average, and short). There were 20 males and 15 females for which lateral cephalograms were obtained biennially between the ages of 4.5 and 12 years and annually through 17 years with the final set of records at a mean age of 25.5 years. All subjects had a Class I molar and canine relationship with less than 3 mm of crowding. All subjects were American white and none had undergone orthodontic therapy. The ratio of the Posterior Face Height (Se-Go) to the Anterior Face Height (Na-Me) and Frankfort Horizontal to Mandibular Plane angle (FMA) in adulthood were used to categorize the subjects according to facial type. The three facial types were variations of normal because abnormal skeletal patterns were excluded. The 15 females were equally divided among the 3 facial types. The data for the female subjects at 15 years and 25 years of age are presented in Table 2-2.

The cranial base, Sella-Nasion, showed no statistically significant difference between the growth profiles, but there was a significant difference in the overall size among the three facial types. In general the greatest differences were between the LFT and SFT. However, the change between 15 to 25 years did not show a significant difference among the three facial types. The maxillary anteroposterior parameter, SNA, showed no statistically significant difference among the growth profiles of the three facial types. However, there was a significant difference among the three facial types in regard to magnitude at 25 years with LFT showing a larger SNA than SFT. With regard to the mandibular parameters, there was a statistically significant difference between AFT and SFT for SNB and between LFT and SFT for FH-NaPg; SNB was greater for SFT than

Table 2-1. Changes in cephalometric values at T1 (median age = 9 years), T2 (median age = 13 years), and T3 (median age = 20 years).

Variables	<u>T1 to T2</u>		<u>T2 to T3</u>		<u>T1 to T3</u>	
	Males	Females	Males	Females	Males	Females
SNA (°)	0.66*	0.04*	0.67*	0.35	1.34*	0.39
SNB (°)	0.80*	0.49	1.47*	0.73*	2.27*	1.22*
ANB (°)	-0.14	-0.44	-0.79	-0.38	-0.93	-0.82*
MP-SeNa (°)	-0.86*	-0.38	-3.00*	-1.96*	-3.86*	-2.34*
Y axis (°)	0.06	-0.12	-1.11*	-0.35	-1.05*	-0.47
Gonial angle (°)	-1.29*	1.14	-2.90*	-3.32*	-4.19*	-2.18*
Se-Na (mm)	2.62*	1.62*	4.26*+	1.64*+	6.88*+	3.26*+
Cranial base angle (°)	0.04	1.45*	1.29*+	0.98*	1.33*	2.43*
Se-Go (mm)	6.23*	3.33	10.26*+	5.16*+	16.49*+	8.49*+
L1-NaB (mm)	0.75	0.10	-0.35+	0.48*+	0.40	0.58
L1-NaB (°)	-0.67	-0.24	-2.96*+	1.17+	-3.63	0.93
L1-MP (°)	4.84*+	-0.34+	-1.43*+	2.39*+	3.41	2.05
U1-L1 (°)	-2.10	1.20	4.05*+	-1.29+	1.95	-0.09
U1-NaA (°)	4.83	-0.52	-5.65	0.50	-0.82	-0.02
U1-NaA (mm)	0.45	0.37	-0.01	0.43	0.44	0.80*
U1-SeNa (°)	0.03	-0.48	0.48	0.86	0.51	0.38
Na-Me (mm)	7.92*	4.52*	10.10*+	4.71*+	18.12*+	9.23*+
Na-ANS (mm)	4.30*+	2.14*+	2.90*	2.01*	7.20*+	4.15*+
ANS-Me (mm)	3.52*	2.21*	6.67*+	2.30*+	10.19*+	4.51*+
U6-PP (mm)	3.38*	4.96*	4.42*+	1.63*+	7.80*	6.59*

*Statistically significant change ($P < 0.05$)

+Statistically significant difference ($P < 0.05$) between males and females

Source: Sinclair PM, Little RM. Dentofacial maturation of untreated normals. Am J Orthod 1985;88:146-56.

Table 2-2. Descriptive statistics for angular and linear measurements at 15 and 25 years of age for three normal female facial types.

Variable	<u>15 years</u>						<u>25 years</u>					
	<u>LFT</u>		<u>AFT</u>		<u>SFT</u>		<u>LFT</u>		<u>AFT</u>		<u>SFT</u>	
	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
Se-Na (mm)	67.7	3.1	66.6	4.4	66.1	1.2	69.0	2.8	67.9	4.0	67.5	1.5
SNA (°)	82.8	4.4	77.7	3.4	80.4	2.0	83.1	4.5	77.9	3.0	80.8	1.3
SNB (°)	78.8	3.6	74.8	2.9	78.4	2.1	78.4	4.0	74.8	2.6	78.5	2.3
FH-Pg (°)	82.7	2.6	83.7	1.5	84.1	3.5	82.3	2.4	83.1	2.4	85.1	3.6
ANB (°)	4.0	1.9	2.9	1.1	2.0	3.2	4.6	1.2	3.1	1.2	2.3	2.8
Na-A-Pg (°)	8.5	5.6	5.7	2.8	2.7	7.3	9.4	4.7	5.3	3.0	2.7	7.1
AO-BO (mm)	0.3	2.1	0.2	2.1	-1.5	2.5	1.0	2.0	0.8	2.1	-0.6	2.9
Overjet (mm)	2.9	0.7	3.5	0.7	3.3	0.9	2.9	0.7	3.4	0.7	3.3	1.0
U1-L1 (°)	132.4	8.1	122.8	10.6	133.4	5.9	132.6	9.9	122.0	11.6	133.9	6.4
U1-SeNa (°)	100.8	5.6	103.1	5.8	102.7	5.8	99.6	6.0	103.2	6.1	102.8	6.9
IMPA (°)	90.9	4.8	98.7	4.3	96.2	5.7	91.0	6.6	98.9	5.2	95.7	5.9
L1-NaB (mm)	5.0	1.2	5.0	2.2	3.2	2.2	5.3	1.7	5.7	2.2	3.3	1.8
Z angle (°)	66.5	4.8	73.1	5.3	74.3	10.6	66.5	4.8	73.1	5.2	74.3	10.6
MP-SeNa (°)	35.9	2.3	35.9	1.5	28.3	3.1	36.5	2.3	35.8	1.0	28.0	3.7
FH-MP (°)	31.9	3.3	27.3	3.7	23.2	3.7	32.9	3.6	27.8	3.3	22.1	3.8
FH-SeGn (°)	63.1	2.7	62.6	3.6	61.2	2.9	64.0	2.9	63.5	4.1	60.6	3.0
UAFH (mm)	48.2	2.0	48.7	1.1	46.7	1.9	49.1	2.5	49.7	1.0	47.6	2.1

Continued

Table 2-2. *Continued.*

Variable	<u>15 years</u>						<u>25 years</u>					
	<u>LFT</u>		<u>AFT</u>		<u>SFT</u>		<u>LFT</u>		<u>AFT</u>		<u>SFT</u>	
	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
TAFH (mm)	109.3	6.7	111.0	2.2	105.1	2.0	113.0	5.1	113.9	2.7	108.1	2.4
Se-Go (mm)	72.0	5.1	73.2	1.2	75.5	2.4	74.2	4.5	75.8	1.9	78.6	2.8
Overbite (mm)	3.8	1.1	2.0	1.8	3.2	1.5	3.5	1.6	3.1	1.5	3.3	2.0

LFT (Long Facial Type)

AFT (Average Facial Type)

SFT (Short Facial Type)

Source: Bishara SE, Jakobsen JR. Longitudinal changes in three normal facial types. Am J Orthod 1985;88:466-502.

AFT and FH-NaPg was greater for SFT than LFT. There was no statistically significant difference among facial types with regard to anteroposterior maxillary-mandibular parameters (ANB, NAP, Wits, and Overjet) though the LFT generally had the largest ANB and AOB measurements. With regard to dental variables, there was no statistically significant difference between growth profiles, but there were significant differences in magnitude, with the maxillary and mandibular incisor more labially inclined in the SFT and more upright in the LFT; the SFT had the most pronounced bony chins; and the LFT had the least pronounced chins. The L1-NB was significantly greater in AFT than SFT. With regard to vertical facial dimensions, LFT had the largest mandibular diversion and SFT the smallest. There was a significant difference in the 15 to 25 year growth period between LFT and AFT as well as between LFT and SFT. SFT showed a significantly greater decrease in FH-MP and MP-SeNa angles. Regarding soft tissue profile parameter Z angle, SFT had less of a facial convexity than either AFT or LFT. Regarding face height, there was a progressive relative decrease in anterior face height and an increase in posterior face height from LFT to SFT.

There is a strong tendency to maintain the overall facial type as facial growth progresses with age and the differences become more pronounced with time. There was a consistent lack of significant differences in profile of the absolute growth curves for all parameters of the 3 facial types. This shows that there is a similar growth behavior or direction. However, there was a consistent significant difference in curve magnitudes. There was a considerable variation even within each facial type. There was more than one combination in size and relationships of the different parts of the dentofacial complex that could produce a certain facial type. Subtle changes in dimension can cumulatively influence the overall direction of growth and the consequent relationships of the face.

Posttreatment Growth

Horowitz and Hixon (1969) suggest that since normal growth changes occur in both those treated and untreated orthodontically; "relapse" should be reserved to describe changes resulting from improper treatment, inadequate mechanics, or poor patient cooperation.

Forsberg (1979) performed a longitudinal study on growth changes in the adult face from 24 to 34 years of age. The sample consisted of 25 men and 24 women. All subjects were Swedish and had been students at the Faculty of Odontology in Stockholm. A few subjects had received orthodontic treatment in childhood. A lateral cephalometric radiograph was taken at T1 ($\bar{x}$ = 24 years of age) and T2 ($\bar{x}$ = 34.2 years of age) for women. The results for the women are

shown in Table 2-3 as the present study is limited to the study of females. Forsberg suggested that the increase in face height was not due to growth in the sutures or condylar cartilage because these processes would have largely been completed by this time. Bone apposition, which continues well into adulthood, was not thought to be a major factor because it is minimal and not likely to give measureable changes on a cephalogram. Forsberg suggested that increase in face height is due to the posterior (downward-backward) rotation of the mandible, which agrees with the observed increase in Se-Na to MP angle, the increase in ANS-Me, and the other changes. Forsberg states that rotation of the lower jaw could be due to continued eruption of the teeth. There was continued eruption of the maxillary incisor, but no corresponding increase in overbite. In addition, the vertical distance from Nasion to the upper incisor (I_s) increased over time. Forsberg suggested that the upper incisors adjusted to the new lower jaw position. There were many significant soft tissue profile changes. The reference line, FH, was established by drawing a line perpendicular to Frankfort Horizontal at Sella. The tip of the nose moved anteriorly while the upper and lower lips retruded. Soft tissue Pogonion moved back, corresponding to the hard tissue posterior rotation of the mandible.

Behrents (1984) conducted a longitudinal assessment of the Bolton-Brush Study participants to evaluate growth in the aging craniofacial skeleton. He suggested that it was difficult to draw conclusions based on previous studies because they were not comparable due to differences in age, race, sex, measurements, designs of study, and methods of information gathering.

Behrents' sample was derived from those who had participated in the Bolton study as children. The Bolton study was unique in that longitudinal data were gathered from the 1930s to 1960s for a large sample size and precise standardization of the recordings was possible. Behrent's recall study consisted of the cephalometric material for 160 individuals. The same equipment used originally was used in the present study, so the standardization was precise. A range of dental malocclusions was present.

Behrents first discusses growth after 17 years of age by examining the initial films (age 17 or greater) and final films (age 25 or greater). These data documented adult enlargement. 64 of the 70 linear measures increased to statistically significant extents, and 48 of the 69 angular values changed significantly. Of the male sample ($n = 34$), 63 of the 70 linear measures and 38 of the 69 angular measures changed significantly from the initial to final films. Of the female sample ($n = 34$), 59 of 70 linear and 40 of 69 angular variables exhibited a significant change. Since both linear and angular variables were changing, there was an enlargement as well as change in shape.

Table 2-3. Mean differences (d) between T2 (34 years) and T1 (24 years) for women.

Variable	n	d	t-test
Na-Me (mm)	24	0.67	5.81***
Na-ANS (mm)	24	-0.01	-0.08
ANS-Me (mm)	24	0.66	6.30***
Na-I _s (mm)	23	0.57	5.32***
Overbite (mm)	23	0.11	1.17
Overjet (mm)	23	0.07	0.78
U1-SeNa (°)	23	-0.79	-3.32**
U1-L1 (°)	23	-0.17	-0.45
MP-SeNa (°)	24	0.52	3.17**
PP-SeNa (°)	24	-0.02	-0.14
ANB (°)	24	0.26	2.64*
U1-PP (°)	24	0.14	1.01
L1-MP (°)	24	0.38	1.49
Na'-St (mm)	24	1.22	6.33***
St-Me' (mm)	24	-0.43	-3.60**
Pronasale-FH (mm)	24	0.59	4.79***
Upper lip-FH (mm)	24	-0.75	-3.37***
Lower lip-FH (mm)	24	-0.64	-2.95**
Pg'-FHP (mm)	24	-0.83	-4.41***

* $P < 0.05$

** $0.05 > P > 0.001$

*** $P < 0.0001$

Source: Forsberg CM. Facial morphology and ageing: a longitudinal cephalometric investigation of young adults. Eur J Orthod 1979;1:15-23.

Behrents also looked at growth after 25 years of age ($n = 56$). 60 of the 70 linear measures and 32 of the 69 angular variables were significant; thus, again suggesting adults continued to change beyond 25 years of age. For growth after 30 ($n = 27$), 56 of 70 linear measures and 28 of 69 angular measures significantly changed. For growth after 35 ($n = 10$), 43 of 70 linear measures and 19 of 69 angular measures were significantly different. For growth after 40 years of age ($n = 4$), 22 of 70 linear measures and 11 of 69 angular measures were significantly different. Though there was a decrease in the linear and angular measure changes with age, it is apparent that adults continued to change to an undefined final age.

Behrents explored sex-specific changes. For the variables involving distances from Sella and angular relationships to Sella-Nasion, 70 of 70 linear and 8 of 69 angular measures were significantly different between males and females. Males were larger than females and there were distinct configuration differences between the sexes at all times, which confirms sexual dimorphism. The major shape differences between males and females were of the upper facial areas. Males were approximately 5% to 9% larger than females overall. Males were larger to begin with in adulthood, grew more, and were larger in later adulthood. Females changed little in early adulthood, but grew again in their twenties and thirties, which happen to coincide with the events of pregnancy. Males showed a more continuous deceleration of growth through time that never ended. Though there was individual variation in growth patterns, both sexes tended to exhibit a vertical growth pattern with older age.

Some persons had received orthodontic treatment, so a treated sample ($n = 28$) was analyzed separately to see the adult changes. 60 of the 70 linear and 23 of 69 angular measurements disclosed significant growth between initial and final examinations, showing that orthodontically treated people likewise grew well into adulthood. There were significant differences between the treated and untreated samples for 34 of 70 linear and 51 of 69 angular measurements. The treated group had a different type of craniofacial configuration. However, this may be what caused them to seek treatment or have treatment recommended. The treated group exhibited a smaller more posteriorly located mandible. They grew “poorly” before treatment, were treated, and then continued to grow poorly thereafter.

The following comments summarize the changes seen in Behrents’ untreated sample study. The cranial base remained found to be stable except at its extreme extensions. The occipital condyle area changed slightly with a downward and forward movement. Bolton point and Basion to Nasion showed significant changes. Basion continued to remodel downward and backward without change in the cranial base angle. Porion is fairly stable except for a slight

but consistent elevation in females continuing into the twenties. The anterior cranial base from Sella to the endocranial surface of the frontal bone is very stable. Nasion continues to move forward as does the ectocranial surface of the frontal bone.

The posterior aspects of the midface are fairly inactive though there are a few small changes. PM vertical is a fairly stable reference plane. The posterior palate continues downward into the thirties. The posterior nasal spine remodels posteriorly and inferiorly. The nasal bone continues to move forward. Orbitale continues to move forward from Sella. Anterior nasal spine showed an anterior downward movement in the twenties. There was an angular change in the position of ANS relative to Sella-Nasion during the twenties and thirties. Point A continues to move away from the cranial base, but the angular relationship between the cranial base and A Point remains stable, suggesting that the maxilla is coming forward consistent with anterior movement at Nasion.

The mandible shows considerable change. Menton moves downward and females show a clockwise (downward-backward) rotation through time. Gnathion and Pogonion behaved similarly. In females, the mandible does not move as far forward as Nasion with age. B Point moves away from the cranial base with time with a clockwise change in angulation in females. The chin seems to move down and forward in males, whereas it moves more straight down in females. Gonion moves down and back in females and down and forward in males. The anterior border of the ramus of the mandible is resorbed back, while the posterior border remains stationary in females and moves forward in males. The coronoid process moved forward and upward with time. Anterior Articulare was stable at early stages of adulthood, but in later stages showed a significant downward movement. Posterior Articulare got farther from the front of the face with age, suggesting that the mandible grows in length. The condyle's relation to Sella, remained stable and there was little change except for a more posterior position in the female with age. Females appear to have a less prominent mandible, but a more prominent chin with age. The length of the mandible, body, and ramus all increased with time.

The dentition exhibits considerable activity with age. There is a steeper occlusal plane in regard to Downs occlusal plane to Frankfort plane into the late twenties, though this is not apparent when measuring to the Sella-Nasion plane. The female occlusal plane seems to remain constant with time, but males show a flattening of the occlusal plane as measured to Frankfort plane. The upper incisors upright with age. The lower incisors tilt anteriorly in the female; this may be to maintain occlusal contact as the mandibular plane rotates clockwise. The interincisal angle as a result is changed in males, but remains fairly stable in females due to the offsetting of the movements of the incisors two movements.

The upper molar uprights in males and has a tendency to be more distally inclined in females. The lower molars become more upright in males and mesially tip in females. There is a continued increase in height of the alveolus and vertical drift of the teeth. There was no change in overbite.

The soft tissue profile underwent larger changes than the osseous structures, but were similar in pattern. Soft tissue Glabella moved forward well into the thirties. In addition, it was higher in females, though the pattern for both sexes was downward with time. Soft tissue Nasion behaved similarly. The tip of the nose continued to move forward and downward with time. Subnasale moved downward across all ages. The combined effect is the nose becoming more “pointed” with time. Similarly, the angle from Pronasale through Subnasale to the upper lip (I_s) becomes more acute with age. Soft tissue Point A moves forward by an amount similar to Subnasale. The upper lip lengthens. Stomion continues to move away from Sella and downward from Sella-Nasion and the Anterior Nasal Spine. The lower lip, soft tissue Point B, and soft tissue Pogonion follow the same pattern. The angle formed by the lower lip (I_L), mental sulcus, and Pogonion becomes deeper in the sample of females.

Soft tissue Gnathion and soft tissue Menton came forward and downward for all ages. Males have a more prominent soft tissue Pogonion, less acute mental sulcus, more prominent lower lip, and a larger more angled nose. The relation of Stomion to the nose remains the same, suggesting that the midface is moving proportionately downward and forward through time. The soft tissue Pogonion relation to Stomion increases slightly with age, suggesting that the mandible follows a slightly different developmental course. As the upper lip flattens, lower lip prominence increases, soft tissue Pogonion increases, and the profile straightens with time.

Results for the untreated female group at T1 (ages 17-18) and T2 (31-50) and the measurements of interest to the present study are presented in Table 2-4. The above age brackets were chosen because the present study T1 mean age was 16 years and T2 mean age was 39 years.

Behrents' results show that though small, there is evidence of continued remodeling within the craniofacial complex. Thus, there may be no end to growth. These changes impact the bone, dentition, and periodontium. We must anticipate that there are post-orthodontic changes over time due to the continued growth of the craniofacial complex.

Driscoll-Gilliland, Buschang and Behrents (2001) studied 44 untreated subjects from the Broadbent-Bolton Growth Study and 43 treated patients to compare the skeletal and dental changes over the long term. Cephalograms and

Table 2-4. Skeletal, dental, and soft tissue changes of untreated females between T1 (ages 17-18) and T2 (ages 31-50).

Variable	<u>T1</u>		<u>T2</u>	
	$\bar{x}$	sd	$\bar{x}$	sd
Se-Na (mm)	71.8	3.2	73.4	2.6
Se-A (mm)	86.6	3.6	87.7	4.5
Se-B (mm)	108.2	3.6	108.8	5.4
Se-Gn (mm)	124.2	5.0	125.5	7.2
SeGn-SeNa (°)	67.2	3.0	66.3	2.3
Na perp. to PP (mm)	52.9	2.3	53.0	2.5
Me perp. to PP (mm)	63.7	3.5	64.3	5.2
ANS-Me (mm)	66.5	3.6	66.5	5.4
Na-Me (mm)	117.4	4.1	117.9	6.7
Se-Go (mm)	75.3	4.9	76.3	5.5
Se-Ba (mm)	46.1	2.5	45.0	3.0
Na-Se-Ba (°)	128.7	5.8	129.8	5.3
SNA (°)	81.7	3.3	81.4	3.6
SNB (°)	78.6	3.1	78.3	2.7
A to N perp. to FH (mm)	3.1	4.0	5.2	4.3
Cd-A Point (mm)	90.8	4.3	94.1	3.6
Go-Pg (mm)	76.7	4.8	79.5	5.1
SeNa-PP (°)	7.9	3.1	8.5	3.3
FMA (°)	25.5	5.8	22.6	5.4
MP-SeNa (°)	32.1	4.8	30.4	3.3
NAP (°)	174.2	4.3	173.4	4.5
U1-L1 (°)	130.6	10.6	136.0	10.0
U1-SeNa (°)	101.7	8.3	98.8	9.2
U1-NaA (°)	20.4	7.4	17.9	9.8
U1-NaA (mm)	20.4	7.4	17.9	9.8
L1-NaB (mm)	4.9	1.7	4.2	2.3
IMPA (°)	95.6	6.8	94.8	7.1
FH-DOP (°)	8.4	3.9	8.4	5.1
SeNa-DOP (°)	14.8	4.5	15.7	4.8
U1-PP (mm)	28.6	2.1	29.0	3.1
U6-PP (mm)	23.3	2.0	23.5	2.2
FH-NaPg (°)	86.4	3.6	87.7	4.0

Source: Behrents RG. A treatise on the continuum of growth in the aging craniofacial skeleton: a longitudinal assessment of the Bolton-Brush study participants recalled in the 1980's. Dissertation University of Michigan, 1984.

models were taken at the deband appointment (T1: $\bar{x}$ = 14.3; sd = 1.5 and $\bar{x}$ = 15.2; sd = 1.1 years, respectively) and posttreatment (T2: $\bar{x}$ = 23.2; sd = 3.4 and $\bar{x}$ = 28.9; sd = 3.6 years, respectively). The treated group consisted just of cases treated with 4 premolar extractions to reduce variability. At T1 (posttreatment), there were important differences in age, skeletal characteristics, and malocclusion among the treated and untreated groups. The untreated subjects were a year younger than the treated subjects and the mean anterior facial height was 6 mm shorter in the untreated than the treated group. The untreated subjects had normal anteroposterior dimensions whereas the treated subjects were maxillary and mandibular retrusive. The untreated subjects had more malocclusion, overjet, overbite, and crowding than the treated subjects for obvious reasons.

All skeletal dimensions except SNA, which did not change in either group, and mandibular rotation, which changed only in the treated group, changed significantly in both groups. Anterior and posterior facial heights increased 4 to 5 mm. SNB increased in both groups while the SeNa-GoMe decreased 2°. The only significant difference between the groups was the larger yearly incremental increases in lower anterior facial height and posterior facial height in the untreated group compared with the treated group. From T1 to T2, both groups exhibited similar patterns of skeletal growth with twice as much downward as forward growth, which is congruent with other studies. Most of this vertical growth came from the lower anterior face and ramus, though there were small increases in the upper facial height as well.

In terms of dental changes, the largest change was 4 to 5 mm of inferior displacement of the lower incisor attributable to growth; there was a net downward movement of the lower incisor relative to Sella. The anterior displacement of the lower incisor attributable to growth was approximately 2 mm in both groups, which is half the amount of vertical growth displacement. When adjusted for age differences, the untreated group had significantly more downward growth displacement of the lower incisor than the treated group. Overjet did not change significantly in the untreated subjects, but increased approximately 1.4 mm in the treated subjects. Similarly, overbite increased 0.3 mm in the untreated subjects and 1.5 mm in the treated subjects. After adjustment for age differences, the overjet and overbite increases were significantly greater for the treated group than the untreated group. The upper incisor moved forward 1.6 mm in the untreated and 2.7 mm in the treated groups, but there was no significant difference of the upper incisor anterior movement or inclination between the untreated and treated groups. Dental and skeletal changes for the untreated and treated groups are shown in Table 2-5.

Gormely and Richardson (1999) studied the linear and angular changes in

Table 2-5. Skeletal and dental changes from 14 to 23 years of age in untreated and treated subjects.

Variable	<u>Untreated (n = 44)</u>			<u>Treated (n = 43)</u>		
	$\bar{x}$	sd	Significance	$\bar{x}$	sd	Significance
Na-ANS	1.4	1.4	***	1.6	1.6	***
ANS-Me	3.3	2.2	***	2.0	1.8	***
SNA	0.1	1.0	ns	0.1	2.0	ns
SNB	0.6	1.3	**	0.5	1.5	*
SeNa-GoMe	-1.7	2.5	***	-2.2	2.6	***
Mandibular rotation	-0.6	2.6	ns	-1.6	2.0	***
L1-MP	0.2	3.9	ns	-1.1	4.0	ns
Overjet	-0.2	1.0	ns	1.4	1.1	***
Overbite	-0.3	0.8	*	1.5	1.1	***
U1-SeNa	0.2	3.6	ns	-1.2	5.1	ns
U1-L1	1.4	5.0	ns	4.5	7.4	***

Within-group changes: ns, not statistically significant; *P < 0.05; **P < 0.01; ***P < 0.001

Source: Driscoll-Gilliland J, Buschang PH, Behrents RG. An evaluation of growth and stability in untreated and treated subjects. Am J Orthod Dentofacial Orthop 2001;120:588-97.

dentofacial dimensions during subjects' third decade of life. Lateral cephalometric radiographs were available for 21 males and 26 females at ages 18 (T1) and 21 (T2). 15 of the males and 22 of the females had cephalograms at 28 years (T3). The subjects had not had orthodontic treatment. The data for the cephalometric parameters for females are shown in Table 2-6.

The inclination of both upper and lower incisors did not change significantly from T1 to T3 except for the maxillary incisors retroclining between T1 and T2. The mandible showed a slight backward rotation from T2 to T3. There was an increase in total anterior face height (Na-Me) with most of this change occurring between T2 and T3. The upper anterior face height (Na-PP) increased significantly also during this time period, but the lower anterior face height (Me-PP) increased earlier from T1 to T2. Mandibular corpus length showed a significant increase from T2 to T3. This study showed that the dental relationships tend to remain relatively constant, but that the face height and jaw length continue to increase into the third decade of life in untreated subjects.

Long Term Posttreatment Changes

Having highlighted some of the changes that occur as part of the natural process of maturation and growth, we turn to studies that explore the long-term skeletodental changes of cases following orthodontic treatment.

We also look at studies that explore posttreatment changes and its relationship to growth and aging. Lastly, we turn to studies that look at various pretreatment factors that may be predictive of posttreatment relapse.

Skeletal Changes

Ahn and Schneider (2000) performed a cephalometric analysis of posttreatment vertical changes in 33 white adults (25 females and 8 males) with a mean age of 28.4 years pretreatment (T1) and 33.2 years posttreatment (T2). Cephalograms were taken 5.6 years after T2 (T3). The sample consisted of 8 Class I, 22 Class II, and 3 Class III patients. During treatment, the Y-axis angle showed a significant increase of 1.5°, the MP angle increased 1.5°, and Pogonion moved backward 1.7 mm. AFH, LAFH, and PFH all increased during treatment. The FOP angle tipped down 1.9°, the maxillary incisors retroclined 3.8°, and the mandibular incisors proclined 6.4° resulting in a 3.0 mm decrease in overjet. These movements are typical of Class II elastic wear. Overbite decreased 2.6 mm during treatment despite the 2.1 mm extrusion of the maxillary incisors. The mandibular incisors intruded 2.4 mm. Most of the overbite correction was due to

Table 2-6. Cephalometric variables for females at 18 years (T1), changes from 18-21 years (T1-T2), changes from 21-28 years (T2-T3), and changes from 18-28 years (T1-T3).¹

Variable	<u>T1</u>		<u>T1-T2</u>		<u>T2-T3</u>		<u>T1-T3</u>	
	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
U1-PP (°)	107.68	5.54	-0.90	0.44*	0.41	0.56	-0.66	0.59
L1-MP (°)	95.96	6.49	0.77	0.45	-0.38	0.38	0.48	0.53
PP-MP (°)	25.92	6.12	-0.22	0.22	-0.8	0.30*	0.74	0.29*
U1-L1 (°)	130.03	11.99	0.33	0.59	-0.84	0.67	-0.52	0.75
Na-PP (mm)	53.29	3.37	-0.12	0.18	0.45	0.19*	0.45	0.13*
Me-PP (mm)	66.07	5.03	0.56	0.17**	1.54	0.24***	2.16	0.31***
Na-Me (mm)	119.38	7.36	0.42	0.22	2.07	0.28***	2.60	0.34***
Go-Pg (mm)	75.31	5.35	-0.30	0.28	1.54	0.44**	1.66	0.43***

*P < 0.05; **P < 0.01; ***P < 0.001

Source: Gormely JS, Richardson ME. Linear and angular changes in dento-facial dimensions in the third decade. Br J Orthod 1999;26:51-5.

molar extrusion; the maxillary molars extruded 0.9 mm and the mandibular molars extruded 1.0 mm. In this study, the vertical molar movements were not associated with changes in the Y-axis angle. During posttreatment, the Y-axis angle showed a statistically significant relapse of 0.4° and the chin position relapsed as well, even though a significant amount of correction remained. The AFH, LAFH, and PFH did not exhibit significant changes. The FOP angle and the vertical position of the molars were stable. Overbite relapsed 78% largely due to the movement of the mandibular incisors. Overjet relapsed 29% largely due to the maxillary incisors continuing retroclination. Seven patients showed an increase in the Y-axis angle after treatment, which averaged 0.6° . The remaining 26 patients showed a mean Y-axis angle decrease of 0.6° . It was found that 75% of the clockwise rotation of the Y-axis angle persisted at the recall examination. Large treatment changes in the Y-axis angle and horizontal position of Pogonion were not followed by large amounts of relapse. Counterclockwise relapse may be detrimental in patients where an increase in convexity is undesirable. It was concluded that changes in mandibular position during treatment was not predictive of the posttreatment movement of this bone.

Harris, Gardner and Vaden (1999) performed a longitudinal cephalometric and cast analysis to study long-term (10 to 15 years) postorthodontic craniofacial changes. There were 36 patients treated by one practitioner using standard Edgewise appliances. There were 9 Class I malocclusions, 19 Class II division 1 malocclusions, 7 Class II division 2 malocclusions, and 1 Class III malocclusion. All patients were treated with the extraction of premolars. Recall records were taken an average of 5.5 years and an average of 14.4 years after treatment (mean pretreatment age = 12.9 years; posttreatment average age = 16.2 years; first recall average age = 21.6 years; second recall average age = 30.5 years).

The maxillary skeletal changes included a continued increase in midface length (Cd-A Point) representing a downward and forward growth of the maxilla during late adolescence; the posttreatment increase was 65% of the treatment increase. Mandibular skeletal change included a 3.9 mm increase in linear distance of Ar-Gn from posttreatment to the first recall and remained statistically unchanged at the second recall possibly due to the deceleration of facial growth; the posttreatment increase was 65% of the treatment increase. Mandibular length (Cd-Gn) increased an average of 3.9 mm at the first recall and 1.0 mm from the first to second recall examination; the posttreatment increase in mandibular length was 73% of the treatment increase. The mandibular corpus length (Go-Pg) increased 1.9 mm by the first recall examination and remained statistically unchanged thereafter; the posttreatment increase in mandibular corpus length was 53% of the treatment increase. The anteroposterior position of Pogonion relative to Nasion-Perpendicular showed a significant decrease of 1.5

mm from posttreatment to the first recall examination. This change was attributed to the downward and backward rotation of the mandible or forward growth of Nasion. Lower anterior facial height increased 1.7 mm from posttreatment to the first recall examination and remained statistically unchanged to the second recall examination. Posterior facial height (Se-Go) increased an average of 3.5 mm by the first recall examination and 1.0 mm by the second recall examination. FMA decreased an average of 1.6° by the first recall examination. ANB angle increased an average of 2.3° by the second recall examination. The angle of facial convexity (Na-A-Pg) decreased 1.0° by the first recall examination and then by 1.1° by the second recall examination. The Y-axis decreased an average of 0.9° by the first recall examination. Both Downs' Occlusal Plane and the Functional Occlusal Plane angles decreased (1.8° and 2.4°, respectively) by the first recall examination.

Continued increases in Ar-Go, Cd-Go, and Se-Go showed an increase in posterior facial height, and they reflect ramus growth and gonial remodeling. The posterior vertical growth exceeded the anterior growth posttreatment. The PFH/AFH ratio continued to increase showing a counterclockwise rotation of the mandibular and occlusal planes. However, both anterior and posterior facial height remained unchanged at the second recall examination, which indicated decrease of facial growth with age. The decrease in FMA posttreatment showed a counterclockwise rotation of the mandible. This was confirmed by the similar change in Y-axis. These changes moved Pogonion and Gnathion farther forward. Mandibular growth was confirmed by increases in mandibular length and corpus length. Facial convexity continued to decrease, resulting in a flattening of the profile, which is attributed to continued mandibular growth and counterclockwise mandibular rotation. The increase in overjet and Cd-A by the posttreatment examination suggests an anterior movement of A Point. As can be seen, there was continued mandibular and maxillary growth into "early adulthood." Vertical maxillary growth continued through the late recall period. There was a counterclockwise rotation of the mandibular and occlusal planes between 16 to 21 years of age.

In summary, it was found that most skeletal linear measurements increased significantly from the end of treatment to the first recall (16 to 21 years), but that there were few changes thereafter (21 to 30 years). Because there was little change from first to second recall in any of the variables, results suggest that if relapse occurs, it is likely to happen soon after treatment.

Dental Changes

Class II Division 1

Fidler *et al.* (1995) studied the long term stability of Class II division 1 malocclusions. Dental casts and cephalograms of 78 patients (33 males and 45 females; sexes pooled) of the Orthodontic Department of the University of Washington were studied. There were 37 patients treated with extraction of four first premolars and 41 patients treated without extraction with a mean age of 11.2 years prior to treatment (T1). The average time out of treatment was 14 years. The cephalometric measurements made posttreatment (T2) and 14 years later (T3) are shown in Table 2-7.

The changes from T2 (after treatment) to T3 (14 years out of treatment) were small, with few patients exhibiting changes greater than 1.5 mm, regardless of the variable. There was a positive association between increase in overjet from T2 to T3 and changes toward a Class II relationship of posterior teeth, increase in overbite, and increase in maxillary incisor proclination. There was no association between the increase in overjet from T2 to T3 and pretreatment condition. Between the extraction and nonextraction group, the inclination of the mandibular border increased more in the nonextraction group from T1 to T2 ($\bar{x} = 0.45$; sd 2.06, $P < 0.05$). The average of the linear measurements for vertical position of the maxillary first molar increased more in patients treated nonextraction ($\bar{x} = 4.15$; sd = 2.57) than in the extraction group from T2 to T3 ($\bar{x} = 1.92$; sd = 1.84, $P < 0.001$). However, this change was not associated with changes in mandibular plane angle or facial height ratio. There was a significant amount of growth posttreatment, though the angular measurements remained unchanged. It was concluded that the most important factor in long term stability was the posttreatment relationship and function and not the appliance used or whether extractions were used.

First Premolar Extraction

Little, Wallen, and Riedel (1981) studied casts of 65 first-premolar extraction cases from the University of Washington at least 10 years out of treatment. The median age pretreatment was 13 years old, at posttreatment was 15 years and 2 months old, and at recall was 30 years and 1 month old. Angle Class III cases were excluded. The irregularity index, mandibular intercanine width, mandibular arch length, overbite, and overjet were measured. There were no significant differences between posttreatment and long-term crowding between various Angle malocclusions and sexes as shown in Table 2-8. Long

Table 2-7. Mean linear and angular measurement on cephalograms made after treatment (T2) and a mean of 14 years posttreatment (T3) in 78 patients treated for angle Class II, division 1 malocclusion.

Variable	<u>T2</u>		<u>T3</u>	
	$\bar{x}$	sd	$\bar{x}$	sd
SNA (°)	79.38	3.72	79.53	3.31
SNB (°)	75.54	3.62	75.87	3.39
ANB (°)	3.85	2.04	3.67	2.29
Cd-A (mm)	92.39	4.92	94.62	5.15**
AOBO (mm)	0.25	2.34	1.63	2.42**
U1-L1 (°)	129.76	7.46	129.93	7.82
IMPA (°)	98.27	5.29	98.32	6.04
U1-SeNa	98.13	7.05	99.51	7.19*
U6-PP (mm)	18.47	2.56	20.70	2.83**
Na-Me (mm)	121.39	7.14	124.91	7.54**
Se-Go (mm)	79.38	6.12	84.79	8.34**
MP-SeNa (°)	33.85	5.32	32.23	6.17**

*P < 0.05; **P < 0.001

Source: Fidler BC, Årtun J, Joondeph DR, Little RM. Long-term stability of Angle Class II, division 1 malocclusions with successful occlusal results at end of active treatment. Am J Orthod Dentofac Orthop 1995;107:276-85.

Table 2-8. Mandibular anterior irregularity index values.

	<u>Class I</u>			<u>Class II-1</u>			<u>Class II-2</u>			<u>All classes</u>		
	n	$\bar{x}$	sd	n	$\bar{x}$	sd	n	$\bar{x}$	sd	n	$\bar{x}$	sd
Pretreatment												
Male	9	8.93	5.28	11	4.39	2.10	3	8.46	2.43			
Female	18	7.76	4.81	15	8.41	4.05*	5	5.02	2.74*			
Pooled	27	8.14	4.50	26	6.71	3.88	8	6.31	3.03	61	7.31	4.29
Posttreatment												
Male	9	2.10	0.50	12	1.62	0.61	3	1.58	0.19			
Female	21	1.65	0.61	15	1.69	0.76	5	1.88	0.74			
Pooled	30	1.78	0.61	27	1.66	0.68	8	1.77	0.59	65	1.73	0.63
Long term recall												
Male	9	4.79	1.22	12	3.72	1.36	3	4.60	2.18			
Female	21	4.75	2.30	15	5.24	2.07	5	3.86	1.30			
Pooled	30	4.82	2.01	27	4.56	1.92	8	4.13	1.58	65	4.63	1.91

*Males and females differ significantly $P \leq 0.01$

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.

term irregularity could not be predicted from the amount of initial crowding, which is shown in Table 2-9.

More than 60% showed lower canine expansion of more than 1 mm during treatment. 60/65 cases showed lower canine constriction in the long term ($\bar{x} = -2.02$; $sd = 1.57$, $P < 0.0001$). The arch width change during treatment was a poor predictor of long term crowding ($r = 0.24$, $P < 0.07$). Arch length continued to decrease after treatment ($\bar{x} = 3.48$; $sd = 0.19$, $P < 0.001$). There was a significant increase in overbite for all cases in the long term ($\bar{x} = 0.76$; $sd = 0.15$, $P < 0.001$), but compared to pretreatment, there was a net reduction in overbite ($\bar{x} = -0.54$; $sd = 0.22$, $P < 0.02$) and overjet 10 years posttreatment. As many as half the rotations returned in a pattern different from the original condition. Long term alignment was variable and unpredictable with less than 30% of cases maintaining satisfactory mandibular anterior alignment over the long term. The Angle class, length of retention, age, sex, and the measured variables were of no value in predicting the long term result.

Little, Riedel, and Engst (1990) studied the long term stability and relapse of 30 cases of serial extraction of first premolars from the files of the orthodontic clinic at the University of Washington and faculty offices. The range of posttreatment time to the recall examination was 10 to 22 years. Irregularity index, mandibular arch length, mandibular intercanine width, overbite, and overjet were measured. Average mandibular anterior irregularity was 1.80 ($sd = 0.91$) mm at T2 (end of treatment) and 4.39 ($sd = 1.64$) mm at T3 (long term), which was a significant ($P < 0.05$) increase. Comparing the 5 year serial extraction posttreatment cases with the matched late extraction group, there was no difference in mandibular anterior alignment. The authors found no clinically significant correlations between the T3 irregularity index and T1, T2 or T3 variables. Though no means were given, the authors found that in general mandibular intercanine width and mandibular arch length decreased whereas crowding, overbite, and overjet increased. These results do not support the reasoning that serial extraction may be more stable in the long term.

Second Premolar Extractions

McReynolds and Little (1990) studied 46 cases with mandibular second-premolar extractions from the files of the University of Washington, faculty offices, and private orthodontic practices in Seattle.

There were 14 cases in the mixed dentition extraction group; mandibular second premolars were congenitally missing or extracted. There were 32 cases in the permanent dentition extraction group. The time out of treatment was 15

Table 2-9. Long term changes in irregularity.

<u>Pretreatment irregularity</u>	<u>Net change</u>	
	Increased	Decreased
Minimal (< 3.5 mm)	13	1
Moderate (3.5 to 6.5 mm)	6	8
Severe (> 6.5 mm)	0	33

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.

years for the mixed dentition group (n = 14) and 17 years for the permanent dentition group (n = 32). Cephalograms as well as casts were obtained pretreatment (T1), end of treatment (T2), and over the long term (T3). The cephalometric data for the early extraction group and the late extraction group are shown in Table 2-10.

The difference in mean cephalometric variables between the early extraction and late extraction group was not significant.

Overbite

Simons and Joondeph (1973) studied the lateral cephalograms of 70 cases 10 years out of treatment who had been treated as adolescents at the University of Washington Department of Orthodontics or from Dr. Riedel's private practice.

Five groups were established based on overbite as follows:

- Group A (n = 68): Entire sample.
- Group B (n = 33): Initial overbite 1.0 to 2.7 mm
- Group C (n = 35): Initial overbite 2.8 to 7.9 mm
- Group D (n = 22): Final overbite 2.2 to 1.5 mm
- Group E (n = 22): Final overbite 3.0 to 5.2 mm

The mean overall superimpositions showed that the occlusal plane to Frankfort plane angle opened during treatment then decreased to its original dimension in the long term. The mandible grew downward and forward. The maxillary first molar and mandibular first molar continued to erupt and migrate mesially while the maxillary incisor continued to erupt and showed a tendency to protrude. The mandibular incisor continued to erupt vertically and tended to retrocline. Depression as well as protrusion of the mandibular incisor during treatment was correlated with overbite relapse. These results favor the idea that the original mandibular incisor position has limitations. The arch length decreased between the first molar and incisors. The gonial angle decreased over the long term. Mean overall superimpositions showed Group B to exhibit a downward and forward growth of the mandible, while Group C showed a more horizontal growth. Group C showed a greater degree of overbite relapse. Mean superimpositions of Group D suggested a more vertical pattern of growth when compared to Group A. Group E showed less vertical mandibular growth when compared to Groups D and A.

Group A (entire sample) and Group C (deep initial overbite) were further tested because they showed the most significant correlations to other craniofacial

Table 2-10. Cephalometric data for the early extraction group and the late extraction group.

Variable	<u>Early extraction</u>				<u>Late extraction</u>			
	<u>T2</u>		<u>T3</u>		<u>T2</u>		<u>T3</u>	
	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
ANB (°)	3.6	1.8	3.4	2.5	3.0	1.7	3.6	1.8
SNA (°)	80.2	4.8	80.9	3.7	79.1	4.1	80.9	3.4
SNB (°)	76.6	4.2	77.5	3.8	76.1	4.1	77.3	3.5
U1-L1 (°)	136.7	7.5	136.5	8.2	134.0	10.1	135.5	12.5
OP-SeNa (°)	18.9	3.9	19.8	3.9	17.8	4.56	17.3	5.3
IMPA (°)	89.2	6.4	91.0	7.3	91.8	7.2	91.6	8.3
L1-NaB (°)	23.3	4.8	23.4	5.1	25.0	6.2	23.4	8.0
Y axis (°)	68.7	4.5	69.1	3.8	67.0	4.2	66.6	4.6
LAFH (mm)	69.4	8.3	72.0	8.4	85.6	4.9	67.8	5.4
UAFH (mm)	54.7	3.3	57.0	3.2	53.7	3.7	54.8	4.1
TAFH (mm)	124.1	10.9	129.0	11.1	119.3	7.1	122.5	8.0
MP-SeNa (°)	37.5	3.4	36.4	5.6	35.9	6.0	34.4	6.8
LPFH (mm)	45.0	4.0	49.0	4.3	65.6	4.9	67.8	5.4
TPFH (mm)	77.2	5.4	82.3	5.8	75.1	5.1	79.3	6.7
Md length (mm)	107.9	7.3	112.3	7.3	106.9	5.2	111.0	6.9

Source: McReynolds DC, Little RM. Mandibular second premolar extraction — postretention evaluation of stability and relapse. Angle Orthod 1990;61:133-44.

characteristics. First, sex and age were looked upon. There was no difference between sexes of the initial overbite and treatment change in overbite. However, in the long term, females exhibited greater overbite relapse. The authors believe this to be due more to the age at which treatment began because males had more vertical growth remaining after treatment. Posttreatment overbite stability was similar regardless of extraction or nonextraction treatment. Generally, Class I and Class II, division 2 cases showed greater overbite relapse.

In summary, patients with a deep initial overbite had a deep overbite 10 years out of treatment whereas those with a small initial overbite had a small overbite 10 years out of treatment. Those patients who had a large decrease in overbite during treatment had the greatest amount of relapse in the long term. The initial maxillary incisor position was not correlated with overbite relapse. Patients with the greatest amount of growth in the ramus and body of the mandible following treatment had the least amount of overbite relapse 10 years out of treatment. Lack of mandibular growth and a strong horizontal growth pattern were correlated with overbite relapse. An increase in anterior denture height (ANS-Me) was related to overbite stability. Continued vertical eruption of molars was also associated with overbite stability. Relapse in overbite was correlated with a decrease in the occlusal plane to Frankfort Horizontal angle.

Continued Eruption

Continued eruption is a term used to describe the eruptive movements of the teeth that occur after emergence into occlusion. Iseri and Solow (1996) performed a longitudinal study on the continued eruption of maxillary incisors and first molars in girls from 9 to 25 years of age. Data were collected from 147 lateral cephalograms from the archives of the implant study of Arne Björk. The selection criterion was the presence of bilateral posterior maxillary implants and anterior maxillary implants. There were various types of malocclusions.

The continued eruption of a maxillary tooth was defined as the displacement of the tooth in relation to the maxillary base, which was assessed by superimposition on the maxillary implants. Two maxillary superimpositions were made for each film, one at the anterior implant point and one at the posterior implant point. The average continued eruption was 6.0 mm downward and 2.5 mm forward for maxillary incisors and 8.0 mm downward and 3.0 mm forward for maxillary first molars. Due to the difference between incisor and molar eruption, there was a mean decrease in the occlusal plane inclination in relation to the implant line of 4.5° from 10 to 16 years of age, after which there was no significant change; this corresponded to the end of pubertal growth spurt in girls. The maxillary central incisor eruption rate decreased from 10 to 18 years

of age. For the maxillary first molars, the peak rate was at 12 years and a gradual decrease followed until 17 years of age. There was considerable variability in the amount and direction of continued eruption of incisors and molars, which was related to the direction of facial development.

Soft Tissue Profile

Anderson, Joondeph, and Turpin (1973) studied 70 cases averaging 10 years posttreatment from the University Washington Department of Orthodontics to examine the profile changes after treatment. Alignment of the headfilms on the Y axis was done on the facial plane (Na-Pg) and on the most labial point of contact of the lips on the X axis. A cross-sectional analysis of soft tissue thickness of the sample was made. Following treatment, maxillary incisors showed a significant anterior or labial relapse of 1.0 mm when superimposed on the maxilla (palatal plane, anterior nasal spine, and key ridge), but showed a slight retraction when measured to the facial plane. This could be due to growth at Nasion and Pogonion resulting in an anterior movement of the facial plane. Ten years out of treatment, the mandibular incisor was lingually repositioned 2.5 mm for the small overjet correction group and 1.1 mm for the large overjet correction group. Thickness of the lower lip relative to the labial surface of the lower incisor showed no significant change during or after treatment though minor decreases were seen. The soft tissue thickness measurement from A Point decreased 1.0 mm in thickness overall (T3-T1). The soft tissue thickness from B Point to the inferior labial sulcus showed no change. Pogonion relative to Na-B line over the entire period increased 1.4 mm for females with the majority of the increase following after treatment; the authors felt this to be due to the appositional bone growth at Pogonion. Nose length as measured from the facial plane increased 1.8 mm for females. Following orthodontic treatment, there was a significant flattening of the facial profile with relative retrusion of the lips and teeth. Most cases ($n = 67$) showed retraction of upper and lower lips relative to E plane. All profiles were studied before treatment and 10 years out of treatment relative to the esthetic plane and all cases showed a decrease in dentofacial protrusion. The soft tissue profile changes were a combination of orthodontic treatment and maturation. The result of these effects was a flattening of the facial profile.

Wilson *et al.* (1999) studied the cephalometric radiographs of 88 patients to see if there was a difference between soft tissue profile changes of a group treated with serial extraction and no subsequent orthodontic treatment, serial extraction and orthodontic treatment, and adolescent patients treated with four first-premolar extractions. 76% of the patients were treated in private practice of faculty members and 24% were treated in the Graduate Orthodontic Clinic of the

University of Washington. There were three groups: A (serial extraction without subsequent orthodontic treatment; n = 28; 13 males, 15 females), B (serial extraction with orthodontic treatment; n = 30; 6 males, 24 females), and C (four first-premolar extractions; n = 30; 4 males, 26 females). Cephalograms were taken at T0 (preextraction), T1 (postextraction), T2 (posttreatment), and T3 (long term).

From T2 to T3, there were several significant changes in all three groups including alterations at Pogonion, Nasion, Pronasale, an increase in facial height, and a decrease in ANB angle. No statistically significant difference was found between groups from the end of treatment to the long-term examination. However, there were several associations between variables as is seen in Table 2-11.

Zierhut *et al.* (2000) studied 63 Class II division 1 Caucasian adolescents (23 first premolar extraction, 40 nonextraction) from the University of Washington files to compare the long term ($\bar{x}$ = 14 years) soft tissue profile changes. There were 33 females and 30 males. The mean sample characteristics are shown in Table 2-12.

There was no statistically significant difference between the extraction and nonextraction groups for the hard and soft tissue profile variables. Table 2-13 lists the changes from end of treatment (T2) to long-term recall examination (T3) for the extraction and nonextraction groups. The lips became more retrusive relative to the esthetic plane in both groups over the long term. Overall superimpositions showed that this change resulted from mandibular growth and nose development as evidenced by an anterior movement of soft tissue Pogonion and soft tissue Nasion contributed more to the flattening of the profile than an actual lip retraction. The significant and similar amounts of mandibular growth and nasal development in the long term exceeded the slight forward movement of the lips.

Some predictors for the position of the lower lip in the long term were found. The more retruded the lower lip was to the esthetic plane and the greater the lower lip thickness at the pretreatment examination, the more likely it was to be retruded after treatment and in the long term. The greater lower lip thickness relation mentioned above may be due to initial excess overjet.

Stephens *et al.* (2005) studied 40 white Class I and Class II patients treated by the same orthodontist at an average of 15 years posttreatment. 20 patients were treated with four-premolar extraction and 20 were treated nonextraction. They stated that the presumption of those in favor of nonextraction was that extraction led to retruded lower faces and that the presumption of those in favor

Table 2-11. Correlation coefficients of the associations between changes from T2-T3.

Correlations	SET	LET
<u>Hard tissue to soft tissue</u>		
A-A'	0.75	
B-lower lip	0.94	0.82
B-A	0.77	0.77
<u>Soft tissue to soft tissue</u>		
Upper lip-A'	0.93	0.88
Lower lip-upper lip	0.89	0.94
B'-A'	0.83	0.71
B'-lower lip	0.89	0.88
Pg'-lower lip	0.77	0.90
Pg'-B'	0.93	0.93

SET (Serial Extraction Treatment).

LET (Late Extraction Treatment)

Source: Wilson JR, Little RM, Joondeph DR, Doppel DM. Comparison of soft tissue profile changes in serial extraction and late premolar extraction. Angle Orthod 1999;69:165-74.

Table 2-12. Mean ages at T1, T2, and T3 and mean treatment and posttreatment times.

Variable	Extraction	Nonextraction
Mean age T1	12.6	11.3
Mean age T2	15.9	14.7
Mean age T3	31.3	31.9
Mean treatment time	2.9	2.5
Mean posttreatment time	13.0	14.5

Source: Zierhut EC, Joondeph DR, Årtun J, Little RM. Long-term profile changes associated with successfully treated extraction and nonextraction Class II division 1 malocclusion. *Angle Orthod* 2000;70:208-19.

Table 2-13. Changes from T2-T3 for extraction and nonextraction groups.

Variable	Extraction (n = 23)		Nonextraction (n = 40)	
	$\bar{x}$	sd	$\bar{x}$	sd
L1-NaB (mm)	0.23	1.16	0.03	1.79
L1-NaB (°)	0.61	4.61	-1.05	3.99
IMPA (°)	0.64	4.34	-0.08	4.52
U1-NaA (mm)	0.88	1.20	0.71	1.23
U1-NaA (°)	2.50	6.35	1.10	4.18
NAPg (°)	-1.14	3.25	-1.34	3.76
ANB (°)	-0.36	1.19	-0.59	1.32
Lower lip to E plane	-1.44	1.67	-2.46	2.04
Upper lip thickness	-1.43	1.71	-1.73	1.69
Lower lip thickness	0.25	1.24	-0.06	1.51

Source: Zierhut EC, Joondeph DR, Årtun J, Little RM. Long-term profile changes associated with successfully treated extraction and nonextraction Class II division 1 malocclusion. Angle Orthod 2000;70:208-19.

of extraction was that nonextraction led to the “blowing out” of incisors. The results showed that both groups were more retruded after treatment, and there was a flatter profile over the long term of 15 years; males showed more retrusion. There were no significant differences between the extraction and nonextraction groups; both groups showed similar changes over time (Table 2-14).

These changes followed normal patterns for untreated subjects resulting from the greater growth in the chin and nose with age. In conclusion, the type of treatment was not related to the posttreatment changes.

Factors Possibly Predictive of Posttreatment Stability

Some studies have investigated factors that may contribute to stability in the long-term.

Stable and Unstable Results

Ormiston *et al.* (2005) compared groups of patients with the most stable and unstable treatment results as rated by the peer assessment rating (PAR) index to identify factors associated with stability. The sample consisted of 86 patients (30 males, 56 females) from the archives at the University of Washington. Dental casts and cephalograms were taken at pretreatment (T1), posttreatment (T2), and an average of 14.4 years after treatment (T3). The sample was divided into 2 groups: stable ($n = 45$) and unstable ($n = 41$). The stable group was those with an unweighted PAR score of less than 3 at T3. The unstable group was those with an unweighted PAR score of greater than 10 at T3. The differences between the groups in terms of age at the start of treatment, treatment time, posttreatment time, extraction percentages and patterns were not significant. Ormiston *et al.* found more women in the stable group (80%); men were more than 4 times as likely to have unstable occlusions. Of note, men experienced more facial growth, which suggests that growth can be a contributing factor to instability. Growth could correct poor occlusion, but it could also cause good occlusion to deteriorate, depending on the situation. Ormiston *et al.* also noted that there were significantly more Class II patients in the unstable group (71%); they were twice as likely to be unstable with all other factors constant. In addition, more severe malocclusions tended to have greater relapse posttreatment (Table 2-15). Pretreatment occlusion was identified as a possible predictor of long-term stability.

Table 2-14. Posttreatment (T2) and long term (T3) cephalometric measurements and changes.

Variable	<u>Extraction</u>		<u>Nonextraction</u>	
	$\bar{x}$	sd	$\bar{x}$	sd
T2				
Na'-Sn-Pg' (°)	163.6	4.9	163.5	4.8
Upper lip E line (mm)	-5.9	1.4	-5.4	2.1
Lower lip E line (mm)	-3.6	2.2	-4.2	2.2
U1-SeNa (°)	105.6	6.2	103.8	6.6
L1-NaB (mm)	3.9	1.8	3.4	1.8
T3				
Na'-Sn-Pg' (°)	167.6	4.9	166.4	5.6
Upper lip E line (mm)	-7.3	2.0	-7.0	2.7
Lower lip E line (mm)	-4.9	3.0	-5.7	2.7
U1-SeNa (°)	105.1	6.6	104.9	7.6
L1-NaB (mm)	3.9	2.3	3.1	2.0
Long term changes				
Na'-Sn-Pg' (°)	4.0	3.5*	2.9	3.7*
Upper lip E line (mm)	-1.5	1.5*	-1.6	2.5*
Lower lip E line (mm)	-1.3	1.5*	-1.6	2.2*
U1-SeNa (°)	-0.6	4.3	1.1	4.0
L1-NaB (mm)	0.1	1.0	-0.3	1.2

*Significant ($P < 0.05$) changes within group

Source: Stephens CK, Boley JC, Behrents RG, Alexander RG, Buschang PH. Long-term profile changes in extraction and nonextraction patients. Am J Orthod Dentofacial Orthop 2005;128:450-7.

Table 2-15. Variables at T1, T2, and T3 in the unstable and stable groups.

Variable	Time	P-value	<u>Unstable</u>		<u>Stable</u>	
			$\bar{x}$	sd	$\bar{x}$	sd
Overbite (mm)	T1	0.1744	4.5	2.3	3.9	2.0
Overbite (mm)	T2	0.7377	2.4	1.1	2.1	1.1
Overbite (mm)	T3	0.0036	3.6	1.9	2.7	0.9
Overjet (mm)	T1	0.0299	6.5	3.7	4.9	3.5
Overjet (mm)	T2	0.0523	2.5	0.9	2.1	0.7
Overjet (mm)	T3	0.0000	3.9	1.5	2.4	0.7
SNA (°)	T1	0.5236	81.6	3.4	82.2	4.3
SNA (°)	T2	0.5740	80.1	3.4	80.6	4.3
SNA (°)	T3	0.5245	80.5	4.0	81.0	4.5
SNB (°)	T1	0.0451	76.0	3.5	77.6	3.8
SNB (°)	T2	0.0349	76.0	3.6	77.7	3.7
SNB (°)	T3	0.0190	76.6	3.9	78.4	3.6
ANB (°)	T1	0.0325	5.6	2.0	4.6	2.6
ANB (°)	T2	0.0199	4.1	2.3	2.9	2.5
ANB (°)	T3	0.0155	4.0	2.8	2.6	2.4

Source: Ormiston JP, Huang GJ, Little RM, Decker JD, Seuk GD. Retrospective analysis of long-term stable and unstable orthodontic treatment outcomes. *Am J Orthod Dentofacial Orthop* 2005;128:568-74.

Overbite

Kim and Little (1999) studied 62 Class II division 2 patients from the University of Washington files to search for predictors of posttreatment overbite. There were 31 men and 31 women. Casts and cephalograms were measured an average of 15 years posttreatment. At recall, Group 1 ($n = 33$) were those that had an overbite ≥ 4 mm and group 2 ($n = 29$) were those with overbite < 4 mm. The cephalometric mean measurements are shown in Table 2-16.

The long term changes in overbite in Class II division 2 cases were highly variable. Maxillary and mandibular incisors that were very upright pretreatment tended to have deeper initial overbites and showed a tendency to return to this state over the long term. A favorable vertical growth pattern contributed to the maintenance of a stable overbite. This can be seen in Table 2-17.

Trabecular and Cortical Bone

Rothe *et al.* (2006) looked at the trabecular and cortical bone of the mandible as risk factors for orthodontic relapse, specifically in the incisor region. This region was chosen because it is often the site of crowding in the long term.

The subjects were from the posttreatment database at the University of Washington; those with mandibular canine or incisor extractions were excluded. There were two groups: relapse ($n = 60$, 61% female, Irregularity Index > 6.0 mm 10 years out of treatment) and a control stable group ($n = 263$, 69% female, Irregularity Index < 3.5 mm 10 years out of treatment). The mandibular Irregularity Index was measured on dental casts. Records were taken at pretreatment (T1), posttreatment (T2), and 10 years posttreatment (T3). The mean Irregularity Index at T1 in the relapse group was higher ($\bar{x} = 0.8$; $sd = 3.4$) than in the stable group ($\bar{x} = 0.9$; $sd = 3.2$), which was significant ($P < 0.05$). At T2, the same trend followed with the relapse group II ($\bar{x} = 1.5$; $sd = 0.9$) and the stable group ($\bar{x} = 0.9$; $sd = 0.6$).

Lateral cephalograms, panoramic radiographs, and mandibular periapical radiographs were used to measure the mandibular cortical thickness. Fractal analysis was used to assess the trabecular structure of the lower incisor area. The mandibular cortical thickness dimensions were consistently smaller in the relapse group. The mean cortical thickness in both groups increased from T1 to T3. The results are presented in Table 2-18.

Patients with thinner mandibular cortices were at greater risk for experiencing dental relapse, but there was no difference in the trabecular

Table 2-16. Cephalometric changes of Class II division 2 cases at pretreatment (T1), posttreatment (T2), and the recall examination (T3).

Variable	<u>T1</u>		<u>T2</u>		<u>T3</u>	
	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
SN-MP (°)***	30.2	5.2	29.8	5.3	27.2	6.6
SN-PP (°)*	7.9	3.4	8.7	3.3	8.4	3.2
SN-OP (°)***	14.5	4.7	16.2	4.8	13.9	5.4
Go-Me (mm)***	70.5	5.9	74.0	5.7	76.3	6.2
Na-Me (mm)***	112.7	8.1	119.3	7.9	121.5	8.1
Se-Go (mm)***	75.4	7.1	80.9	7.0	84.9	8.0
Na-PP (mm)***	51.9	3.8	54.3	3.4	55.1	3.4
Me-PP (mm)***	60.9	5.3	65.0	5.7	66.4	6.2
SNA (°)	82.2	3.0	80.8	2.9	81.0	3.0
SNB (°)***	76.6	2.8	77.4	3.0	78.2	3.3
ANB (°)**	5.6	2.1	3.4	2.1	2.9	2.5
AO-BO (mm)	3.4	2.5	0.9	2.1	1.3	2.5
IMPA (°)***	90.3	7.0	94.8	6.4	91.2	6.9
U1-L1 (°)***	149.4	12.2	137.1	9.7	144.3	10.7
U6-PP (mm)***	21.4	3.0	23.1	2.6	24.3	3.0
Upper lip-E plane (mm)***	-2.2	2.7	-5.5	2.5	-8.4	3.3
Lower lip-E plane (mm)***	-2.5	2.8	-5.0	2.4	-7.2	3.2
Se-Gn (mm)***	121.7	8.0	129.2	7.6	132.9	8.6
Overbite (mm)***	6.2	1.4	2.7	1.2	4.1	1.4
Overjet (mm) **	3.1	1.3	1.7	0.6	2.0	0.6

Significance of paired t-test between T2-T3: *P < 0.05; **P < 0.01; ***P < 0.001

Source: Kim TW, Little RM. Postretention assessment of deep overbite correction in Class II division 2 malocclusion. Angle Orthod 1999;69:175-86.

Table 2-17. Variables that showed significant differences between group 1 (overbite ≥ 4.0 mm at T3) and group 2 (overbite < 4.0 mm at T3).

Variable	T1				T3			
	Group 1		Group 2		Group 1		Group 2	
	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
AFH (mm)	112.2	8.3	113.4	7.9	119.4	6.7	123.9	8.9*
LAFH (mm)	60.5	5.3	61.3	5.3	64.8	4.8	68.2	7.1
U1-L1 ($^{\circ}$)	153.1	11.1	145.2	12.2	148.9	9.8	139.1	9.3**
U6-PP (mm)	21.3	3.0	21.6	3.1	23.5	2.7	25.2	3.2*
Lower lip-E plane (mm)	-3.1	2.3	-1.8	3.2+	-7.4	3.5	-7.0	3.0
Facial length (mm)	121.2	8.5	122.2	7.5	130.6	7.9	135.6	8.7*
Overbite (mm)	6.6	1.4	5.8	1.3*	5.2	0.9	3.0	0.9
Overjet (mm)	2.8	1.2	3.5	1.4*	2.1	0.6	1.9	0.5

*P < 0.1; **P < 0.01

Source: Kim TW, Little RM. Postretention assessment of deep overbite correction in Class II division 2 malocclusion. Angle Orthod 1999;69:175-86.

Table 2-18. Mean mandibular cortical thickness (CT) in mm at T1, T2, and T3.

Time	Variable	<u>Relapse</u>		<u>Stable</u>		P-value
		$\bar{x}$	sd	$\bar{x}$	sd	
T1	CT (pan)	3.50	0.49	3.80	0.78	0.28
	CT (ceph)	3.51	0.64	3.78	0.75	0.01*
T2	CT (pan)	4.04	0.49	4.33	0.77	0.24
	CT (ceph)	3.95	0.69	4.38	0.80	0.00*
T3	CT (pan)	4.62	0.96	4.73	0.83	0.59
	CT (ceph)	4.65	0.91	4.94	0.89	0.03*

CT (Cortical Thickness)

*P < 0.05

Source: Rothe LE, Bollen AM, Little RM, Herring SW, Chaison JB, Chen CSK, Hollender LG. Trabecular and cortical bone as risk factors for orthodontic relapse. Am J Orthod Dentofacial Orthop 2006;129:476-84.

structure of the bone. Consequently, thickness of cortical bone may play a role in the multifactorial problem of dental relapse following orthodontic treatment.

Closing Thoughts

Long-term stability is an important goal of orthodontic treatment. The orthodontist seeks to maintain the teeth in an ideal functional and esthetic position over the long-term. However, the teeth have a tendency to return towards their pretreatment conditions, and teeth change positions even in the absence of treatment. Oppenheim (1934) conveyed his frustration stating, "Retention is one of the most difficult problems in orthodontia; in fact, it is *the* problem." Adding to this problem are the high expectations of patients.

In medicine the recurrence of an orthopedic problem and its retreatment are an accepted thing, but the same attitude does not prevail where orthodontics is concerned. The laity thinks of the teeth as little ivory pegs held in bone as if in concrete, moved during orthodontic treatment into an esthetically appealing position where they are locked into place, impervious to the exigencies of biology, to stay there in gleaming array forever more [Graber 1966:331].

There is no simple answer to the problem of orthodontic relapse. However, as can be seen from this review, the specialty has repeatedly approached this problem in an objective scientific fashion. By studying the literature we can gain an understanding of what factors are within our control and those that are not. We can apply this knowledge in clinical practice and provide the most stable long-term results possible for our patients.

CHAPTER 3. MATERIALS AND METHODS

Sample Selection

Data consist of cephalograms of 51 females, all of whom had received comprehensive orthodontic treatment, most involving extractions (first premolars, second premolars, or a combination of the two). Records were obtained from the standard Edgewise practice of Dr. James L. Vaden (Cookeville, Tennessee). The standard Edgewise treatment philosophy emphasizes the importance of not only an esthetic dental result, but an esthetic facial result achieved through the extraction of teeth when necessary. Uprighting teeth over basal bone is considered important for a stable result and the diagnostic facial triangle (FMA, IMPA, FMIA) is used to make cephalometrics a diagnostic tool and guide in treatment, and in the evaluation of treatment results.

This is a sample of convenience. The study analyzed those patients who Dr. Vaden was able to enroll in a recall examination to evaluate the long term posttreatment changes; inclusion was based only on the person complying to undergo a recall examination consisting of a lateral cephalogram, panoramic radiograph, intra and extraoral photos, and dental casts. All women were phenotypically normal American whites.

Sample Description

A breakdown according to Angle's molar classification revealed 17 subjects with a Class I molar relationship (Angle), 27 Class II division 1, 6 Class II division 2, and 1 Class III prior to treatment. The mean age at the beginning of treatment was 13.4 years, with patients remaining in active treatment an average of 2.4 years. The mean age at the posttreatment appointment was 15.8 years old. Recall records were taken an average of 23.4 years after the end of active treatment. The mean age at the recall examination was 39.1 years. This is shown in Table 3-1 and Figure 3-1.

Table 3-1. Ages of the sample at the examination.

Variable	$\bar{x}$	sd
Age at end of treatment	15.8	2.2
Age at recall	39.1	3.5
Duration to recall	23.4	3.4

Figure 3-1. Cases arranged by end date showing the times until the recall examination.

Cephalometric Analysis

The analog cephalograms were scanned using a UMAX Powerlook III flatbed scanner at 300 dpi and 256 gray scale, and the scans were saved as TIFF files. The radiographs in TIFF format were imported into the Dolphin Imaging Cephalometric Tracing and Analysis module (version 10; Dolphin Imaging & Management Solutions, Chatsworth, CA). A custom cephalometric analysis was created on the Dolphin Imaging software. The variables can broadly be grouped into three broad categories of skeletal, dental, and integumental dimensions of interest.

The cephalograms were digitally traced using the Dolphin system. This involved identifying the landmarks necessary for the variables of interest. Landmarks that were ambiguous were compared to the original film to aid in location. When there was a large discrepancy between the left and right images, an average was taken.

There had been a change in cephalometers from the end of treatment to the recall examination. However, no information regarding the first cephalometer was available except that it was a Boyd Rotating Anode. The current cephalometer is a Wehmer — GE with a source-to-film distance of 65 inches and a source-to-midline distance of 5 feet.

To visualize the changes from posttreatment to the recall examination, the digitized cephalograms were superimposed on the Sella-Nasion line with registration at Sella. The posttreatment tracing is shown in black and the recall examination tracing is shown in blue. The superimpositions can be found in Appendix A.

The following alphabetical list provides definitions of the landmarks (evaluated with the cephalogram oriented with Frankfort Horizontal parallel to the plane of reference) used in this study:

- ANS (Anterior nasal spine): the spinous process of the maxilla forming the most anterior projection of the floor of the nasal cavity.
- A Point (Subspinale): the most dorsal point on the curve of the maxilla between the Anterior Nasal Spine and Supradentale.
- Ba (Basion): the most dorsal point on the anterior rim of the foramen magnum.

- B Point (Supramentale): the posterior point on the exterior bony curvature of the mandibular symphysis between Infradentale and Pogonion.
- Cd (Condylion): the most superior-posterior point on the curvature of the capitulum of the condylar process.
- Gn (Anatomic gnathion): the most anterior-inferior point on the exterior surface of the mandibular symphysis.
- Go (Anatomic gonion): the most posterior-inferior point on the gonial process of the mandible.
- St_i: the uppermost point on the vermillion border of the lower lip.
- St_s: the lowermost point on the vermillion border of the upper lip.
- LIA (Lower incisor apex): the apex of the mandibular central incisor.
- LIE (Lower incisor edge): the incisal edge of the mandibular central incisor.
- Me (Menton): the most inferior point on the exterior margin of the mandibular symphysis.
- Na (Nasion): the most anterior point at the suture between the nasal and frontal bones
- Na' (Soft tissue nasion): the point of greatest concavity along the integument between the forehead and the nose.
- Or (Orbitale): the lowest point on the inferior margin of the bony orbit.
- PNS (Posterior nasal spine): the most posterior point on the bony hard palate.
- Po (Porion): the point on the superior rim of the external auditory meatus.
- Pg (Pogonion): the most anterior point on the anterior contour of the bony chin.

- Pg' (Soft tissue pogonion): the most prominent, anterior point on the integumental chin.
- Pr' (Pronasale): the most anterior (ventral) point of the nose (tip of the nose).
- Se (Sella turcica): the midpoint of the hypophyseal fossa, determined by visual inspection.
- Sn (Subnasale): the posterior-superior point at which the columella merges with the upper lip.
- U6 cusp: the mesiobuccal cusp tip of the maxillary first molar.
- W (Symphysis): the most posterior point of the lingual outline of the mandibular symphysis.

The following alphabetical list provides definitions of the lines used in this study:

- E line: the line defined by soft tissue Pogonion' and Pronasale'.
- FH (Frankfort horizontal): the line through Porion and Orbitale.
- L1 axis: the line through the apex and incisal tip of the mandibular central incisor.
- MP (Mandibular plane): the line through Gonion and Menton.
- OP (Occlusal plane): the line that bisects the vertical distance between the upper and lower incisal edges and the most posterior molar occlusal contact. This is Downs' occlusal plane.
- PP (Palatal plane): the line defined by Anterior Nasal Spine and Posterior Nasal Spine
- U1 axis: the line through the apex and incisal tip of the maxillary central incisor.

The following codes are used to characterize the sorts of dimensions. As defined, these are coded as SL, Proj Horz, and Proj Vert:

SL Straight-line distance between two points.

Proj Horz The point is projected forward or backward on a horizontal plane.

Proj Vert The point is projected upward to downward from a landmark to a horizontal plane.

The following is a list of the 27 cephalometric variables (Appendix A) measured in this analysis to characterize skeletal relationships:

1. Sella to Nasion distance [SL]
2. Sella to Point A distance [SL]
3. Sella to Point B distance [SL]
4. Sella to Gnathion distance [SL]
5. Sella-Gnathion to Sella-Nasion angle
6. Nasion perpendicular to PP distance [Proj Vert]
7. Menton perpendicular to PP distance [Proj Vert]
8. ANS to Menton distance [SL]
9. Nasion to Menton distance {SL}
10. Sella to Gonion distance [SL]
11. Sella-Gonion / Nasion-Menton ratio
12. Sella to Basion distance [SL]
13. Nasion-Sella-Basion angle
14. Sella-Nasion-A Point angle
15. Sella-Nasion-B Point angle
16. A point-Nasion-B Point angle
17. Point A to Point B distance perpendicular to DOP [SL]
18. Nasion to Point A distance perpendicular to FH [Proj Horz]

19. Nasion to Point B distance perpendicular to FH [Proj Horz]
20. Condylion to Point A distance [SL]
21. Gonion to Menton distance [SL]
22. Gonion to Pogonion distance [SL]
23. FH to PP angle – can be positive or negative.
24. MP to FH angle
25. MP to Sella-Nasion angle
26. Nasion-Point A to Point A-Pogonion angle (NAP)
27. FH to Nasion-Pogonion angle

The following is a list of the 13 cephalometric variables measured in this analysis to characterize dental relationships:

1. Interincisal angle (U1 to L1 angle)
2. Incisor overbite (OP)
3. Incisor overjet (OP)
4. U1 to Sella-Nasion angle
5. U1 to Nasion-Point A angle
6. U1 to Nasion-Point A distance [SL]
7. L1 to Nasion-Point B angle
8. L1 to Nasion-Point B distance [SL]
9. L1 to MP angle
10. L1 to FH angle
11. OP to FH angle
12. U1 to PP distance [Proj Vert]

13. U6 cusp to PP distance [Proj Vert]

The following is a list of the eight cephalometric variables measured in this analysis to characterize integumental relationships:

1. Lower lip to E line distance [SL]
2. Upper lip to E line distance [SL]
3. Soft Tissue Nasion-Pronasale-Soft Tissue Pogonion Angle
4. Subnasale to St_s distance [SL]
5. Soft Tissue Point A to the outermost point of the upper lip distance perpendicular to FH [Proj Horz]
6. Soft Tissue Point B to the outermost point on the lower lip distance perpendicular to FH [Proj Horz]
7. Pronasale to Subnasale distance perpendicular to FH [Proj Horz]

The variables measured are shown in Table 3-2.

Statistical Design

Data outputted from the Dolphin system were entered into an Excel spreadsheet (Microsoft Corporation, Redmond, WA) then transferred to the JMP statistical package (SAS Institute Inc., Cary, NC). Exploratory data analysis (Tukey 1977) was performed, searching for outliers; those due to technical errors were corrected. Descriptive statistics were computed including arithmetic mean ($\bar{x}$), standard deviation (sd), standard error of mean (sem), upper and lower 95% confidence limit (L_2 , L_1), sample size (n), sample variance (s^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. The null hypothesis was that the change from posttreatment (T1) to recall examination (T2) was not statistically different from zero. All tests were two-tail evaluated at an alpha of 0.05. No correction was made for multiple comparisons. One-sample t-tests (Sokal and Rohlf 1995) were used to evaluate whether a cephalometric variable changed systematically from the end of treatment and the recall examination. In practice the changes were calculated in Excel, and the JMP statistical package was used to test whether the change differed from zero. That

Table 3-2. Abbreviations of variables measured arranged by craniofacial region.

Variable measured	Abbreviation
Cranial base	
Sella to Nasion distance	Se-Na (mm)
Sella to Basion distance	Se-Ba (mm)
Saddle angle	Ba-Se-Na (°)
Nasomaxillary complex	
Sella to A Point distance	Se-A (mm)
Upper facial height	Na-PP (mm)
Sella-Nasion-A Point angle	SNA (°)
A Point to Nasion projected (FH)	A-Na-FH (mm)
Condylion to A Point distance	Cd-A (mm)
Palatal plane angle (FH)	PP-FH (°)
Angle of Convexity	NAP (°)
Facial angle	FH-Na-Pg (°)
Mandible	
Sella to B Point distance	Se-B (mm)
Y axis	Na-Se-Gn (°)
Sella to Gnathion distance	Se-Gn (mm)
Lower facial height	Me-PP (mm)
Upper facial height	ANS-Me (mm)
Posterior facial height	Se-Go (mm)
Sella-Nasion-B Point angle	SNB (°)
B Point to Nasion-perpendicular	B-Na-FH (mm)
Gonion to Menton distance	Go-Me (mm)
Gonion to Pogonion distance	Go-Pg (mm)
Mandibular plane angle (FH)	FMA (°)
Mandibular plane angle (SeNa)	Se-Na-MP (°)
Inter-arch relationships	
PFH/TFH ratio	Se-Go/Na-Me
Total facial height	Na-Me (mm)
A Point-Nasion-B Point angle	ANB (°)
Dental changes	
Wits analysis	AOBO (mm)
Interincisal angle	U1-L1 (°)
<i>Continued</i>	

Table 3-2. *Continued*

Variable measured	Abbreviation
Overbite	Overbite (mm)
Overjet	Overjet (mm)
U1 to Sella-Nasion angle	U1-SeNa (°)
U1 to Nasion-A Point angle	U1-Na-A (°)
U1 to Nasion-A Point distance	U1-Na-A (mm)
L1 to Nasion-B angle	L1-Na-B (°)
L1 to Nasion-B Point distance	L1-Na- B (mm)
Incisor mandibular plane angle	IMPA (°)
Frankfort mandibular incisor plane angle	FMIA (°)
Occlusal plane angle (FH)	OP-FH (°)
Incisor-Palatal plane distance	U1-PP (mm)
Molar-Palatal plane distance	U6-PP (mm)
The integumental profile	
Lower lip to the E line distance	Li-E (mm)
Upper lip to the E line distance	Ls-E (mm)
Pg' to most protrusive lip	Z Angle (°)
Soft tissue convexity	Na'-Pr'-Pg' (°)
Upper lip length	Sn-Sts (mm)
Upper lip thickness	A' to Upper lip-FH (mm)
Lower lip thickness	B' to Lower lip-FH (mm)
Nose prominence	Pr' to Sn-FH (mm)

is, the actual mean change was tested against a hypothesized mean change of zero ($df = n-1$).

CHAPTER 4. RESULTS

The results regarding the changes seen from posttreatment (T1) to the recall examination (T2) are discussed below (Figure 4-1).

Cephalometric Superimpositions

Examples of representative changes noted by the process of superimposition are given in the Appendix B. The posttreatment and long term recall examination digitized cephalograms were superimposed by registering on Sella and orientating along Sella-Nasion. The posttreatment tracing is represented in black and the long term recall examination tracing is represented in blue. Some of the posttreatment radiographs had soft tissue burnout because a soft tissue mask or intensifying screen was not used.

Descriptive Statistics

For convenience all calculated descriptive and inferential statistics are presented in Appendix C-E. This was done to reduce the bulk of the report and for the convenience of the reader in viewing the calculations.

Cranial Base

There was no significant change in the measures of cranial base that were analyzed.

Nasomaxillary Complex

The mean change of approximately 0.5 mm in the Sella to A Point length showed that there is a trend towards growth, but that the inter-individual variability made the average insignificant.

The upper face height, measured as the Nasion to Palatal Plane distance, showed no significant group increase. However, there was evidence of modest growth in some individuals.

There was an average increase of 0.3° in the SNA angle from posttreatment to the recall examination, but this was not significant though

Figure 4-1. Summary of posttreatment changes of cephalometric variables.

larger than the SNB angle change. However, the horizontal distance from A Point to Nasion when projected perpendicularly onto Frankfort Horizontal showed a significant ($P = 0.0053$) though subtle change ($\bar{x} = 0.8$ mm), which is a more apparent change in A Point (ventral growth of maxillae relative to Nasion) than documented by the SNA angle.

The distance from Condylion to A Point increased an average of 0.7 mm ($P = 0.0236$), which simply provides confirmation of mandibular growth. Prior studies (Björk) suggest that most of this was condylar growth. Again, while significant statistically, the mean change of less than a millimeter probably is inconsequential clinically.

The angulation of the Palatal Plane relative to Frankfort Horizontal remained quite stable ($\bar{x} = 0.1^\circ$; $P = 0.7405$) on the average. Coupled with the observation that upper face height increased a little (but not significantly) over this long interval suggests that angulation of the Palatal Plane — at least on the average — can be expected to remain stable.

Consistent with other measures of profile change (ANB, AOBO), there is little systematic change in the bony profile (NAP) over time in these women. This seems largely attributable to their overall lack of posttreatment facial growth. On the other hand, there are some outliers.

Subject A-48 had the greatest change of 7.9° . The original radiographs were inspected and it appears that in the recall examination radiograph, the patient may have not been positioned as well since there is appreciable asymmetry of the mandibular plane. As a result, the A Point is not well defined and this may have lead to inaccurate A Point identification. Subject A-28 had the greatest decrease in NAP of -5.4° , which appears to be caused by a greater forward growth of Pogonion as compared to Nasion and A Point.

Downs' facial angle (FH-NaPg) is an important measure of the bony facial profile that relies on different variables than reviewed in prior paragraphs (ANB, AOBO). The facial angle increased just a bit with aging ($\bar{x} = 0.7^\circ$), but the consistency of the increases across the sample caused the small mean to differ significantly from zero ($P = 0.0020$).

Mandible

The change in the distance from Sella to B Point was not significant. The Na-Se-Gn angle did not show any significant changes.

The distance from Sella to Gnathion is one of the most comprehensive measures of facial growth in that it crosses several craniofacial complexes. Yet, in these women, the average increase ($\bar{x} = 0.7$ mm) is barely significant statistically ($P = 0.0310$).

The measure of lower facial height (Me-PP, ANS-Me) did not show systematic growth even though other studies of men show appreciable increases in lower facial height during this age interval.

The measure of posterior facial height (Se-Go) showed an average change of 0.7 mm ($P = 0.0679$). Increases in posterior facial height may be due to maturation (growth) of the pterygomasseteric sling (muscles). This change is interesting, but has nothing to do with treatment — just normative aging. It is probably too subtle even to affect the perception of facial morphology.

There was no significant finding in the SNB angle. However, the measurement of the distance from Nasion to B Point when projected perpendicularly on Frankfort Horizontal shows a mean change of 0.7 mm ($P = 0.0457$), which shows there is only slight mandibular growth after treatment, but this is marginally significant. By paired t-test, the amounts of forward growth of A Point and B Point are the same. In the average case, then, prominence of the lower face (at A and B Points) was not altered with post-treatment growth.

The measurement of the corpus length (Go-Me) showed an average increase of 0.8 mm ($P = 0.0374$). The distance from Gonion to Pogonion shows an average increase of 1.3 mm ($P = 0.0017$), which affirms an increase in corpus length. This differs from the previous measure of corpus length (Go-Me) in that the chin is included. Counterclockwise (upward-forward) rotation suggests that Go-Pg increases. Also, the envelope of error for Pogonion makes this a more precise measure than Gonion, which may partly explain the difference in results from the previous Go-Me measurement. Statistically (by paired t-test) there is a highly significant difference between the amounts of Go-Me and Go-Pg growth ($t = 3.0$; $df = 48$; $P = 0.0040$). This suggests to us that the difference is indeed due to the inclusion of Pogonion as part of corpus length. Counterclockwise rotation of the symphysis that had been Menton to that of Pogonion with age would account for much of the difference. Moreover, Enlow and Harris (1964) show that the region of Pogonion is appositional over time.

The average case experienced a decrease of $\frac{1}{2}$ degree in FMA over the observation period. This is not significant statistically ($P = 0.09$), but is in the same direction (*i.e.*, flattening) observed for the much larger changes in FMA that occur during the interval of active growth (Ricketts 1981).

Effectively there is no mean change in the SeNa-MP angle. The change is less than when MP is measured relative to FH, suggesting that Nasion may be elevating very slightly with age, and this is consistent with the remodeling changes described in the literature. In particular, the superior aspects of the anterior cranial base are appositional, which creates distortion when Sella-Nasion superimpositions are used over the long term (Coben 1966). The extreme cases noted here are of concern to us (maximum = +4.6°; minimum = -4.3°). We attribute these comparatively large “changes” to difficulties in identifying the key landmarks in these individuals, even though we have re-examined the tracings.

Inter-Arch Relationships

There was no change in the ratio of posterior facial height to anterior facial height (Se-Go/Na-Me), so the “shape” remained constant over a quarter of a century in these women. Even combining the upper facial height and lower facial height (Na-Me), there is no significant change with age or time. Statistics and inspection of cases with greater changes show that most of the change in total facial height (even though nonsignificant) occurred in upper facial height.

As discussed, SNA increased a little and SNB decreased a little so ANB increased to a marginally significant extent statistically ($P = 0.0302$). But the mean change of 0.4 mm is unimportant clinically and most cases changed much less.

Dental Changes

The mean change in AOBO was 0.8 mm, which was larger than the change in ANB. There was “self improvement” with increasing age in this measure of facial harmony. The mean was -1.8 mm at the end of treatment, and this resolved to close to 1.0 mm at the recall examination (Jacobsen: $\bar{x} \approx 0$). This is the same change as noted with ANB, suggesting late continued mandibular growth — as noted in prior studies.

The average interincisal angle remained remarkably stable in the present sample. The average angle was 131° at the end of treatment, and this increased to about 132° at the long-term recall examination. Of note, though, individual changes were much more obvious. For example, A-32 experienced an increase of 20° due to a deepening and uprighting of the upper incisors. Conversely, A-3 had a 10° increase with interincisal angle because both upper and lower incisors

proclined. In both cases, upon inspection of the pretreatment radiographs, it appears that these dental changes reflect the return to pretreatment conditions.

On average, overbite deepened ($\bar{x} \approx 1.0$ mm), and, with benefit of longitudinal data (and consistency of the increases across the sample), this change is highly significant statistically ($P < 0.0001$). Clinically, the mean change of a millimeter probably is inconsequential, though cases near the extreme (maximum ≈ 5.0 mm) would be obvious. A-32 experienced the greatest deepening of the bite to 4.7 mm and upon inspection of the pretreatment radiograph, it can be seen that she started off with a deep bite.

Overjet increased $\frac{1}{2}$ mm on the average, but, as with overbite, this change is highly significant statistically ($P = 0.0010$) because of the consistency of the change and rigor of analysis. The descriptive statistics also show a limited range of change of about ± 2 mm around zero.

The marginally significant trend is for U1 to upright slightly over time ($\bar{x} \approx 1 \frac{1}{2}^\circ$). The large sample variance is noteworthy, disclosing appreciable inter-individual variation in the long-term response to local forces. At the upper extreme, A-28 experienced 8° of proclination after treatment, but the inspection of the pretreatment radiograph shows the inclination of the upper incisor to be closer to that of posttreatment; the recall examination radiograph does show the upper incisor to have proclined. At the other extreme, A-32 underwent 14° of uprighting because as mentioned previously initially the teeth were upright and this case presented a deep bite.

Interpretation of the U1-NaA angle is largely a duplication of the prior variable (U1-SeNa), the major difference is that here the forward movement of A Point slightly enhances the apparent change. On average, the maxillary central incisor uprighted roughly 2° relative to the Nasion-A line (which is the facial reference line advocated by Steiner, 1953). Just as with U1-SeNa, the same outliers stand out from the mean. Millimetrically, the anteroposterior position of U1-NaA was very stable. The trivial mean change does tend to obscure the appreciable inter-individual variation that ranges from ≈ -6 to $+4$ mm.

On average, the L1-NaB angle did not change at all. However, on a case by case basis, some subjects experienced considerable change from $\approx -8^\circ$ to $+7^\circ$. A-32 experienced 8° of L1 uprighting probably as a response to the return to a deep bite as seen in the pretreatment radiograph. Two cases — A-18 and A-31 — exhibited the greatest proclination at about 7° . On the recall examination radiograph for A-31, there could be seen two images of the lower incisor and the outer one was traced, which was the one that was more proclined. Inspection of the pretreatment radiograph of A-18 shows the lower incisor to be more

proclined than the posttreatment radiograph. Millimetrically, the L1-NaB is largely a duplication of the L1-NaB angle. There is no mean change, but with appreciable inter-individual variation — with precisely the same extreme cases.

Quite as expected from the prior four measures of incisor position, the IMPA angular measurement evaluated relative to the mandibular plane was stable on the average ($P = 0.56$). Likewise too, inter-individual variation was appreciable, ranging from about -8° to about 11° . Because the reference plane is different here than for the prior measures of U1 and L1, the extreme cases are different. A-39 experienced the greatest angular uprighting ($\sim 8^\circ$), while case <Nancy Jones> proclined the most ($\sim 11^\circ$) after treatment to an angulation resembling the pretreatment angulation.

FMIA is another key angle in the Tweed analysis, and there was no significant changes with this angle. A-42 showed the greatest uprighting of the lower incisor of $\sim 9^\circ$, while A-17 and A-31 showed the greatest proclining of the lower incisors of $\sim 7^\circ$ and this is consistent with the L1-NaB finding.

On the average, the OP-FH angle also remained stable across the two examinations. As seen from the other dental variables, there is notable inter-individual variability. This particular distribution is unusual in that there is a statistical outlier, with a change of 11° (Table D-38). The outlier is A-9, where there was no asymmetry in the posttreatment (T1) radiograph, but there was a very large asymmetry in the recall examination (T2) radiograph, which could be due to poor patient positioning.

Continued Eruption

U1-PP is the measurement of the vertical distance from the incisal edge of U1 normal to the Palatal Plane. These statistics show that there is demonstrable continued eruption of U1 during adulthood ($P = 0.0063$), such as that documented by Iseri and Solow (1996). The extent of remodeling of the palatal plane cannot be measured in this study, so the mean change of 0.6 mm is only an estimate of the true continued eruption of U1.

Analogous with the prior variable, U6-PP, shows the change in distance (from U6 perpendicular to PP) and is interpreted here as evidence for continued eruption. As noted, the extent of remodeling of the nasal floor cannot be known here, so the downward displacement of U6 ($\bar{x} \approx 0.7$ mm) is viewed as more of a qualitative than absolute estimate of the true movement.

The Integumental Profile

The lower lip (L_i) to E line average distance is -4.3 mm at the end of treatment, which exceeds Ricketts' norm. By t-test, this mean of -4.3 mm is highly significantly greater than Ricketts' -3.0 mm ($t = 3.1$; $p = 0.0029$). The mean distance increased to a mean of -6.3 mm at the recall examination, making the mean posttreatment change $\bar{x} = -1.7$ mm. The lower lip thickness (B' to lower lip distance projected perpendicular to FH) showed an average thickening of 0.3 mm, but this was not a significant finding ($P = 0.3508$).

The upper lip (L_s) to the E line behaves almost the same as just noted for the lower lip: the upper lip is well behind the E-Plane at the end of treatment ($\bar{x} = -6.9$ mm). It receded farther with growth, to a mean of -8.8 mm at the recall examination. The paired change averaged 1.7 mm, which is a highly significant change statistically ($P = 0.0006$). By paired t-test, the changes in L_i and L_s relative to the E Plane are equivalent ($t = 0.2$; $P = 0.85$). The upper lip length ($Sn-St_s$) did not show any significant change. The upper lip thickness (A' to upper lip distance projected perpendicular to FH) thinned an average of -0.5 mm ($P < 0.0280$).

Merrifield's Z-angle is another popular measure of lip position, but, by relying on the "more prominent" lip, its interpretation is imprecise as to the source of the change. In these cases (all females), the Z angle averaged 79° at the end of treatment, and the mean increased to 83° at the recall examination. Development, then, consisted of an average increase in this angle of 4.1° , which is highly significantly different from zero. The recall examination radiograph for A-10, who was an outlier (change of 12.9°), did not have a clear depiction of the nose, but the lips in the posttreatment did look "pouchy" and looked more pleasing in the recall examination radiograph.

The soft tissue convexity ($Na'-Pr'-Pg'$ angle) showed no systematic change. The nose prominence (Pr' to Sn distance projected perpendicular to FH) showed an average change of 2.3 mm. The nose grew as expected and this was a significant finding $P < 0.0001$.

CHAPTER 5. DISCUSSION

Orthodontics involves moving teeth into “ideal” positions, but this is away from the equilibrium position of the maloccluded teeth, so there is a tendency for the teeth to return towards their original state of biomechanical equilibrium (Weinstein *et al.* 1963; Proffit 1978; Thuer *et al.* 1999). The problem of posttreatment relapse is not a new one (Hawley 1919; Case 1920; Hellman 1940), but its analysis is complicated by the effects of posttreatment growth that invariably occur concurrently (Behrents *et al.* 1993).

In the present study the average age was about 16 years at the end of treatment and at the recall examination the average age was about 40 years. This interval captures late adolescent plus early adult growth. Forsberg (1979), Thilander (2000), Israel (1973), and Behrents (1984) – among others – found small but detectable changes occurring in true adulthood, so it is expected that there will be small changes occurring in the present sample as well. Israel (1973) and Behrents (1984) found that the craniofacial complex continues to remodel throughout life. Among the anticipated posttreatment changes are a general enlargement of the skeleton, downward-and-forward movement of the maxilla and mandible away from the cranial base, continued forward growth of the soft tissue nose and chin (making the lips appear more retrusive over time), and a flattening of the facial profile (NAP).

The following sections discuss the cephalometric changes found in the present study based on analysis of the posttreatment changes in a cohort of 51 American white women (17 Class I, 27 Class II division 1, 6 Class II division 2, 1 Class III) out of a single private practice in Cookeville, TN, about 23 years out of treatment.

Before going into detail, Table 5-1 below compares the results found in this study, the Behrents (1984) study on untreated normals, and the Kim and Little (1999) study out of the University of Washington.

These studies were chosen for a general comparison because they are comparable long term cephalometric studies. It should be noted that the present study and the Kim and Little (1999) study out of the University of Washington had a majority of Class II cases whereas the Behrents study looked at normal occlusions. In addition, the Kim and Little (1999) study pooled sexes whereas the present study included only females and the Behrents (1984) study provided data for females. There are differences amongst the studies, but it is interesting to see these results side by side as the Behrents study and the Washington studies are frequently cited in the literature.

Table 5-1. Comparisons of the posttreatment changes in six cephalometric variables in the present study, the Behrents (1984) study, and the Kim and Little (1999) study.

Variable	Present study $\bar{x}$	Behrents $\bar{x}$	Kim and Little $\bar{x}$
SNA	0.30	-0.30	0.20
SNB	-0.11	1.0	0.80
ANB	0.43	0.00	-0.50
IMPA	0.35	-0.80	-3.60
OB	1.15	0.00	1.40
OJ	0.54	0.00	0.30

*Note: Present study (23 years posttreatment), Behrents (T1 = 17-18; T2 = 31-50), Kim and Little (15 years posttreatment).

Overall, all three studies show that there was not much change in the above cephalometric variables in the long term. In the present study, which included a majority of Class II cases, there was a small increase in ANB over the long term. The Behrents study did not show a change in ANB, which could be attributable to the fact that this study observed Class I cases. Harris and Behrents (1988) found that in orthodontically untreated persons followed from approximately 20 years to 55 years those starting with a Class I molar relationship stayed thus and those with a Class II or Class III molar relationship became more Class II or Class III over time. The decrease in ANB seen in the Kim and Little study, which is not expected as this study observed Class II cases, could be due to the inclusion of males in this study because males exhibit larger amounts of growth during adulthood than females. There was not much change in the IMPA in the present study or the Behrents study, but there was a larger retroclination of the lower incisors in the Kim and Little study. This could be a compensatory effect of the dentition in response to the larger amount of growth in the mandible seen in the Washington study, which is most likely due to the pooling of the sexes in this study. There was more change in the overbite and overjet in the treated samples when compared to the untreated Behrents sample. However, this would be expected as the position of the teeth in the treated samples is not their equilibrium positions. Nevertheless, even in the treated samples there was not much change in the dentition and the orthodontic result was fairly stable over the long term.

Cranial Base

The measures of cranial base analyzed in the present study (Se-Ba and the saddle angle) did not change during the study interval, which is expected since the spheno-occipital synchondroses has fused by the end of treatment in females and there would be no growth in the sutures (Melsen 1972, Roche and Lewis 1974, Lewis and Roche 1977).

Behrents (1984) studied an untreated sample and the age range is comparable to the current study with data available for only females. For the Sella to Basion distance there was no increase detected from about 17 years old to the late 30s. The Sella to Nasion distance showed no increase from the 17-18 year range to the 21-30 year range, but increased an average of 1.6 mm from the late teens to the 31-50 year interval. Israel (1973) found that the cranial base enlarged with age, with increases in distance from Sella to Nasion and from Sella to Basion, but that the saddle angle remained the same, suggesting a symmetrical (proportional) pattern remodeling.

Nasomaxillary Complex

The midface showed more activity in terms of bony remodeling than the cranial base. The maxilla continued to move downward and forward away from the cranial base (Figure 5-1) as evidenced by increases in dimensions such as Se-A and A Point to Na (FH). This would be expected from normative growth (*i.e.* remodeling, drift). Resorption of the floor of the nasal cavity and apposition at the bony palate contributes to the downward drift of the nasomaxillary complex. Growth at the circumaxillary sutures contributes to the downward-forward movement of the nasomaxillary complex.

Mandible

There were subtle changes in the mandible (Figure 5-2). The mandible grew as evidenced by an increase in the Sella to Gnathion, Gonion to Menton, and Gonion to Pogonion distances. However, there was no detectable change in the Sella to B Point distance. This could be because the area of B Point is an area of resorption whereas Gnathion is a part of the chin, which is an area of apposition. Enlow and Harris (1964) showed the region of Pogonion to be appositional over time, though their histological method did not permit quantification of the amount of changes. Another factor in the increase of the Gonion to Pogonion measurement could be the counterclockwise rotation of the mandible as evidenced by a decrease in the FMA angle. This counterclockwise rotation could be a reason why there was no apparent growth in the lower facial height because there were approximately equal increases in the ramus height (Se-Go) and corpus length (Go-Me), which may be a result of the development of the gonial process with age. However, the distance from Gonion to Menton is probably a poor measure of corpus length because the envelope of error (Baumrind and Frantz 1971) is greatest along the horizontal axis, so measurements can be imprecise. In the Forsberg (1979) study, the women showed an approximately $\frac{1}{2}^{\circ}$ clockwise rotation of the mandible, which is in contrast to the present study. Forsberg suggested that the increase in lower facial height was unlikely to be due to growth in the sutures or condylar cartilage because these structures would have reached adult size by this time. Forsberg suggested that the increase in face height was due to downward-backward rotation of the mandible, which agrees with the observed increase in Se-Na to MP angle seen in his study. The mandible grew after treatment, with apposition at Gonion and Pogonion, as seen in other studies (Israel 1973; Behrents 1984; Kim and Little 1999). The amounts of change were, however, subtle in the present study (Figure 5-2). Sella-Gnathion—a measure of overall facial growth—increased only 0.7 mm on the average, which was equal to the forward growth at B Point measured perpendicular to FH. In the Kim and Little (1999) study, there

Figure 5-1. Average posttreatment changes in the midface dimensions in the present study. The two dimensions exhibiting statistically significant changes are flagged with an asterisk (alpha = 0.05; two-tail test).

Figure 5-2. Posttreatment changes in the mandible in the present study. The dimensions exhibiting statistically significant changes are flagged with an asterisk (alpha = 0.05; two-tail test).

was a larger increase of approximately 3.0 mm in Se-Gnathion, but this could be due to the pooling of sexes in this study where the males would show greater amounts of growth into adulthood.

Of note, then, both A Point and B Point grew significantly following treatment, but A Point grew forward slightly more on average. The net result is a slight but statistically significant increase in the ANB angle of an average of 0.4°. This lesser growth at B Point may be attributable to the bulk of the cases being Class II at the start of treatment.

Inter-Arch Relationships

The ratio of the posterior facial height to the anterior facial height (Se-Go/Na-Me) exhibited no significant change, suggesting that the proportionality ("shape") of the lower third of the face remained constant. The posttreatment position of A Point and B Point were stable over this age interval, and the ANB angle did not have a clinically relevant change ($\bar{x} = 0.4^\circ$; $P = 0.0302$). A Point and B Point remodel corresponding to the change in the position of the incisors (Reitan 1964); it could be that the stability of the dentition seen in this sample leads to the stability in these points. The increase in ANB could reflect the fact that most of the patients were Class II initially; but, the increase of 0.4° is not clinically relevant. The increase in the distance from A Point to Nasion projected perpendicular to FH and the lack of change in Sella-B is reflective of the Class II growth pattern in which the maxilla shows more growth than the mandible (Stahl *et al.* 2008). Downs' facial angle (1948) is an important measure of the bony facial profile. The facial angle (NAP) increased 0.7°, but the consistency of the increases across the sample caused this small mean to differ significantly from zero ($P = 0.0020$). This systematic increase shows that Pogonion grew forward relative to Nasion, thereby increasing the inferior-posterior angle between the Nasion-Pogonion line and Frankfort Horizontal. Statistically, then, the facial plane (Na-Pg) uprighted slightly with age, but it is unlikely that the mean change would be discernible clinically. This trend toward a straightening of the bony facial profile (FH to Na-Pg) was also found in the Behrents (1984) study. In other terms, when the facial profile (Na-Pg) is evaluated without using A Point, forward growth of the mandible (leading to "flattening" of the profile) becomes more evident.

Dental Changes

The literature shows that, regardless of the treatment technique used, relapse has been a problem in orthodontics (Little, Riedel and Årtun (1988)).

Subjects who present with extreme deep bites, open bites, protrusion, or retroclination all have tendencies to return towards their pretreatment conditions (though seldom to the full extent). Simons and Joondeph (1973) found that patients with a deep initial overbite had a deep overbite 10 years out of treatment whereas those with a small initial overbite had a small overbite 10 years out of treatment. Those patients who had a large decrease in overbite during treatment had the greatest amount of relapse in the long term. Also, they found that females had a greater amount of overbite relapse when compared to males, but that this was because females had less vertical growth remaining posttreatment than did males. The present study showed a remarkable stability of the dentition over the long term, with very few dental changes (Figure 5-3). The upper incisor uprighted about $1\frac{1}{2}^{\circ}$ and overbite increased (1.2 mm; $P < 0.0001$) as did overjet (0.5 mm; $P = 0.0010$), but these average changes seem clinically inconsequential. Kim and Little (1999) observed changes 15 years posttreatment and found comparable changes in overbite (1.4 mm; $P < 0.001$) and overjet (0.3 mm; $P < 0.01$).

The uprighting of the upper incisors could have contributed to the increase in overbite. Another cause of the increase in overbite could be continued eruption of the incisors. Forsberg (1979) also found an uprighting of the upper incisor, but he did not find an increase in overbite, which could have been due to the clockwise rotation of the mandible in the women in his study. The relationships of the incisors to one another and the individual inclinations and positions showed long term stability in the present study (*i.e.*, U1-L1, IMPA, FMIA). On the other hand, Kim and Little (1999) found significant uprighting of the dentition over time with a decrease in IMPA by -3.6° ($P < 0.001$) and an increase in U1-L1 by 7.2° ($P < 0.001$). These larger changes may be due to the larger amounts of growth seen in this study in which male subjects were included.

Also of interest was whether we could identify the effects of continuous eruption documented in studies such as Whittaker *et al.* (1985), Varrela *et al.* (1995), and Iseri and Solow (1996). There are no immobile fiducial landmarks here, so palatal plane (ANS-PNS) was used as an approximation where remodeling is known to be ongoing (Enlow and Bang 1965; Baumrind *et al.* 1987). Continued eruption was evident as seen in the increases in the U1-PP and U6-PP distances. The Forsberg (1979) study documented a similar small amount of continued eruption of the upper incisor. The mean change in the present study of the maxillary molar was only slightly greater than that evidenced by the maxillary incisor, so, while the difference is in the right direction, there is not strong support for flattening of the occlusal plane as suggested by Iseri and Solow (1996). However, as was found by Simons and Joondeph (1973),

Figure 5-3. Average posttreatment dental changes in the present study. The variables exhibiting a significant change across ages are flagged with an asterisk (alpha = 0.05; two-tail test).

continued eruption of the molars in the present study could have contributed to the stability in overbite.

The Integumental Profile

Ricketts (1981) suggests that the lower lip (L_i) is about 3.0 mm behind the E Line at 15 years of age in pleasing profiles – and that this distance increases about 1 ¼ mm each 5 year interval thereafter due to continued growth of the nose and chin. The lower lip was -4.3 mm behind the E line at the end of treatment, which exceeds Ricketts' norm and this may be thought to be due to the high frequency of premolar extractions in the present sample. However, it is comparable to that found in the Kim and Little study of -5.0 mm, which included both extraction and nonextraction cases. In the present study, the mean distance increased to a mean of -6.3 mm at the recall examination, making the mean posttreatment change -1.7 mm. In the Kim and Little (1999) study, the mean distance increased to -7.2 mm, making the mean posttreatment change -2.2 mm ($P < 0.001$). Thus, it seems that this change is not due to the extraction of teeth but rather an effect of aging.

The upper lip to the E line behaved almost the same as for the lower lip: The upper lip was -6.9 mm behind the E line and it 'receded' farther to -8.8 mm at the recall examination. The paired change averaged 1.7 mm, which is a highly significant change statistically ($P = 0.0006$). By paired t-test, the changes in the upper and lower lip relative to the E line are equivalent ($t = 0.2$; $P = 0.85$). We note then that (1) Ricketts' estimated rate of change is excessive compared to our findings, (2) the increased distance is a highly significant decrease, but (3) these distances, by themselves do not suggest anything about whether the posttreatment decreases is due to nose-and-chin growth, loss of tissue tone, or some combination of the two. In fact, the nose grew 2.25 mm ($P < 0.0001$), which affects both the E line and Z angle.

Merrifield's Z-angle is another popular measure of lip position, but, by relying on the "more prominent" lip, its interpretation is imprecise as to the source of the change. In these cases (all female), the Z angle averaged 79° at the end of treatment, and the mean increased to 83° at the recall examination, so development consisted in an average increase in this angle of 4.1°, which is highly significantly different from zero. This uprighting is probably due to a combination of the chin coming forward and flattening (loss of support) of the lips, which thinned 0.5 mm ($P = 0.028$).

Other studies (Forsberg 1979, Behrents 1984) have documented the continued forward movement of the nose and the retrusion of the lips as part of

normative growth. In the present study, there is a relative retrusion of the lips as the nose and chin come forward (Figure 5-4), but this effect is augmented by thinning and 'drooping' of the Stomion line. The literature shows that there is a loss of muscle mass with age (Finch and Schneider 1985), which thins the lips (more so in the lower lip in this study). We also confirmed 'drooping' of the Stomion line as the upper lip elongated (S_m-St_s), causing the lower incisors to become more visible with progressive adulthood.

Overview

Craniofacial growth continued after treatment, although to a smaller degree than found in other studies; this may be because our sample was exclusively female whereas other studies included males. Women grow less and for a shorter period of time than men following puberty (Behrents 1984, Sinclair and Little 1985).

Dentally, there was a remarkable stability as can be seen by the lack of significant change in the mean inclinations of the teeth with respect to each other and to their respective jaws.

The principal changes consist of these five features:

1. The maxilla grew forward a little ($\bar{x} \approx \frac{3}{4}$ mm).
2. The mandible grew forward a little ($\bar{x} \approx \frac{1}{2}$ mm), but this is less than maxillary growth.
3. ANB increased ($\bar{x} \approx \frac{3}{4}^\circ$) because of greater (though absolutely trivial) maxillary growth. Most of the cases were Class II at the start of treatment, and this increase in ANB probably reflects this inherent retrognathia.
4. No statistically significant increase in facial height (Na-Me) was detected, and, likewise, the facial planes did not change significantly (Se-Na to FH, Se-Na to PP, Se-Na to MP), but there was a counterclockwise rotation of the mandible.

Figure 5-4. Average posttreatment changes in soft tissue relationships in the present study. Asterisks denote the five variables exhibiting statistically significant changes (alpha = 0.05; two-tail test).

CHAPTER 6. SUMMARY AND CONCLUSIONS

This longitudinal cephalometric study examined 51 females treated orthodontically in their teens and then re-examined at an average of 40 years of age (> 20 years out of treatment); 33 of the 51 females were Class II with all but 3/51 treated with premolar extractions. Major findings were:

- The cranial base measurements examined in this study showed no change. This region had the least amount of activity when compared to the other areas examined.
- There was a continued downward forward growth of the maxilla (*i.e.* Se-A: 0.5 mm; A Point to Na (FH): 0.8 mm; Cd-A: 0.7 mm).
- There was a continued downward and forward growth of the mandible (*i.e.* Se-Gn: 0.7 mm; B Point to Na (FH): 0.7 mm).
- The gonial process is an area of apposition with age as shown by increases in Se-Go and Go-Me.
- Go-Me, Go-Pg, and the facial angle increased disclosing continued increases in corpus length. There was a statistically (by paired t-test) highly significant difference ($t = 3.0$; $df = 48$; $P = 0.0040$) between the amounts of Go-Me and Go-Pg growth, suggesting the difference is due to the inclusion of Pogonion, which is appositional over time.
- In contrast to the problems of relapse described in the literature, the dentition exhibited remarkable stability in this sample. There was a tendency for the upper incisor to upright over time, with an increase in overbite and overjet, but these changes were clinically inconsequential.
- There was continued eruption of the dentition, which seems to be a normative function of aging. All teeth had antagonists.
- The facial profile (Downs' facial angle) tended to straighten with age.
- Continued growth of the nose and chin contributed to the retrusion of the lips with age.

It is likely that posttreatment changes will continue to perplex the orthodontic specialty. In the present study, there were subtle amounts of craniofacial growth and a lack of orthodontic relapse.

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APPENDIX A.
CEPHALOMETRIC VARIABLES

Figure A-1. Schematic tracing of a lateral cephalogram showing construction of Se-Na (mm).

Figure A-2. Schematic tracing of a lateral cephalogram showing construction of Se-Ba (mm).

Figure A-3. Schematic tracing of a lateral cephalogram showing construction of Ba-Se-Na angle.

Figure A-4. Schematic tracing of a lateral cephalogram showing construction of Se-A (mm).

Figure A-5. Schematic tracing of a lateral cephalogram showing construction of Na-PP (mm).

Figure A-6. Schematic tracing of a lateral cephalogram showing construction of SNA angle.

Figure A-7. Schematic tracing of a lateral cephalogram showing construction of A to Na - FH (mm).

Figure A-8. Schematic tracing of a lateral cephalogram showing construction of Cd-A (mm).

Figure A-9. Schematic tracing of a lateral cephalogram showing construction of the PP-FH angle.

Figure A-10. Schematic tracing of a lateral cephalogram showing construction of the NAP angle.

Figure A-11. Schematic tracing of a lateral cephalogram showing construction of the FH-NaPg angle.

Figure A-12. Schematic tracing of a lateral cephalogram showing construction of the Se-B (mm).

Figure A-13. Schematic tracing of a lateral cephalogram showing construction of the Na-Se-Gn angle.

Figure A-14. Schematic tracing of a lateral cephalogram showing construction of the Na-Se-Gn (mm).

Figure A-15. Schematic tracing of a lateral cephalogram showing construction of Me-PP (mm).

Figure A-16. Schematic tracing of a lateral cephalogram showing construction of ANS-Me (mm).

Figure A-17. Schematic tracing of a lateral cephalogram showing construction of the Se-Go (mm).

Figure A-18. Schematic tracing of a lateral cephalogram showing construction of the SNB angle.

Figure A-19. Schematic tracing of a lateral cephalogram showing construction of B to Na - FH (mm).

Figure A-20. Schematic tracing of a lateral cephalogram showing construction of Go-Me (mm).

Figure A-21. Schematic tracing of a lateral cephalogram showing construction of Go-Pg (mm).

Figure A-22. Schematic tracing of a lateral cephalogram showing construction of the FMA angle.

Figure A-23. Schematic tracing of a lateral cephalogram showing construction of the SeNa-MP angle.

Figure A-24. Schematic tracing of a lateral cephalogram showing construction of Se-Go/Na-Me.

Figure A-25. Schematic tracing of a lateral cephalogram showing construction of Na-Me (mm).

Figure A-26. Schematic tracing of a lateral cephalogram showing construction of the ANB angle.

Figure A-27. Schematic tracing of a lateral cephalogram showing construction of AO-BO (mm).

Figure A-28. Schematic tracing of a lateral cephalogram showing construction of the U1-L1 angle.

Figure A-29. Schematic tracing of a lateral cephalogram showing construction of the Overbite.

Figure A-30. Schematic tracing of a lateral cephalogram showing construction of the Overjet.

Figure A-31. Schematic tracing of a lateral cephalogram showing construction of the U1-SeNa angle.

Figure A-32. Schematic tracing of a lateral cephalogram showing construction of the U1-NaA angle.

Figure A-33. Schematic tracing of a lateral cephalogram showing construction of the U1-NaA (mm).

Figure A-34. Schematic tracing of a lateral cephalogram showing construction of the L1-NaB angle.

Figure A-35. Schematic tracing of a lateral cephalogram showing construction of the L1-NaB (mm).

Figure A-36. Schematic tracing of a lateral cephalogram showing construction of the IMPA angle.

Figure A-37. Schematic tracing of a lateral cephalogram showing construction of the FMIA angle.

Figure A-38. Schematic tracing of a lateral cephalogram showing construction of the OP-FH angle.

Figure A-39. Schematic tracing of a lateral cephalogram showing construction of the U1-PP (mm).

Figure A-40. Schematic tracing of a lateral cephalogram showing construction of the U6-PP (mm).

Figure A-41. Schematic tracing of a lateral cephalogram showing construction of the L_s -E (mm).

Figure A-42. Schematic tracing of a lateral cephalogram showing construction of the L_i -E (mm).

Figure A-43. Schematic tracing of a lateral cephalogram showing construction of the Z angle.

Figure A-44. Schematic tracing of a lateral cephalogram showing construction of the Na'-Pr'-Pg' angle.

Figure A-45. Schematic tracing of a lateral cephalogram showing construction of the Sn-St_s (mm).

Figure A-46. Schematic tracing of a lateral cephalogram showing construction of the A' to Upper lip - FH (mm).

Figure A-47. Schematic tracing of a lateral cephalogram showing construction of the B' to Lower lip - FH (mm).

Figure A-48. Schematic tracing of a lateral cephalogram showing construction of the Pr' to Sn - FH (mm).

APPENDIX B.
SUPERIMPOSITIONS

Note:

T1 (Black) = Posttreatment tracing

T2 (Blue) = Long Term Recall tracing

Superimpositions are on Sella-Nasion line with registration at Sella.

All subjects are female.

Figure B-1. Computerized tracings of subject 1 evaluated at 15.7 and 34.3 years of age.

Figure B-2. Computerized tracings of subject 2 evaluated at 16.2 and 41.1 years of age.

Figure B-3. Computerized tracings of subject 3 evaluated at 16.1 and 44.6 years of age.

Figure B-4. Computerized tracings of subject 4 evaluated at 14.3 and 42.1 years of age.

Figure B-5. Computerized tracings of subject 5 evaluated at 13.2 and 42.9 years of age.

Figure B-6. Computerized tracings of subject 6 evaluated at 22.7 and 46.1 years of age.

Figure B-7. Computerized tracings of subject 7 evaluated at 15.3 and 41.6 years of age. Note: Patient mouth open at T1.

Figure B-8. Computerized tracings of subject 8 evaluated at 14.5 and 33.9 years of age.

Figure B-9. Computerized tracings of subject 9 evaluated at 13.5 and 38.9 years of age.

Figure B-10. Computerized tracings of subject 10 evaluated at 14.1 and 37.4 years of age.

Figure B-11. Computerized tracings of subject 11 evaluated at 15.2 and 34.1 years of age.

Figure B-12. Computerized tracings of subject 12 evaluated at 13.3 and 37.1 years of age.

Figure B-13. Computerized tracings of subject 13 evaluated at 14.3 and 35.8 years of age.

Figure B-14. Computerized tracings of subject 14 evaluated at 16.7 and 41.3 years of age.

Figure B-15. Computerized tracings of subject 15 evaluated at 14.2 and 36.4 years of age.

Figure B-16. Computerized tracings of subject 16 evaluated at 15.0 and 37.0 years of age.

Figure B-17. Computerized tracings of subject 17 evaluated at 11.8 and 36.0 years of age.

Figure B-18. Computerized tracings of subject 18 evaluated at 14.7 and 35.7 years of age.

Figure B-19. Computerized tracings of subject 19 evaluated at 15.6 and 33.7 years of age.

Figure B-20. Computerized tracings of subject 20 evaluated at 16.1 and 42.0 years of age.

Figure B-21. Computerized tracings of subject 21 evaluated at 15.9 and 41.8 years of age.

Figure B-22. Computerized tracings of subject 22 evaluated at 16.4 and 42.9 years of age.

Figure B-23. Computerized tracings of subject 23 evaluated at 16.7 and 39.3 years of age.

Figure B-24 Computerized tracings of subject 24 evaluated at 14.5 and 42.3 years of age.

Figure B-25. Computerized tracings of subject 25 evaluated at 15.5 and 44.0 years of age.

Figure B-26. Computerized tracings of subject 26 evaluated at 16.0 and 42.5 years of age.

Figure B-27. Computerized tracings of subject 27 evaluated at 16.1 and 38.6 years of age.

Figure B-28. Computerized tracings of subject 28 evaluated at 15.4 and 36.8 years of age.

Figure B-29. Computerized tracings of subject 29 evaluated at 15.0 and 41.9 years of age.

Figure B-30. Computerized tracings of subject 30 evaluated at 15.6 and 37.3 years of age.

Figure B-31. Computerized tracings of subject 31 evaluated at 16.5 and 41.9 years of age.

Figure B-32. Computerized tracings of subject 32 evaluated at 15.1 and 34.6 years of age.

Figure B-33. Computerized tracings of subject 33 evaluated at 16.2 and 35.6 years of age.

Figure B-34. Computerized tracings of subject 34 evaluated at 13.5 and 38.6 years of age.

Figure B-35. Computerized tracings of subject 35 evaluated at 14.6 and 35.6 years of age.

Figure B-36. Computerized tracings of subject 36 evaluated at 20.4 and 37.2 years of age.

Figure B-37. Computerized tracings of subject 37 evaluated at 14.9 and 40.2 years of age.

Figure B-38. Computerized tracings of subject 38 evaluated at 13.9 and 37.3 years of age.

Figure B-39. Computerized tracings of subject 39 evaluated at 16.6 and 41.4 years of age.

Figure B-40. Computerized tracings of subject 40 evaluated at 24.7 and 45.7 years of age.

Figure B-41. Computerized tracings of subject 41 evaluated at 19.7 and 42.5 years of age.

Figure B-42. Computerized tracings of subject 42 evaluated at 15.0 and 40.8 years of age.

Figure B-43. Computerized tracings of subject 43 evaluated at 13.9 and 44.4 years of age.

Figure B-44. Computerized tracings of subject 44 evaluated at 15.4 and 45.4 years of age.

Figure B-45. Computerized tracings of subject 45 evaluated at 17.1 and 36.7 years of age.

Figure B-46. Computerized tracings of subject 46 evaluated at 18.7 and 43.1 years of age.

Figure B-47. Computerized tracings of subject 47 evaluated at 15.2 and 34.6 years of age.

Figure B-48. Computerized tracings of subject 48 evaluated at 16.3 and 37.2 years of age.

Figure B-49. Computerized tracings of subject 49 evaluated at 15.0 and 42.0 years of age.

Figure B-50. Computerized tracings of subject 50 evaluated at 16.4 and 35.5 years of age.

Figure B-51. Computerized tracings of subject 51 evaluated at 15.3 and 37.8 years of age

APPENDIX C.
DESCRIPTIVE STATISTICS (T1)

Table C-1. Descriptive statistics at the end of the active phase of treatment for T1_Se-A (mm).

Statistic	Estimate
Arithmetic mean	87.38
Standard deviation	3.87
Standard error of mean	0.54
Upper 95% confidence limit	88.47
Lower 95% confidence limit	86.29
Sample size (n)	51
Sample variance	14.99
Skewness	0.45
Kurtosis	0.97
Coefficient of variation	4.43
Number of cases missing	0
Maximum value	98.8
Median value	87.1
Minimum value	77.8

Table C-2. Descriptive statistics at the end of the active phase of treatment for T1_Se-B (mm).

Statistic	Estimate
Arithmetic mean	111.49
Standard deviation	4.72
Standard error of mean	0.66
Upper 95% confidence limit	112.81
Lower 95% confidence limit	110.16
Sample size (n)	51
Sample variance	22.25
Skewness	0.04
Kurtosis	-0.29
Coefficient of variation	4.23
Number of cases missing	0
Maximum value	122.3
Median value	111.8
Minimum value	101.3

Table C-3. Descriptive statistics at the end of the active phase of treatment for T1_Na-Se-Gn (°).

Statistic	Estimate
Arithmetic mean	67.68
Standard deviation	3.86
Standard error of mean	0.55
Upper 95% confidence limit	68.79
Lower 95% confidence limit	66.58
Sample size (n)	49
Sample variance	14.89
Skewness	-0.10
Kurtosis	-0.59
Coefficient of variation	5.70
Number of cases missing	2
Maximum value	75.9
Median value	68.1
Minimum value	59.1

Table C-4. Descriptive statistics at the end of the active phase of treatment for T1_Se-Gn (mm).

Statistic	Estimate
Arithmetic mean	134.57
Standard deviation	6.00
Standard error of mean	0.86
Upper 95% confidence limit	136.30
Lower 95% confidence limit	132.85
Sample size (n)	49
Sample variance	36.01
Skewness	-0.20
Kurtosis	-0.94
Coefficient of variation	4.46
Number of cases missing	2
Maximum value	144.1
Median value	134.5
Minimum value	122.8

Table C-5. Descriptive statistics at the end of the active phase of treatment for T1_Na-PP (mm).

Statistic	Estimate
Arithmetic mean	54.79
Standard deviation	2.75
Standard error of mean	0.38
Upper 95% confidence limit	55.56
Lower 95% confidence limit	54.01
Sample size (n)	51
Sample variance	7.55
Skewness	0.27
Kurtosis	-0.10
Coefficient of variation	5.01
Number of cases missing	0
Maximum value	61.6
Median value	54.9
Minimum value	48.9

Table C-6. Descriptive statistics at the end of the active phase of treatment for T1_Me-PP (mm).

Statistic	Estimate
Arithmetic mean	68.87
Standard deviation	5.22
Standard error of mean	0.74
Upper 95% confidence limit	70.36
Lower 95% confidence limit	67.39
Sample size (n)	50
Sample variance	27.21
Skewness	-0.08
Kurtosis	-0.49
Coefficient of variation	7.57
Number of cases missing	1
Maximum value	80.2
Median value	69.1
Minimum value	58.2

Table C-7. Descriptive statistics at the end of the active phase of treatment for T1_ANS-Me (mm).

Statistic	Estimate
Arithmetic mean	70.38
Standard deviation	5.69
Standard error of mean	0.80
Upper 95% confidence limit	72.00
Lower 95% confidence limit	68.76
Sample size (n)	50
Sample variance	32.36
Skewness	0.08
Kurtosis	-0.25
Coefficient of variation	8.08
Number of cases missing	1
Maximum value	82.9
Median value	70.35
Minimum value	58.5

Table C-8. Descriptive statistics at the end of the active phase of treatment for T1_Na-Me (mm).

Statistic	Estimate
Arithmetic mean	124.59
Standard deviation	6.43
Standard error of mean	0.91
Upper 95% confidence limit	126.42
Lower 95% confidence limit	122.76
Sample size (n)	50
Sample variance	41.34
Skewness	0.32
Kurtosis	-0.36
Coefficient of variation	5.16
Number of cases missing	1
Maximum value	139.4
Median value	124.2
Minimum value	110.8

Table C-9. Descriptive statistics at the end of the active phase of treatment for T1_Se-Go (mm).

Statistic	Estimate
Arithmetic mean	81.59
Standard deviation	5.32
Standard error of mean	0.76
Upper 95% confidence limit	83.12
Lower 95% confidence limit	80.06
Sample size (n)	49
Sample variance	28.29
Skewness	-0.45
Kurtosis	0.29
Coefficient of variation	6.52
Number of cases missing	2
Maximum value	92.6
Median value	82.4
Minimum value	66.8

Table C-10. Descriptive statistics at the end of the active phase of treatment for T1_Se-Go/Na-Me (%).

Statistic	Estimate
Arithmetic mean	65.77
Standard deviation	5.22
Standard error of mean	0.75
Upper 95% confidence limit	67.26
Lower 95% confidence limit	64.27
Sample size (n)	49
Sample variance	27.24
Skewness	-0.11
Kurtosis	0.26
Coefficient of variation	7.94
Number of cases missing	2
Maximum value	76.6
Median value	66.2
Minimum value	51.1

Table C-11. Descriptive statistics at the end of the active phase of treatment for T1_Se-Ba (mm).

Statistic	Estimate
Arithmetic mean	46.13
Standard deviation	3.13
Standard error of mean	0.44
Upper 95% confidence limit	47.01
Lower 95% confidence limit	45.24
Sample size (n)	51
Sample variance	9.82
Skewness	0.33
Kurtosis	0.42
Coefficient of variation	6.79
Number of cases missing	0
Maximum value	55.1
Median value	45.8
Minimum value	39.8

Table C-12. Descriptive statistics at the end of the active phase of treatment for T1_Ba-Se-Na (°).

Statistic	Estimate
Arithmetic mean	129.69
Standard deviation	4.45
Standard error of mean	0.62
Upper 95% confidence limit	130.94
Lower 95% confidence limit	128.44
Sample size (n)	51
Sample variance	19.78
Skewness	-0.84
Kurtosis	1.23
Coefficient of variation	3.43
Number of cases missing	0
Maximum value	136.5
Median value	130.3
Minimum value	114.6

Table C-13. Descriptive statistics at the end of the active phase of treatment for T1_SNA (°).

Statistic	Estimate
Arithmetic mean	79.29
Standard deviation	3.67
Standard error of mean	0.51
Upper 95% confidence limit	80.32
Lower 95% confidence limit	78.26
Sample size (n)	51
Sample variance	13.46
Skewness	0.22
Kurtosis	0.65
Coefficient of variation	4.63
Number of cases missing	0
Maximum value	88.7
Median value	79.3
Minimum value	70.4

Table C-14. Descriptive statistics at the end of the active phase of treatment for T1_SNB (°).

Statistic	Estimate
Arithmetic mean	77.65
Standard deviation	3.22
Standard error of mean	0.45
Upper 95% confidence limit	78.56
Lower 95% confidence limit	76.74
Sample size (n)	51
Sample variance	10.40
Skewness	0.20
Kurtosis	-0.43
Coefficient of variation	4.15
Number of cases missing	0
Maximum value	84.3
Median value	77.4
Minimum value	71.1

Table C-15. Descriptive statistics at the end of the active phase of treatment for T1_ANB (°).

Statistic	Estimate
Arithmetic mean	1.64
Standard deviation	1.99
Standard error of mean	0.28
Upper 95% confidence limit	2.20
Lower 95% confidence limit	1.07
Sample size (n)	51
Sample variance	3.98
Skewness	-0.31
Kurtosis	0.03
Coefficient of variation	121.93
Number of cases missing	0
Maximum value	5.5
Median value	1.7
Minimum value	-3.3

Table C-16. Descriptive statistics at the end of the active phase of treatment for T1_AOBO (mm).

Statistic	Estimate
Arithmetic mean	-1.79
Standard deviation	2.58
Standard error of mean	0.36
Upper 95% confidence limit	-1.06
Lower 95% confidence limit	-2.51
Sample size (n)	51
Sample variance	6.65
Skewness	-0.27
Kurtosis	-0.45
Coefficient of variation	-144.23
Number of cases missing	0
Maximum value	3.0
Median value	-1.8
Minimum value	-8.0

Table C-17. Descriptive statistics at the end of the active phase of treatment for T1_A-Na-FH (mm).

Statistic	Estimate
Arithmetic mean	-4.68
Standard deviation	4.07
Standard error of mean	0.57
Upper 95% confidence limit	-3.54
Lower 95% confidence limit	-5.83
Sample size (n)	51
Sample variance	16.58
Skewness	-0.23
Kurtosis	-0.01
Coefficient of variation	-87.00
Number of cases missing	0
Maximum value	4.1
Median value	-4.2
Minimum value	-13.9

Table C-18. Descriptive statistics at the end of the active phase of treatment for T1_B-Na-FH (mm).

Statistic	Estimate
Arithmetic mean	-10.53
Standard deviation	5.61
Standard error of mean	0.79
Upper 95% confidence limit	-8.95
Lower 95% confidence limit	-12.11
Sample size (n)	51
Sample variance	31.46
Skewness	-0.51
Kurtosis	0.64
Coefficient of variation	-53.28
Number of cases missing	0
Maximum value	0.6
Median value	-10.2
Minimum value	-26.7

Table C-19. Descriptive statistics at the end of the active phase of treatment for T1_Cd-A (mm).

Statistic	Estimate
Arithmetic mean	87.36
Standard deviation	4.55
Standard error of mean	0.64
Upper 95% confidence limit	88.64
Lower 95% confidence limit	86.08
Sample size (n)	51
Sample variance	20.74
Skewness	0.26
Kurtosis	-0.72
Coefficient of variation	5.21
Number of cases missing	0
Maximum value	96.2
Median value	87.3
Minimum value	78.8

Table C-20. Descriptive statistics at the end of the active phase of treatment for T1_Go-Me (mm).

Statistic	Estimate
Arithmetic mean	70.84
Standard deviation	4.43
Standard error of mean	0.63
Upper 95% confidence limit	72.11
Lower 95% confidence limit	69.56
Sample size (n)	49
Sample variance	19.63
Skewness	-0.01
Kurtosis	-0.45
Coefficient of variation	6.25
Number of cases missing	2
Maximum value	79.8
Median value	71.0
Minimum value	62.0

Table C-21. Descriptive statistics at the end of the active phase of treatment for T1_Go-Pg (mm).

Statistic	Estimate
Arithmetic mean	73.70
Standard deviation	4.55
Standard error of mean	0.64
Upper 95% confidence limit	75.00
Lower 95% confidence limit	72.41
Sample size (n)	50
Sample variance	20.72
Skewness	0.03
Kurtosis	-0.47
Coefficient of variation	6.18
Number of cases missing	1
Maximum value	84.1
Median value	74.2
Minimum value	63.9

Table C-22. Descriptive statistics at the end of the active phase of treatment for T1_PP-FH (°).

Statistic	Estimate
Arithmetic mean	-0.86
Standard deviation	3.71
Standard error of mean	0.52
Upper 95% confidence limit	0.18
Lower 95% confidence limit	-1.91
Sample size (n)	51
Sample variance	13.79
Skewness	-0.19
Kurtosis	1.39
Coefficient of variation	-429.49
Number of cases missing	0
Maximum value	9.7
Median value	-1.1
Minimum value	-12.3

Table C-23. Descriptive statistics at the end of the active phase of treatment for T1_FMA (°).

Statistic	Estimate
Arithmetic mean	26.62
Standard deviation	6.18
Standard error of mean	0.88
Upper 95% confidence limit	28.40
Lower 95% confidence limit	24.84
Sample size (n)	49
Sample variance	38.20
Skewness	0.29
Kurtosis	0.52
Coefficient of variation	23.22
Number of cases missing	2
Maximum value	43.6
Median value	26.3
Minimum value	13.9

Table C-24. Descriptive statistics at the end of the active phase of treatment for T1_Se-Na-MP (°).

Statistic	Estimate
Arithmetic mean	32.99
Standard deviation	6.60
Standard error of mean	0.94
Upper 95% confidence limit	34.89
Lower 95% confidence limit	31.10
Sample size (n)	49
Sample variance	43.63
Skewness	0.38
Kurtosis	0.31
Coefficient of variation	20.02
Number of cases missing	2
Maximum value	52.5
Median value	32.4
Minimum value	20.1

Table C-25. Descriptive statistics at the end of the active phase of treatment for T1_NAP (°).

Statistic	Estimate
Arithmetic mean	-0.33
Standard deviation	5.56
Standard error of mean	0.78
Upper 95% confidence limit	1.23
Lower 95% confidence limit	-1.90
Sample size (n)	51
Sample variance	30.89
Skewness	-0.18
Kurtosis	-0.34
Coefficient of variation	-1667.31
Number of cases missing	0
Maximum value	11.0
Median value	0.1
Minimum value	-13.6

Table C-26. Descriptive statistics at the end of the active phase of treatment for T1_FH-Na-Pg (°).

Statistic	Estimate
Arithmetic mean	85.80
Standard deviation	3.53
Standard error of mean	0.49
Upper 95% confidence limit	86.79
Lower 95% confidence limit	84.80
Sample size (n)	51
Sample variance	12.47
Skewness	-0.56
Kurtosis	0.64
Coefficient of variation	4.12
Number of cases missing	0
Maximum value	92.8
Median value	86.1
Minimum value	75.7

Table C-27. Descriptive statistics at the end of the active phase of treatment for T1_UL-L1 (°).

Statistic	Estimate
Arithmetic mean	130.14
Standard deviation	7.44
Standard error of mean	1.04
Upper 95% confidence limit	132.23
Lower 95% confidence limit	128.05
Sample size (n)	51
Sample variance	55.30
Skewness	0.06
Kurtosis	-0.34
Coefficient of variation	5.71
Number of cases missing	0
Maximum value	145.0
Median value	129.6
Minimum value	112.8

Table C-28. Descriptive statistics at the end of the active phase of treatment for T1_Overbite (mm).

Statistic	Estimate
Arithmetic mean	1.17
Standard deviation	1.01
Standard error of mean	0.14
Upper 95% confidence limit	1.45
Lower 95% confidence limit	0.89
Sample size (n)	51
Sample variance	1.02
Skewness	0.24
Kurtosis	0.85
Coefficient of variation	86.21
Number of cases missing	0
Maximum value	4.0
Median value	1.2
Minimum value	-1.2

Table C-29. Descriptive statistics at the end of the active phase of treatment for T1_Overjet (mm).

Statistic	Estimate
Arithmetic mean	3.24
Standard deviation	0.71
Standard error of mean	0.10
Upper 95% confidence limit	3.43
Lower 95% confidence limit	3.04
Sample size (n)	51
Sample variance	0.50
Skewness	0.03
Kurtosis	-0.15
Coefficient of variation	21.80
Number of cases missing	0
Maximum value	4.9
Median value	3.2
Minimum value	1.6

Table C-30. Descriptive statistics at the end of the active phase of treatment for T1_U1-SeNa (°)

Statistic	Estimate
Arithmetic mean	105.95
Standard deviation	6.09
Standard error of mean	0.85
Upper 95% confidence limit	107.66
Lower 95% confidence limit	104.24
Sample size (n)	51
Sample variance	37.03
Skewness	-0.13
Kurtosis	-0.97
Coefficient of variation	5.74
Number of cases missing	0
Maximum value	117.2
Median value	106.6
Minimum value	94.6

Table C-31. Descriptive statistics at the end of the active phase of treatment for T1_U1-Na-A (°).

Statistic	Estimate
Arithmetic mean	26.66
Standard deviation	6.30
Standard error of mean	0.88
Upper 95% confidence limit	28.43
Lower 95% confidence limit	24.89
Sample size (n)	51
Sample variance	39.67
Skewness	-0.46
Kurtosis	0.26
Coefficient of variation	23.63
Number of cases missing	0
Maximum value	38.3
Median value	27.2
Minimum value	7.9

Table C-32. Descriptive statistics at the end of the active phase of treatment for T1_U1-Na-A (mm).

Statistic	Estimate
Arithmetic mean	4.41
Standard deviation	2.72
Standard error of mean	0.38
Upper 95% confidence limit	5.18
Lower 95% confidence limit	3.65
Sample size (n)	51
Sample variance	7.42
Skewness	0.11
Kurtosis	0.44
Coefficient of variation	61.75
Number of cases missing	0
Maximum value	11.4
Median value	4.3
Minimum value	-2.0

Table C-33. Descriptive statistics at the end of the active phase of treatment for T1_L1-Na-B (°).

Statistic	Estimate
Arithmetic mean	21.59
Standard deviation	5.75
Standard error of mean	0.81
Upper 95% confidence limit	23.20
Lower 95% confidence limit	19.97
Sample size (n)	51
Sample variance	33.06
Skewness	-0.33
Kurtosis	-0.21
Coefficient of variation	26.63
Number of cases missing	0
Maximum value	32.7
Median value	22.5
Minimum value	8.5

Table C-34. Descriptive statistics at the end of the active phase of treatment for T1_L1-Na-B (mm).

Statistic	Estimate
Arithmetic mean	3.70
Standard deviation	1.96
Standard error of mean	0.27
Upper 95% confidence limit	4.25
Lower 95% confidence limit	3.15
Sample size (n)	51
Sample variance	3.85
Skewness	0.03
Kurtosis	-0.03
Coefficient of variation	52.99
Number of cases missing	0
Maximum value	8.4
Median value	3.7
Minimum value	0.0

Table C-35. Descriptive statistics at the end of the active phase of treatment for T1_IMPA (°).

Statistic	Estimate
Arithmetic mean	90.89
Standard deviation	6.53
Standard error of mean	0.93
Upper 95% confidence limit	92.76
Lower 95% confidence limit	89.01
Sample size (n)	49
Sample variance	42.65
Skewness	-0.23
Kurtosis	-0.66
Coefficient of variation	7.19
Number of cases missing	2
Maximum value	103.3
Median value	90.3
Minimum value	75.8

Table C-36. Descriptive statistics at the end of the active phase of treatment for T1_FMIA (°).

Statistic	Estimate
Arithmetic mean	62.47
Standard deviation	6.78
Standard error of mean	0.95
Upper 95% confidence limit	64.38
Lower 95% confidence limit	60.56
Sample size (n)	51
Sample variance	46.04
Skewness	0.00
Kurtosis	-0.12
Coefficient of variation	10.86
Number of cases missing	0
Maximum value	78.2
Median value	62.5
Minimum value	48.5

Table C-37. Descriptive statistics at the end of the active phase of treatment for T1_OP-FH (°).

Statistic	Estimate
Arithmetic mean	11.14
Standard deviation	3.78
Standard error of mean	0.53
Upper 95% confidence limit	12.20
Lower 95% confidence limit	10.08
Sample size (n)	51
Sample variance	14.31
Skewness	-0.09
Kurtosis	-0.13
Coefficient of variation	33.95
Number of cases missing	0
Maximum value	19.9
Median value	11.0
Minimum value	2.9

Table C-38. Descriptive statistics at the end of the active phase of treatment for T1_U1-PP (mm).

Statistic	Estimate
Arithmetic mean	29.53
Standard deviation	3.11
Standard error of mean	0.44
Upper 95% confidence limit	30.41
Lower 95% confidence limit	28.66
Sample size (n)	51
Sample variance	9.65
Skewness	-0.04
Kurtosis	-0.24
Coefficient of variation	10.52
Number of cases missing	0
Maximum value	35.8
Median value	29.5
Minimum value	23.0

Table C-39. Descriptive statistics at the end of the active phase of treatment for T1_U6-PP (mm).

Statistic	Estimate
Arithmetic mean	23.66
Standard deviation	2.29
Standard error of mean	0.32
Upper 95% confidence limit	24.31
Lower 95% confidence limit	23.02
Sample size (n)	51
Sample variance	5.25
Skewness	0.27
Kurtosis	0.46
Coefficient of variation	9.69
Number of cases missing	0
Maximum value	30.4
Median value	24.1
Minimum value	19.6

Table C-40. Descriptive statistics at the end of the active phase of treatment for T1_Li-E (mm).

Statistic	Estimate
Arithmetic mean	-4.26
Standard deviation	2.78
Standard error of mean	0.40
Upper 95% confidence limit	-3.46
Lower 95% confidence limit	-5.07
Sample size (n)	48
Sample variance	7.72
Skewness	-0.15
Kurtosis	-0.27
Coefficient of variation	-65.21
Number of cases missing	3
Maximum value	1.9
Median value	-4.3
Minimum value	-11.2

Table C-41. Descriptive statistics at the end of the active phase of treatment for T1_{Ls}-E (mm).

Statistic	Estimate
Arithmetic mean	-6.93
Standard deviation	2.84
Standard error of mean	0.41
Upper 95% confidence limit	-6.10
Lower 95% confidence limit	-7.75
Sample size (n)	48
Sample variance	8.07
Skewness	-0.73
Kurtosis	0.39
Coefficient of variation	-41.01
Number of cases missing	3
Maximum value	-2.4
Median value	-6.2
Minimum value	-15.0

Table C-42. Descriptive statistics at the end of the active phase of treatment for T1_Z Angle (°).

Statistic	Estimate
Arithmetic mean	79.03
Standard deviation	8.38
Standard error of mean	1.21
Upper 95% confidence limit	81.46
Lower 95% confidence limit	76.59
Sample size (n)	48
Sample variance	70.22
Skewness	0.15
Kurtosis	0.32
Coefficient of variation	10.60
Number of cases missing	3
Maximum value	98.5
Median value	78.9
Minimum value	60.2

Table C-43. Descriptive statistics at the end of the active phase of treatment for T1_Na'-Pr'-Pg' (°).

Statistic	Estimate
Arithmetic mean	130.35
Standard deviation	4.08
Standard error of mean	0.61
Upper 95% confidence limit	131.57
Lower 95% confidence limit	129.12
Sample size (n)	45
Sample variance	16.66
Skewness	0.25
Kurtosis	-0.10
Coefficient of variation	3.13
Number of cases missing	6
Maximum value	139.9
Median value	130.2
Minimum value	122.0

Table C-44. Descriptive statistics at the end of the active phase of treatment for T1_Sn-L_s (mm).

Statistic	Estimate
Arithmetic mean	20.67
Standard deviation	2.39
Standard error of mean	0.35
Upper 95% confidence limit	21.37
Lower 95% confidence limit	19.97
Sample size (n)	47
Sample variance	5.69
Skewness	-0.26
Kurtosis	0.11
Coefficient of variation	11.55
Number of cases missing	4
Maximum value	25.2
Median value	20.3
Minimum value	14.4

Table C-45. Descriptive statistics at the end of the active phase of treatment for T1_A' to Upper Lip-FH (mm).

Statistic	Estimate
Arithmetic mean	2.69
Standard deviation	1.46
Standard error of mean	0.21
Upper 95% confidence limit	3.12
Lower 95% confidence limit	2.26
Sample size (n)	47
Sample variance	2.12
Skewness	0.10
Kurtosis	-0.39
Coefficient of variation	54.07
Number of cases missing	4
Maximum value	6.0
Median value	2.5
Minimum value	-0.6

Table C-46. Descriptive statistics at the end of the active phase of treatment for T1_B' to Lower lip-FH (mm).

Statistic	Estimate
Arithmetic mean	-0.08
Standard deviation	2.04
Standard error of mean	0.30
Upper 95% confidence limit	0.52
Lower 95% confidence limit	-0.68
Sample size (n)	47
Sample variance	4.18
Skewness	-0.11
Kurtosis	-0.59
Coefficient of variation	-2529.08
Number of cases missing	4
Maximum value	3.9
Median value	-0.3
Minimum value	-4.8

Table C-47. Descriptive statistics at the end of the active phase of treatment for T1_Pr' to Sn-FH (mm).

Statistic	Estimate
Arithmetic mean	17.25
Standard deviation	2.31
Standard error of mean	0.33
Upper 95% confidence limit	17.93
Lower 95% confidence limit	16.58
Sample size (n)	48
Sample variance	5.34
Skewness	0.12
Kurtosis	-0.33
Coefficient of variation	13.39
Number of cases missing	3
Maximum value	22.7
Median value	17.2
Minimum value	12.5

APPENDIX D.
DESCRIPTIVE STATISTICS (T2)

Table D-1. Descriptive statistics at the recall examination for T2_Se-A (mm).

Statistic	Estimate
Arithmetic mean	87.94
Standard deviation	3.92
Standard error of mean	0.55
Upper 95% confidence limit	89.04
Lower 95% confidence limit	86.83
Sample size (n)	51
Sample variance	15.35
Skewness	0.82
Kurtosis	0.38
Coefficient of variation	4.46
Number of cases missing	0
Maximum value	99.6
Minimum value	81.9

Table D-2. Descriptive statistics at the recall examination for T2_Se-B (mm).

Statistic	Estimate
Arithmetic mean	111.10
Standard deviation	4.75
Standard error of mean	0.67
Upper 95% confidence limit	112.44
Lower 95% confidence limit	109.76
Sample size (n)	51
Sample variance	22.57
Skewness	0.03
Kurtosis	-0.59
Coefficient of variation	4.28
Number of cases missing	0
Maximum value	121.7
Median value	110.7
Minimum value	101.6

Table D-3. Descriptive statistics at the recall examination for T2_Na-Se-Gn (°).

Statistic	Estimate
Arithmetic mean	67.73
Standard deviation	4.18
Standard error of mean	0.59
Upper 95% confidence limit	68.91
Lower 95% confidence limit	66.56
Sample size (n)	51
Sample variance	17.49
Skewness	-0.09
Kurtosis	-0.09
Coefficient of variation	6.17
Number of cases missing	0
Maximum value	77.2
Median value	67.7
Minimum value	57.2

Table D-4. Descriptive statistics at the recall examination for T2_ Na-Se-Gn (°).

Statistic	Estimate
Arithmetic mean	135.35
Standard deviation	5.95
Standard error of mean	0.83
Upper 95% confidence limit	137.02
Lower 95% confidence limit	133.68
Sample size (n)	51
Sample variance	35.40
Skewness	-0.10
Kurtosis	-0.88
Coefficient of variation	4.40
Number of cases missing	0
Maximum value	146.3
Median value	135.3
Minimum value	123.6

Table D-5. Descriptive statistics at the recall examination for T2_Na-PP (mm).

Statistic	Estimate
Arithmetic mean	55.20
Standard deviation	2.76
Standard error of mean	0.39
Upper 95% confidence limit	55.98
Lower 95% confidence limit	54.42
Sample size (n)	51
Sample variance	7.64
Skewness	-0.14
Kurtosis	-0.67
Coefficient of variation	5.01
Number of cases missing	0
Maximum value	61.4
Median value	55.6
Minimum value	48.8

Table D-6. Descriptive statistics at the recall examination for T2_Me-PP (mm).

Statistic	Estimate
Arithmetic mean	68.93
Standard deviation	5.21
Standard error of mean	0.73
Upper 95% confidence limit	70.39
Lower 95% confidence limit	67.47
Sample size (n)	51
Sample variance	27.11
Skewness	-0.05
Kurtosis	-0.65
Coefficient of variation	7.55
Number of cases missing	0
Maximum value	78.7
Median value	69.0
Minimum value	59.1

Table D-7. Descriptive statistics at the recall examination for T2_ANS-Me (mm).

Statistic	Estimate
Arithmetic mean	70.41
Standard deviation	5.51
Standard error of mean	0.77
Upper 95% confidence limit	71.96
Lower 95% confidence limit	68.86
Sample size (n)	51
Sample variance	30.37
Skewness	0.01
Kurtosis	-0.29
Coefficient of variation	7.83
Number of cases missing	0
Maximum value	81.5
Median value	70.6
Minimum value	59.4

Table D-8. Descriptive statistics at the recall examination for T2_Na-Me (mm).

Statistic	Estimate
Arithmetic mean	124.89
Standard deviation	6.60
Standard error of mean	0.92
Upper 95% confidence limit	126.75
Lower 95% confidence limit	123.04
Sample size (n)	51
Sample variance	43.53
Skewness	0.31
Kurtosis	-0.29
Coefficient of variation	5.28
Number of cases missing	0
Maximum value	140.7
Median value	124.3
Minimum value	110.6

Table D-9. Descriptive statistics at the recall examination for T2_Se-Go (mm).

Statistic	Estimate
Arithmetic mean	82.16
Standard deviation	5.28
Standard error of mean	0.74
Upper 95% confidence limit	83.65
Lower 95% confidence limit	80.68
Sample size (n)	51
Sample variance	27.86
Skewness	-0.49
Kurtosis	1.16
Coefficient of variation	6.42
Number of cases missing	0
Maximum value	94.0
Median value	81.8
Minimum value	64.8

Table D-10. Descriptive statistics at the recall examination for T2_Se-Go/Na-Me (%).

Statistic	Estimate
Arithmetic mean	65.99
Standard deviation	5.41
Standard error of mean	0.76
Upper 95% confidence limit	67.51
Lower 95% confidence limit	64.46
Sample size (n)	51
Sample variance	29.26
Skewness	-0.10
Kurtosis	1.79
Coefficient of variation	8.20
Number of cases missing	0
Maximum value	81.5
Median value	66.7
Minimum value	49.0

Table D-11. Descriptive statistics at the recall examination for T2_Se-Ba (mm).

Statistic	Estimate
Arithmetic mean	45.94
Standard deviation	3.00
Standard error of mean	0.42
Upper 95% confidence limit	46.78
Lower 95% confidence limit	45.10
Sample size (n)	51
Sample variance	9.00
Skewness	-0.29
Kurtosis	0.34
Coefficient of variation	6.53
Number of cases missing	0
Maximum value	52.5
Median value	46.2
Minimum value	37.8

Table D-12. Descriptive statistics at the recall examination for T2_Ba-Se-Na (°).

Statistic	Estimate
Arithmetic mean	129.45
Standard deviation	4.27
Standard error of mean	0.60
Upper 95% confidence limit	130.65
Lower 95% confidence limit	128.25
Sample size (n)	51
Sample variance	18.19
Skewness	-1.20
Kurtosis	3.57
Coefficient of variation	3.30
Number of cases missing	0
Maximum value	136.3
Median value	130.0
Minimum value	112.5

Table D-13. Descriptive statistics at the recall examination for T2_SNA (°).

Statistic	Estimate
Arithmetic mean	79.60
Standard deviation	3.74
Standard error of mean	0.52
Upper 95% confidence limit	80.65
Lower 95% confidence limit	78.55
Sample size (n)	51
Sample variance	14.00
Skewness	0.79
Kurtosis	0.50
Coefficient of variation	4.70
Number of cases missing	0
Maximum value	90.1
Median value	78.9
Minimum value	73.0

Table D-14. Descriptive statistics at the recall examination for T2_SNB (°).

Statistic	Estimate
Arithmetic mean	77.54
Standard deviation	3.61
Standard error of mean	0.51
Upper 95% confidence limit	78.55
Lower 95% confidence limit	76.52
Sample size (n)	51
Sample variance	13.02
Skewness	0.38
Kurtosis	-0.48
Coefficient of variation	4.65
Number of cases missing	0
Maximum value	86.2
Median value	77.5
Minimum value	70.9

Table D-15. Descriptive statistics at the recall examination for T2_ANB (°).

Statistic	Estimate
Arithmetic mean	2.06
Standard deviation	2.12
Standard error of mean	0.30
Upper 95% confidence limit	2.66
Lower 95% confidence limit	1.47
Sample size (n)	51
Sample variance	4.49
Skewness	-0.58
Kurtosis	0.69
Coefficient of variation	102.77
Number of cases missing	0
Maximum value	6.8
Median value	2.1
Minimum value	-4.3

Table D-16. Descriptive statistics at the recall examination for T2_AOBO (mm).

Statistic	Estimate
Arithmetic mean	-0.96
Standard deviation	3.15
Standard error of mean	0.44
Upper 95% confidence limit	-0.07
Lower 95% confidence limit	-1.84
Sample size (n)	51
Sample variance	9.92
Skewness	-0.24
Kurtosis	0.65
Coefficient of variation	-329.18
Number of cases missing	0
Maximum value	6.8
Median value	-1.0
Minimum value	-10.1

Table D-17. Descriptive statistics at the recall examination for T2_A-Na-FH (mm).

Statistic	Estimate
Arithmetic mean	-3.83
Standard deviation	3.83
Standard error of mean	0.54
Upper 95% confidence limit	-2.75
Lower 95% confidence limit	-4.90
Sample size (n)	51
Sample variance	14.63
Skewness	0.04
Kurtosis	-0.49
Coefficient of variation	-99.94
Number of cases missing	0
Maximum value	4.0
Median value	-3.8
Minimum value	-12.0

Table D-18. Descriptive statistics at the recall examination for T2_B-Na-FH (mm).

Statistic	Estimate
Arithmetic mean	-9.87
Standard deviation	5.86
Standard error of mean	0.82
Upper 95% confidence limit	-8.23
Lower 95% confidence limit	-11.52
Sample size (n)	51
Sample variance	34.28
Skewness	-0.50
Kurtosis	0.14
Coefficient of variation	-59.30
Number of cases missing	0
Maximum value	1.000
Median value	-9.400
Minimum value	-27.000

Table D-19. Descriptive statistics at the recall examination for T2_Cd-A (mm).

Statistic	Estimate
Arithmetic mean	88.09
Standard deviation	4.54
Standard error of mean	0.64
Upper 95% confidence limit	89.37
Lower 95% confidence limit	86.81
Sample size (n)	51
Sample variance	20.64
Skewness	-0.06
Kurtosis	-0.89
Coefficient of variation	5.16
Number of cases missing	0
Maximum value	96.0
Median value	87.9
Minimum value	79.0

Table D-20. Descriptive statistics at the recall examination for T2_Go-Me (mm).

Statistic	Estimate
Arithmetic mean	71.67
Standard deviation	4.95
Standard error of mean	0.69
Upper 95% confidence limit	73.07
Lower 95% confidence limit	70.28
Sample size (n)	51
Sample variance	24.48
Skewness	-0.36
Kurtosis	0.30
Coefficient of variation	6.90
Number of cases missing	0
Maximum value	83.3
Median value	72.2
Minimum value	59.2

Table D-21. Descriptive statistics at the recall examination for T2_Go-Pg (mm).

Statistic	Estimate
Arithmetic mean	74.96
Standard deviation	4.98
Standard error of mean	0.70
Upper 95% confidence limit	76.37
Lower 95% confidence limit	73.56
Sample size (n)	51
Sample variance	24.85
Skewness	-0.40
Kurtosis	0.28
Coefficient of variation	6.65
Number of cases missing	0
Maximum value	85.6
Median value	75.1
Minimum value	62.2

Table D-22. Descriptive statistics at the recall examination for T2_PP-FH (°).

Statistic	Estimate
Arithmetic mean	-0.78
Standard deviation	3.33
Standard error of mean	0.47
Upper 95% confidence limit	0.16
Lower 95% confidence limit	-1.71
Sample size (n)	51
Sample variance	11.10
Skewness	0.01
Kurtosis	0.11
Coefficient of variation	-429.11
Number of cases missing	0
Maximum value	7.8
Median value	-0.7
Minimum value	-9.4

Table D-23. Descriptive statistics at the recall examination for T2_FMA (°).

Statistic	Estimate
Arithmetic mean	26.10
Standard deviation	6.23
Standard error of mean	0.87
Upper 95% confidence limit	27.85
Lower 95% confidence limit	24.35
Sample size (n)	51
Sample variance	38.76
Skewness	0.25
Kurtosis	1.69
Coefficient of variation	23.86
Number of cases missing	0
Maximum value	45.3
Median value	25.8
Minimum value	8.6

Table D-24. Descriptive statistics at the recall examination for T2_Se-Na-MP (°).

Statistic	Estimate
Arithmetic mean	32.98
Standard deviation	6.70
Standard error of mean	0.94
Upper 95% confidence limit	34.86
Lower 95% confidence limit	31.09
Sample size (n)	51
Sample variance	44.93
Skewness	0.28
Kurtosis	0.96
Coefficient of variation	20.33
Number of cases missing	0
Maximum value	53.1
Median value	32.5
Minimum value	15.8

Table D-25. Descriptive statistics at the recall examination for T2_NAP (°).

Statistic	Estimate
Arithmetic mean	-0.03
Standard deviation	5.84
Standard error of mean	0.82
Upper 95% confidence limit	1.62
Lower 95% confidence limit	-1.67
Sample size (n)	51
Sample variance	34.12
Skewness	0.03
Kurtosis	-0.26
Coefficient of variation	-22916.39
Number of cases missing	0
Maximum value	14.1
Median value	-1.1
Minimum value	-12.7

Table D-26. Descriptive statistics at the recall examination for T2_FH-Na-Pg (°).

Statistic	Estimate
Arithmetic mean	86.47
Standard deviation	3.57
Standard error of mean	0.50
Upper 95% confidence limit	87.48
Lower 95% confidence limit	85.47
Sample size (n)	51
Sample variance	12.78
Skewness	-0.49
Kurtosis	0.53
Coefficient of variation	4.13
Number of cases missing	0
Maximum value	94.0
Median value	87.1
Minimum value	75.8

Table D-27. Descriptive statistics at the recall examination for T2_UL-L1 (°).

Statistic	Estimate
Arithmetic mean	131.55
Standard deviation	8.06
Standard error of mean	1.13
Upper 95% confidence limit	133.81
Lower 95% confidence limit	129.28
Sample size (n)	51
Sample variance	64.97
Skewness	0.13
Kurtosis	1.04
Coefficient of variation	6.13
Number of cases missing	0
Maximum value	154.4
Median value	131.3
Minimum value	109.1

Table D-28. Descriptive statistics at the recall examination for T2_Overbite (mm).

Statistic	Estimate
Arithmetic mean	2.32
Standard deviation	1.29
Standard error of mean	0.18
Upper 95% confidence limit	2.68
Lower 95% confidence limit	1.96
Sample size (n)	51
Sample variance	1.66
Skewness	0.37
Kurtosis	0.35
Coefficient of variation	55.57
Number of cases missing	0
Maximum value	5.7
Median value	2.2
Minimum value	-0.5

Table D-29. Descriptive statistics at the recall examination for T2_Overjet (mm).

Statistic	Estimate
Arithmetic mean	3.78
Standard deviation	1.11
Standard error of mean	0.15
Upper 95% confidence limit	4.09
Lower 95% confidence limit	3.47
Sample size (n)	51
Sample variance	1.22
Skewness	-0.70
Kurtosis	1.91
Coefficient of variation	29.27
Number of cases missing	0
Maximum value	6.1
Median value	3.8
Minimum value	-0.1

Table D-30. Descriptive statistics at the recall examination for T2_U1-SeNa (°).

Statistic	Estimate
Arithmetic mean	104.40
Standard deviation	6.37
Standard error of mean	0.89
Upper 95% confidence limit	106.19
Lower 95% confidence limit	102.61
Sample size (n)	51
Sample variance	40.58
Skewness	-0.26
Kurtosis	-0.03
Coefficient of variation	6.10
Number of cases missing	0
Maximum value	116.5
Median value	104.8
Minimum value	87.9

Table D-31. Descriptive statistics at the recall examination for T2_U1-Na-A (°).

Statistic	Estimate
Arithmetic mean	24.81
Standard deviation	6.38
Standard error of mean	0.89
Upper 95% confidence limit	26.61
Lower 95% confidence limit	23.02
Sample size (n)	51
Sample variance	40.74
Skewness	0.11
Kurtosis	-0.64
Coefficient of variation	25.72
Number of cases missing	0
Maximum value	38.5
Median value	25.0
Minimum value	13.0

Table D-32. Descriptive statistics at the recall examination for T2_U1-Na-A (mm).

Statistic	Estimate
Arithmetic mean	4.12
Standard deviation	2.54
Standard error of mean	0.36
Upper 95% confidence limit	4.84
Lower 95% confidence limit	3.41
Sample size (n)	51
Sample variance	6.45
Skewness	0.94
Kurtosis	0.59
Coefficient of variation	61.57
Number of cases missing	0
Maximum value	12.2
Median value	3.3
Minimum value	0.3

Table D-33. Descriptive statistics at the recall examination for T2_L1-Na-B (°).

Statistic	Estimate
Arithmetic mean	21.58
Standard deviation	6.21
Standard error of mean	0.87
Upper 95% confidence limit	23.32
Lower 95% confidence limit	19.83
Sample size (n)	51
Sample variance	38.52
Skewness	-0.41
Kurtosis	0.09
Coefficient of variation	28.76
Number of cases missing	0
Maximum value	34.4
Median value	22.7
Minimum value	5.9

Table D-34. Descriptive statistics at the recall examination for T2_L1-Na-B (mm).

Statistic	Estimate
Arithmetic mean	3.65
Standard deviation	2.13
Standard error of mean	0.30
Upper 95% confidence limit	4.25
Lower 95% confidence limit	3.05
Sample size (n)	51
Sample variance	4.55
Skewness	0.01
Kurtosis	-0.57
Coefficient of variation	58.52
Number of cases missing	0
Maximum value	8.0
Median value	4.0
Minimum value	-1.1

Table D-35. Descriptive statistics at the recall examination for T2_IMPA (°).

Statistic	Estimate
Arithmetic mean	91.06
Standard deviation	6.55
Standard error of mean	0.92
Upper 95% confidence limit	92.91
Lower 95% confidence limit	89.22
Sample size (n)	51
Sample variance	42.84
Skewness	-0.46
Kurtosis	0.25
Coefficient of variation	7.19
Number of cases missing	0
Maximum value	105.8
Median value	92.6
Minimum value	74.2

Table D-36. Descriptive statistics at the recall examination for T2_FMIA (°).

Statistic	Estimate
Arithmetic mean	62.82
Standard deviation	7.51
Standard error of mean	1.05
Upper 95% confidence limit	64.93
Lower 95% confidence limit	60.71
Sample size (n)	51
Sample variance	56.34
Skewness	0.11
Kurtosis	-0.50
Coefficient of variation	11.95
Number of cases missing	0
Maximum value	80.7
Median value	62.9
Minimum value	48.8

Table D-37. Descriptive statistics at the recall examination for T2_OP-FH (°).

Statistic	Estimate
Arithmetic mean	10.46
Standard deviation	4.66
Standard error of mean	0.65
Upper 95% confidence limit	11.77
Lower 95% confidence limit	9.15
Sample size (n)	51
Sample variance	21.68
Skewness	0.02
Kurtosis	1.32
Coefficient of variation	44.51
Number of cases missing	0
Maximum value	23.3
Median value	10.2
Minimum value	-3.6

Table D-38. Descriptive statistics at the recall examination for T2_U1-PP (mm).

Statistic	Estimate
Arithmetic mean	30.15
Standard deviation	3.02
Standard error of mean	0.42
Upper 95% confidence limit	30.99
Lower 95% confidence limit	29.30
Sample size (n)	51
Sample variance	9.11
Skewness	0.37
Kurtosis	0.69
Coefficient of variation	10.01
Number of cases missing	0
Maximum value	38.3
Median value	29.9
Minimum value	23.7

Table D-39. Descriptive statistics at the recall examination for T2_U6-PP (mm).

Statistic	Estimate
Arithmetic mean	24.32
Standard deviation	2.43
Standard error of mean	0.34
Upper 95% confidence limit	25.00
Lower 95% confidence limit	23.64
Sample size (n)	51
Sample variance	5.91
Skewness	0.51
Kurtosis	0.64
Coefficient of variation	10.00
Number of cases missing	0
Maximum value	31.9
Median value	24.4
Minimum value	20.1

Table D-40. Descriptive statistics at the recall examination for T2_ Li-E (mm).

Statistic	Estimate
Arithmetic mean	-6.28
Standard deviation	2.65
Standard error of mean	0.40
Upper 95% confidence limit	-5.48
Lower 95% confidence limit	-7.07
Sample size (n)	45
Sample variance	7.02
Skewness	-0.55
Kurtosis	0.02
Coefficient of variation	-42.21
Number of cases missing	6
Maximum value	-1.8
Median value	-6.1
Minimum value	-13.6

Table D-41. Descriptive statistics at the recall examination for T2_ L_s-E (mm).

Statistic	Estimate
Arithmetic mean	-8.85
Standard deviation	2.67
Standard error of mean	0.40
Upper 95% confidence limit	-8.05
Lower 95% confidence limit	-9.65
Sample size (n)	45
Sample variance	7.12
Skewness	-0.53
Kurtosis	0.08
Coefficient of variation	-30.15
Number of cases missing	6
Maximum value	-4.7
Median value	-8.7
Minimum value	-16.7

Table D-42. Descriptive statistics at the recall examination for T2_Z Angle (°).

Statistic	Estimate
Arithmetic mean	83.04
Standard deviation	7.99
Standard error of mean	1.19
Upper 95% confidence limit	85.44
Lower 95% confidence limit	80.64
Sample size (n)	45
Sample variance	63.77
Skewness	0.29
Kurtosis	0.68
Coefficient of variation	9.62
Number of cases missing	6
Maximum value	105.8
Median value	83.3
Minimum value	64.7

Table D-43. Descriptive statistics at the recall examination for T2_ Na'-Pr'-Pg' (°).

Statistic	Estimate
Arithmetic mean	130.63
Standard deviation	4.84
Standard error of mean	0.70
Upper 95% confidence limit	132.04
Lower 95% confidence limit	129.23
Sample size (n)	48
Sample variance	23.41
Skewness	-0.29
Kurtosis	-0.28
Coefficient of variation	3.70
Number of cases missing	3
Maximum value	141.7
Median value	131.5
Minimum value	120.6

Table D-44. Descriptive statistics at the recall examination for T2_ Sn-L_s (mm).

Statistic	Estimate
Arithmetic mean	21.49
Standard deviation	2.99
Standard error of mean	0.45
Upper 95% confidence limit	22.39
Lower 95% confidence limit	20.59
Sample size (n)	45
Sample variance	8.94
Skewness	0.10
Kurtosis	0.02
Coefficient of variation	13.92
Number of cases missing	6
Maximum value	28.9
Median value	21.0
Minimum value	14.0

Table D-45. Descriptive statistics at the recall examination for T2_ A' to Upper lip-FH (mm).

Statistic	Estimate
Arithmetic mean	2.24
Standard deviation	1.05
Standard error of mean	0.16
Upper 95% confidence limit	2.55
Lower 95% confidence limit	1.92
Sample size (n)	45
Sample variance	1.11
Skewness	-0.24
Kurtosis	-0.54
Coefficient of variation	47.11
Number of cases missing	6
Maximum value	4.1
Median value	2.2
Minimum value	0.0

Table D-46. Descriptive statistics at the recall examination for T2_ B' to Lower lip-FH (mm).

Statistic	Estimate
Arithmetic mean	0.1
Standard deviation	2.3
Standard error of mean	0.3
Upper 95% confidence limit	0.8
Lower 95% confidence limit	-0.6
Sample size (n)	45
Sample variance	5.27
Skewness	-0.49
Kurtosis	0.40
Coefficient of variation	2649.69
Number of cases missing	6
Maximum value	4.3
Median value	0.2
Minimum value	-5.7

Table D-47. Descriptive statistics at the recall examination for T2_ Pr' to Sn-FH (mm).

Statistic	Estimate
Arithmetic mean	19.52
Standard deviation	2.22
Standard error of mean	0.32
Upper 95% confidence limit	20.17
Lower 95% confidence limit	18.87
Sample size (n)	47
Sample variance	4.93
Skewness	0.65
Kurtosis	0.85
Coefficient of variation	11.37
Number of cases missing	4
Maximum value	26.4
Median value	19.3
Minimum value	15.3

APPENDIX E.
DESCRIPTIVE STATISTICS (T2-T1)

Table E-1. Descriptive statistics for the posttreatment change in Se-A (mm).

Statistic	Estimate
Arithmetic mean	0.55
Standard deviation	2.07
Standard error of mean	0.29
Upper 95% confidence limit	1.14
Lower 95% confidence limit	-0.03
Sample size	51
Sample variance	4.29
Skewness	0.79
Kurtosis	0.08
Coefficient of variation	374.50
Number cases missing	0
Maximum value	6.0
Median value	0.1
Minimum value	-2.8
One-sample t-test	1.91
P-value	0.0623

Table E-2. Descriptive statistics for the posttreatment change in Se-B (mm).

Statistic	Estimate
Arithmetic mean	-0.39
Standard deviation	2.17
Standard error of mean	0.30
Upper 95% confidence limit	0.22
Lower 95% confidence limit	-1.00
Sample size	51
Sample variance	4.72
Skewness	0.55
Kurtosis	-0.44
Coefficient of variation	-562.51
Number cases missing	0
Maximum value	4.5
Median value	-0.7
Minimum value	-3.8
One-sample t-test	-1.27
P-value	0.2101

Table E-3. Descriptive statistics for the posttreatment change in Na-Se-Gn (°).

Statistic	Estimate
Arithmetic mean	0.05
Standard deviation	1.34
Standard error of mean	0.19
Upper 95% confidence limit	0.43
Lower 95% confidence limit	-0.34
Sample size	49
Sample variance	1.80
Skewness	0.31
Kurtosis	-0.86
Coefficient of variation	2861.62
Number cases missing	2
Maximum value	2.9
Median value	-0.1
Minimum value	-2.2
One-sample t-test	0.24
P-value	0.8078

Table E-4. Descriptive statistics for the posttreatment change in Se-Gn (mm).

Statistic	Estimate
Arithmetic mean	0.73
Standard deviation	2.31
Standard error of mean	0.33
Upper 95% confidence limit	1.40
Lower 95% confidence limit	0.07
Sample size	49
Sample variance	5.36
Skewness	0.08
Kurtosis	-0.34
Coefficient of variation	315.07
Number cases missing	2
Maximum value	6.6
Median value	0.8
Minimum value	-3.7
One-sample t-test	2.22
P-value	0.0310

Table E-5. Descriptive statistics for the posttreatment change in Na-PP (mm).

Statistic	Estimate
Arithmetic mean	0.41
Standard deviation	1.69
Standard error of mean	0.24
Upper 95% confidence limit	0.89
Lower 95% confidence limit	-0.06
Sample size	51
Sample variance	2.86
Skewness	0.24
Kurtosis	-0.27
Coefficient of variation	410.99
Number cases missing	0
Maximum value	4.4
Median value	0.1
Minimum value	-3.5
One-sample t-test	1.74
P-value	0.0884

Table E-6. Descriptive statistics for the posttreatment change in Me-PP (mm).

Statistic	Estimate
Arithmetic mean	0.07
Standard deviation	1.47
Standard error of mean	0.21
Upper 95% confidence limit	0.49
Lower 95% confidence limit	-0.35
Sample size	50
Sample variance	2.16
Skewness	0.37
Kurtosis	-0.51
Coefficient of variation	2161.81
Number cases missing	1
Maximum value	3.4
Median value	0.0
Minimum value	-2.6
One-sample t-test	0.33
P-value	0.7450

Table E-7. Descriptive statistics for the posttreatment change in ANS-Me (mm).

Statistic	Estimate
Arithmetic mean	0.06
Standard deviation	1.72
Standard error of mean	0.24
Upper 95% confidence limit	0.55
Lower 95% confidence limit	-0.43
Sample size	50
Sample variance	2.96
Skewness	0.34
Kurtosis	-0.92
Coefficient of variation	2967.97
Number cases missing	1
Maximum value	3.7
Median value	-0.1
Minimum value	-2.6
One-sample t-test	0.24
P-value	0.8127

Table E-8. Descriptive statistics for the posttreatment change in Na-Me (mm).

Statistic	Estimate
Arithmetic mean	0.39
Standard deviation	1.97
Standard error of mean	0.28
Upper 95% confidence limit	0.95
Lower 95% confidence limit	-0.17
Sample size	50
Sample variance	3.87
Skewness	0.12
Kurtosis	-0.82
Coefficient of variation	504.68
Number cases missing	1
Maximum value	4.6
Median value	0.4
Minimum value	-3.2
One-sample t-test	1.40
P-value	0.1675

Table E-9. Descriptive statistics for the posttreatment change in Se-Go (mm).

Statistic	Estimate
Arithmetic mean	0.69
Standard deviation	2.58
Standard error of mean	0.37
Upper 95% confidence limit	1.43
Lower 95% confidence limit	-0.05
Sample size	49
Sample variance	6.64
Skewness	0.28
Kurtosis	-0.83
Coefficient of variation	374.75
Number cases missing	2
Maximum value	5.7
Median value	0.0
Minimum value	-4.7
One-sample t-test	1.87
P-value	0.0679

Table E-10. Descriptive statistics for the posttreatment change in Se-Go/Na-Me (%).

Statistic	Estimate
Arithmetic mean	0.33
Standard deviation	2.24
Standard error of mean	0.32
Upper 95% confidence limit	0.97
Lower 95% confidence limit	-0.32
Sample size	49
Sample variance	5.00
Skewness	0.38
Kurtosis	-0.83
Coefficient of variation	684.48
Number cases missing	2
Maximum value	4.9
Median value	0.0
Minimum value	-3.2
One-sample t-test	1.02
P-value	0.3116

Table E-11. Descriptive statistics for the posttreatment change in Se-Ba (mm).

Statistic	Estimate
Arithmetic mean	-0.18
Standard deviation	2.02
Standard error of mean	0.28
Upper 95% confidence limit	0.38
Lower 95% confidence limit	-0.75
Sample size	51
Sample variance	4.07
Skewness	-0.25
Kurtosis	0.39
Coefficient of variation	-1094.31
Number cases missing	0
Maximum value	4.7
Median value	0.0
Minimum value	-5.0
One-sample t-test	-0.65
P-value	0.5170

Table E-12. Descriptive statistics for the posttreatment change in Ba-Se-Na (°).

Statistic	Estimate
Arithmetic mean	-0.24
Standard deviation	2.27
Standard error of mean	0.32
Upper 95% confidence limit	0.40
Lower 95% confidence limit	-0.88
Sample size	51
Sample variance	5.14
Skewness	0.36
Kurtosis	1.13
Coefficient of variation	-947.86
Number cases missing	0
Maximum value	6.5
Median value	-0.1
Minimum value	-5.0
One-sample t-test	-0.75
P-value	0.4547

Table E-13. Descriptive statistics for the posttreatment change in SNA (°).

Statistic	Estimate
Arithmetic mean	0.31
Standard deviation	1.77
Standard error of mean	0.25
Upper 95% confidence limit	0.80
Lower 95% confidence limit	-0.19
Sample size	51
Sample variance	3.12
Skewness	0.57
Kurtosis	0.33
Coefficient of variation	577.88
Number cases missing	0
Maximum value	5.3
Median value	0.2
Minimum value	-2.6
One-sample t-test	1.24
P-value	0.2223

Table E-14. Descriptive statistics for the posttreatment change in SNB (°).

Statistic	Estimate
Arithmetic mean	-0.1118
Standard deviation	1.3736
Standard error of mean	0.1923
Upper 95% confidence limit	0.2746
Lower 95% confidence limit	-0.4981
Sample size	51
Sample variance	1.89
Skewness	-0.04
Kurtosis	-1.04
Coefficient of variation	-1228.97
Number cases missing	0
Maximum value	2.6
Median value	-0.1
Minimum value	-2.6
One-sample t-test	-0.58
P-value	0.5638

Table E-15. Descriptive statistics for the posttreatment change in ANB (°).

Statistic	Estimate
Arithmetic mean	0.43
Standard deviation	1.36
Standard error of mean	0.19
Upper 95% confidence limit	0.81
Lower 95% confidence limit	0.04
Sample size	51
Sample variance	1.86
Skewness	0.36
Kurtosis	-0.23
Coefficient of variation	320.14
Number cases missing	0
Maximum value	3.8
Median value	0.4
Minimum value	-2.0
One-sample t-test	2.23
P-value	0.0302

Table E-16. Descriptive statistics for the posttreatment change in AOBO (mm).

Statistic	Estimate
Arithmetic mean	0.83
Standard deviation	2.26
Standard error of mean	0.32
Upper 95% confidence limit	1.47
Lower 95% confidence limit	0.20
Sample size	51
Sample variance	5.12
Skewness	0.16
Kurtosis	-0.04
Coefficient of variation	272.11
Number cases missing	0
Maximum value	6.3
Median value	0.7
Minimum value	-4.4
One-sample t-test	2.62
P-value	0.0115

Table E-17. Descriptive statistics for the posttreatment change in A-Na-FH (mm).

Statistic	Estimate
Arithmetic mean	0.85
Standard deviation	2.09
Standard error of mean	0.29
Upper 95% confidence limit	1.44
Lower 95% confidence limit	0.27
Sample size	51
Sample variance	4.36
Skewness	0.63
Kurtosis	0.66
Coefficient of variation	244.93
Number cases missing	0
Maximum value	6.6
Median value	0.7
Minimum value	-3.8
One-sample t-test	2.92
P-value	0.0053

Table E-18. Descriptive statistics for the posttreatment change in B-Na-FH (mm).

Statistic	Estimate
Arithmetic mean	0.65
Standard deviation	2.28
Standard error of mean	0.32
Upper 95% confidence limit	1.29
Lower 95% confidence limit	0.01
Sample size	51
Sample variance	5.18
Skewness	0.16
Kurtosis	-0.48
Coefficient of variation	348.52
Number cases missing	0
Maximum value	5.7
Median value	0.7
Minimum value	-3.3
One-sample t-test	2.05
P-value	0.0457

Table E-19. Descriptive statistics for the posttreatment change in Cd-A (mm).

Statistic	Estimate
Arithmetic mean	0.73
Standard deviation	2.23
Standard error of mean	0.31
Upper 95% confidence limit	1.36
Lower 95% confidence limit	0.10
Sample size	51
Sample variance	4.97
Skewness	0.26
Kurtosis	-0.74
Coefficient of variation	305.76
Number cases missing	0
Maximum value	4.8
Median value	0.5
Minimum value	-3.9
One-sample t-test	2.34
P-value	0.0236

Table E-20. Descriptive statistics for the posttreatment change in Go-Me (mm).

Statistic	Estimate
Arithmetic mean	0.82
Standard deviation	2.70
Standard error of mean	0.39
Upper 95% confidence limit	1.60
Lower 95% confidence limit	0.05
Sample size	49
Sample variance	7.27
Skewness	0.24
Kurtosis	-0.63
Coefficient of variation	327.04
Number cases missing	2
Maximum value	7.2
Median value	0.5
Minimum value	-3.7
One-sample t-test	2.14
P-value	0.0374

Table E-21. Descriptive statistics for the posttreatment change in Go-Pg (mm).

Statistic	Estimate
Arithmetic mean	1.32
Standard deviation	2.81
Standard error of mean	0.40
Upper 95% confidence limit	2.12
Lower 95% confidence limit	0.52
Sample size	50
Sample variance	7.90
Skewness	-0.13
Kurtosis	-1.04
Coefficient of variation	212.35
Number cases missing	1
Maximum value	5.7
Median value	1.1
Minimum value	-4.1
One-sample t-test	3.33
P-value	0.0017

Table E-22. Descriptive statistics for the posttreatment change in PP-FH (°).

Statistic	Estimate
Arithmetic mean	0.09
Standard deviation	1.89
Standard error of mean	0.26
Upper 95% confidence limit	0.62
Lower 95% confidence limit	-0.44
Sample size	51
Sample variance	3.58
Skewness	0.06
Kurtosis	-0.98
Coefficient of variation	2144.33
Number cases missing	0
Maximum value	3.4
Median value	0.1
Minimum value	-3.4
One-sample t-test	0.33
P-value	0.7405

Table E-23. Descriptive statistics for the posttreatment change in FMA (°).

Statistic	Estimate
Arithmetic mean	-0.55
Standard deviation	2.23
Standard error of mean	0.32
Upper 95% confidence limit	0.09
Lower 95% confidence limit	-1.19
Sample size	49
Sample variance	4.97
Skewness	-0.46
Kurtosis	-0.59
Coefficient of variation	-405.94
Number cases missing	2
Maximum value	3.2
Median value	-0.4
Minimum value	-5.6
One-sample t-test	-1.72
P-value	0.0911

Table E-24. Descriptive statistics for the posttreatment change in Se-Na-MP (°).

Statistic	Estimate
Arithmetic mean	-0.08
Standard deviation	2.23
Standard error of mean	0.32
Upper 95% confidence limit	0.56
Lower 95% confidence limit	-0.72
Sample size	49
Sample variance	4.99
Skewness	0.13
Kurtosis	-0.62
Coefficient of variation	-2807.66
Number cases missing	2
Maximum value	4.6
Median value	0.0
Minimum value	-4.3
One-sample t-test	-0.25
P-value	0.8042

Table E-25. Descriptive statistics for the posttreatment change in NAP (°).

Statistic	Estimate
Arithmetic mean	0.31
Standard deviation	2.84
Standard error of mean	0.40
Upper 95% confidence limit	1.11
Lower 95% confidence limit	-0.49
Sample size	51
Sample variance	8.05
Skewness	0.21
Kurtosis	0.00
Coefficient of variation	921.74
Number cases missing	0
Maximum value	7.9
Median value	0.3
Minimum value	-5.4
One-sample t-test	0.77
P-value	0.4421

Table E-26. Descriptive statistics for the posttreatment change in FH-Na-Pg (°).

Statistic	Estimate
Arithmetic mean	0.67
Standard deviation	1.48
Standard error of mean	0.21
Upper 95% confidence limit	1.09
Lower 95% confidence limit	0.26
Sample size	51
Sample variance	2.18
Skewness	0.07
Kurtosis	-0.61
Coefficient of variation	218.69
Number cases missing	0
Maximum value	3.5
Median value	0.6
Minimum value	-2.1
One-sample t-test	3.27
P-value	0.0020

Table E-27. Descriptive statistics for the posttreatment change in UI-L1 (°).

Statistic	Estimate
Arithmetic mean	1.41
Standard deviation	6.84
Standard error of mean	0.96
Upper 95% confidence limit	3.33
Lower 95% confidence limit	-0.51
Sample size	51
Sample variance	46.81
Skewness	0.27
Kurtosis	-0.02
Coefficient of variation	485.32
Number cases missing	0
Maximum value	20.3
Median value	1.3
Minimum value	-10.6
One-sample t-test	1.47
P-value	0.1474

Table E-28. Descriptive statistics for the posttreatment change in Overbite (mm).

Statistic	Estimate
Arithmetic mean	1.15
Standard deviation	1.31
Standard error of mean	0.18
Upper 95% confidence limit	1.52
Lower 95% confidence limit	0.78
Sample size	51
Sample variance	1.73
Skewness	-0.07
Kurtosis	0.40
Coefficient of variation	114.40
Number cases missing	0
Maximum value	4.7
Median value	1.1
Minimum value	-2.1
One-sample t-test	6.24
P-value	<0.0001

Table E-29. Descriptive statistics for the posttreatment change in Overjet (mm).

Statistic	Estimate
Arithmetic mean	0.54
Standard deviation	1.11
Standard error of mean	0.15
Upper 95% confidence limit	0.85
Lower 95% confidence limit	0.23
Sample size	51
Sample variance	1.22
Skewness	-0.42
Kurtosis	-0.44
Coefficient of variation	203.47
Number cases missing	0
Maximum value	2.2
Median value	0.6
Minimum value	-2.4
One-sample t-test	3.51
P-value	0.0010

Table E-30. Descriptive statistics for the posttreatment change in U1-SeNa (°).

Statistic	Estimate
Arithmetic mean	-1.55
Standard deviation	5.23
Standard error of mean	0.73
Upper 95% confidence limit	-0.07
Lower 95% confidence limit	-3.02
Sample size	51
Sample variance	27.40
Skewness	-0.44
Kurtosis	-0.30
Coefficient of variation	-338.38
Number cases missing	0
Maximum value	8.0
Median value	-0.2
Minimum value	-14.3
One-sample t-test	-2.11
P-value	0.0398

Table E-31. Descriptive statistics for the posttreatment change in U1-Na-A (°).

Statistic	Estimate
Arithmetic mean	-1.85
Standard deviation	5.15
Standard error of mean	0.72
Upper 95% confidence limit	-0.40
Lower 95% confidence limit	-3.30
Sample size	51
Sample variance	26.55
Skewness	-0.25
Kurtosis	-0.54
Coefficient of variation	-278.68
Number cases missing	0
Maximum value	8.4
Median value	-1.6
Minimum value	-13.4
One-sample t-test	-2.56
P-value	0.0134

Table E-32. Descriptive statistics for the posttreatment change in U1-Na-A (mm).

Statistic	Estimate
Arithmetic mean	-0.29
Standard deviation	2.17
Standard error of mean	0.30
Upper 95% confidence limit	0.32
Lower 95% confidence limit	-0.90
Sample size	51
Sample variance	4.72
Skewness	-0.11
Kurtosis	-0.34
Coefficient of variation	-754.02
Number cases missing	0
Maximum value	3.8
Median value	-0.6
Minimum value	-5.6
One-sample t-test	-0.95
P-value	0.3481

Table E-33. Descriptive statistics for the posttreatment change in L1-Na-B (°).

Statistic	Estimate
Arithmetic mean	-0.01
Standard deviation	3.86
Standard error of mean	0.54
Upper 95% confidence limit	1.08
Lower 95% confidence limit	-1.09
Sample size	51
Sample variance	14.91
Skewness	-0.09
Kurtosis	-0.75
Coefficient of variation	-49230.75
Number cases missing	0
Maximum value	6.8
Median value	0.3
Minimum value	-8.3
One-sample t-test	-0.01
P-value	0.9885

Table E-34. Descriptive statistics for the posttreatment change in L1-Na-B (mm).

Statistic	Estimate
Arithmetic mean	-0.06
Standard deviation	1.49
Standard error of mean	0.21
Upper 95% confidence limit	0.36
Lower 95% confidence limit	-0.48
Sample size	51
Sample variance	2.23
Skewness	-0.08
Kurtosis	0.36
Coefficient of variation	-2628.12
Number cases missing	0
Maximum value	3.7
Median value	0.0
Minimum value	-4.0
One-sample t-test	-0.27
P-value	0.7869

Table E-35. Descriptive statistics for the posttreatment change in IMPA (°).

Statistic	Estimate
Arithmetic mean	0.35
Standard deviation	4.14
Standard error of mean	0.59
Upper 95% confidence limit	1.54
Lower 95% confidence limit	-0.84
Sample size	49
Sample variance	17.14
Skewness	-0.09
Kurtosis	-0.36
Coefficient of variation	1193.14
Number cases missing	2
Maximum value	10.6
Median value	0.4
Minimum value	-8.2
One-sample t-test	0.59
P-value	0.5602

Table E-36. Descriptive statistics for the posttreatment change in FMIA (°).

Statistic	Estimate
Arithmetic mean	0.35
Standard deviation	4.17
Standard error of mean	0.58
Upper 95% confidence limit	1.52
Lower 95% confidence limit	-0.82
Sample size	51
Sample variance	17.38
Skewness	0.05
Kurtosis	-0.99
Coefficient of variation	1187.90
Number cases missing	0
Maximum value	8.7
Median value	0.0
Minimum value	-7.0
One-sample t-test	0.60
P-value	0.5504

Table E-37. Descriptive statistics for the posttreatment change in OP-FH (°).

Statistic	Estimate
Arithmetic mean	-0.68
Standard deviation	2.96
Standard error of mean	0.41
Upper 95% confidence limit	0.15
Lower 95% confidence limit	-1.51
Sample size	51
Sample variance	8.76
Skewness	0.76
Kurtosis	3.56
Coefficient of variation	-434.98
Number cases missing	0
Maximum value	10.8
Median value	-0.4
Minimum value	-6.5
One-sample t-test	-1.64
P-value	0.1069

Table E-38. Descriptive statistics for the posttreatment change in U1-PP (mm).

Statistic	Estimate
Arithmetic mean	0.61
Standard deviation	1.53
Standard error of mean	0.21
Upper 95% confidence limit	1.04
Lower 95% confidence limit	0.18
Sample size	51
Sample variance	2.35
Skewness	0.59
Kurtosis	1.34
Coefficient of variation	250.36
Number cases missing	0
Maximum value	5.7
Median value	0.6
Minimum value	-2.0
One-sample t-test	2.85
P-value	0.0063

Table E-39. Descriptive statistics for the posttreatment change in U6-PP (mm).

Statistic	Estimate
Arithmetic mean	0.66
Standard deviation	1.47
Standard error of mean	0.21
Upper 95% confidence limit	1.07
Lower 95% confidence limit	0.24
Sample size	51
Sample variance	2.15
Skewness	0.70
Kurtosis	3.17
Coefficient of variation	223.46
Number cases missing	0
Maximum value	5.5
Median value	0.4
Minimum value	-3.8
One-sample t-test	3.20
P-value	0.0024

Table E-40. Descriptive statistics for the posttreatment change in L_i -E (mm).

Statistic	Estimate
Arithmetic mean	-1.89
Standard deviation	2.23
Standard error of mean	0.34
Upper 95% confidence limit	-1.21
Lower 95% confidence limit	-2.57
Sample size	44
Sample variance	4.96
Skewness	0.72
Kurtosis	0.78
Coefficient of variation	-117.76
Number cases missing	7
Maximum value	4.8
Median value	-2.1
Minimum value	-5.8
One-sample t-test	-5.63
P-value	<0.0001

Table E-41. Descriptive statistics for the posttreatment change in L_s-E (mm).

Statistic	Estimate
Arithmetic mean	-1.67
Standard deviation	2.98
Standard error of mean	0.45
Upper 95% confidence limit	-0.76
Lower 95% confidence limit	-2.57
Sample size	44
Sample variance	8.85
Skewness	1.18
Kurtosis	2.34
Coefficient of variation	-178.35
Number cases missing	7
Maximum value	8.3
Median value	-1.8
Minimum value	-6.6
One-sample t-test	-3.72
P-value	0.0006

Table E-42. Descriptive statistics for the posttreatment change in Z Angle (°).

Statistic	Estimate
Arithmetic mean	4.86
Standard deviation	4.32
Standard error of mean	0.67
Upper 95% confidence limit	6.20
Lower 95% confidence limit	3.51
Sample size	42
Sample variance	18.67
Skewness	-0.36
Kurtosis	0.25
Coefficient of variation	88.97
Number cases missing	9
Maximum value	12.9
Median value	4.85
Minimum value	-7.40
One-sample t-test	7.28
P-value	<0.0001

Table E-43. Descriptive statistics for the posttreatment change in Na'-Pr'-Pg' (°).

Statistic	Estimate
Arithmetic mean	0.06
Standard deviation	3.44
Standard error of mean	0.53
Upper 95% confidence limit	1.13
Lower 95% confidence limit	-1.01
Sample size	42
Sample variance	11.82
Skewness	0.73
Kurtosis	0.78
Coefficient of variation	6016.56
Number cases missing	9
Maximum value	10.20
Median value	-0.3
Minimum value	-5.8
One-sample t-test	0.1077
P-value	0.9147

Table E-44. Descriptive statistics for the posttreatment change in Sn-L_s (mm).

Statistic	Estimate
Arithmetic mean	-0.27
Standard deviation	5.28
Standard error of mean	0.81
Upper 95% confidence limit	1.36
Lower 95% confidence limit	-1.90
Sample size	43
Sample variance	27.92
Skewness	-3.10
Kurtosis	11.44
Coefficient of variation	-1958.74
Number cases missing	8
Maximum value	6.5
Median value	0.1
Minimum value	-21.7
One-sample t-test	-0.33
P-value	0.7395

Table E-45. Descriptive statistics for the posttreatment change in A' to Upper lip-FH (mm).

Statistic	Estimate
Arithmetic mean	-0.50
Standard deviation	1.45
Standard error of mean	0.22
Upper 95% confidence limit	-0.06
Lower 95% confidence limit	-0.95
Sample size	43
Sample variance	2.09
Skewness	-0.23
Kurtosis	-0.45
Coefficient of variation	-288.14
Number cases missing	8
Maximum value	2.4
Median value	-0.6
Minimum value	-4.0
One-sample t-test	-2.28
P-value	0.0280

Table E-46. Descriptive statistics for the posttreatment change in B' to Lower lip-FH (mm).

Statistic	Estimate
Arithmetic mean	0.32
Standard deviation	2.21
Standard error of mean	0.34
Upper 95% confidence limit	1.00
Lower 95% confidence limit	-0.36
Sample size	43
Sample variance	4.90
Skewness	0.21
Kurtosis	0.66
Coefficient of variation	694.92
Number cases missing	8
Maximum value	5.8
Median value	-0.1
Minimum value	-5.8
One-sample t-test	0.94
P-value	0.3508

Table E-47. Descriptive statistics for the posttreatment change in Pr' to Sn-FH (mm).

Statistic	Estimate
Arithmetic mean	2.25
Standard deviation	2.09
Standard error of mean	0.32
Upper 95% confidence limit	2.88
Lower 95% confidence limit	1.61
Sample size	44
Sample variance	4.38
Skewness	-0.29
Kurtosis	-0.46
Coefficient of variation	93.25
Number cases missing	7
Maximum value	5.9
Median value	2.1
Minimum value	-2.8
One-sample t-test	7.11
P-value	<0.0001

VITA

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