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FUNCTIONAL APPLIANCE TREATMENT AND THE TIMING OF FACIAL GROWTH

by

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THESIS

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[redacted]

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FUNCTIONAL APPLIANCE TREATMENT AND THE TIMING OF FACIAL GROWTH

I. INTRODUCTION

Functional appliances have seen widespread use throughout Europe since the early part of the twentieth century. (1-3) During the 1970's their use in the United States gained popularity as practitioners became increasingly disappointed with the lack of sagittal skeletal correction obtained with conventional edgewise appliances and headgear treatment that had been commonly used.

Much of this interest in the United States was due to research that showed an increase in condylar growth in rats and monkeys. (4-10) However, numerous other studies have shown that this may not be the case in humans (11-14).

The timing of the adolescent growth spurt has been of great interest to orthodontists as it has been felt that in cases needing growth modification treatment should be done during the growth spurt for the most successful treatment outcome. Determination of the average time of greatest growth intensity has been established by the use of hand wrist films, longitudinal height measurements, and serial lateral cephalometric head films.(15-17) Surprisingly, only a limited number of studies have examined the efficiency of treatment with functional appliances and the variations in growth intensity before the pubertal growth spurt. (18, 19)

The purpose of this study was to evaluate treatment effects of functional appliance therapy relative to the individual's growth intensity. The effects of treatment on skeletal and dentoalveolar development were determined by serial cephalometric analysis correlated with the individual's growth intensity. Groups of subjects were subdivided based on time of treatment start relative to peak growth intensity as assessed by longitudinal height measurements. Skeletal growth of these subgroups (i.e. mandibular length) was analyzed to determine if the amount of growth seen was due to treatment with the functional appliance or whether it was due to the inherent growth rate of the subjects in the subgroups. This study also examined the variation in the treatment effects on the individual patient. Finally, it is hoped that rational guidelines can be developed for optimal timing of functional appliance therapy.

II. REVIEW OF THE LITERATURE

A. FUNCTIONAL APPLIANCES

1. MODE OF ACTION

Intraoral functional appliances have been a cause for debate since their introduction by Pierre Robin in 1902(1) for several reasons. It is not clear that functional appliances actually increase the amount of mandibular condylar growth or whether they change the function of the perioral musculature as has been claimed. When Robin developed a *monobloc* appliance it was to hold the mandible forward in patients with congenitally small mandibles (later known as Pierre Robin Syndrome). This initial appliance was not intended to actually alter jaw growth, but was designed to prevent infants and children from asphyxiating by holding the mandible and tongue forward.

The theory that a functional appliance could be used to modify the development of the stomatognathic system in individuals with a Class II, division I malocclusion was first proposed by Andresen (2). His theory was that forward posturing of the mandible increased the activity of the protractor and elevator muscles, while relaxing and stretching the retractor muscles, and thereby preventing restriction of dentoalveolar development due to 'lower lip trap' and mentalis hyperactivity.

The concept of *functional jaw orthopedics* did not gain wide acceptance until Andresen continued further studies with Häupl. (3) Andresen and Häupl, according to Ahlgren (20), believed that the reflexively evoked contraction patterns in the jaw muscles, elicited by the activator, resulted in changes in the supporting tissues of the dentition which created an environment for the teeth to alter their positions. They believed motion of the activator rather than the immobile activator was responsible for the treatment effects. Andresen and Häupl (3) stated that, "the functional stimuli occurring during the function of an organ have a direct effect on the transformation, formation, and maintenance of the tissues". They also believed that, "the activity of the masticatory muscles and those of the tongue, cheeks, and lips which takes place during sleep is transformed by means of the orthopedic appliance to the tissues of the masticatory organ, including functional tissue-transforming stimuli".

Statements such as these raised controversy, among orthodontists, as to the nature of the muscle activity produced by the activator. The views of Andresen and Häupl were supported by Grude (21) and Schwarz (22), who according to Ahlgren (20),believed the orthodontic forces produced by the activator are primarily due to a continuous active biting into the appliance. Other investigators came to different conclusions. Herren (23) believed that the various forces acting on the mandible i.e. gravity, air pressure, muscle tonus, and tension are normally in equilibrium. When head posture or air pressure changes, the mandibular posture also changes to compensate. Therefore, each alteration of the mandible's environment results in passive movements of the mandible until it finds a new position of equilibrium. The functional appliance acts to hold the mandible into the desired position and prevents it from moving into the variety of rest positions that are noted during sleep. The muscle forces that would normally be maintaining an equilibrium through the posture of the mandible are transmitted to the appliance. The appliance then transmits these forces to the bone and the dentition in specific directions. Selmer-Olsen (24) viewed the activator action as a stretching of the muscles, and other facial soft tissues, resulting from mandibular opening and protruding beyond the rest position. He believed the forces produced were not due to the kinetic energy from active muscle contraction, but rather from the elastic properties of the stretched muscle tissues. Woodside (25-27) later used the term "the viscoelastic properties" of the tissues to describe this phenomenon. This view was also held by Ballard (28) and Harvold (11, 28-31) who felt the frequency of jaw movements is not increased with activator treatment, but that the increased muscle activity results from increased tonus in the stretched tissues. They believed that the immobile activator, rather than the mobile activator was the primary source of treatment effects.

Improved techniques in electromyographic investigations in the middle part of the century gave more conclusive information about the muscle activity of individuals wearing activators. Ahlgren (20) reported that during sleep no increase in muscle activity and no reflex biting was noted with activator wear. His studies supported the views of Selmer-Olsen(24), Woodside(24-27), Ballard(28), and Harvold(11, 28-31) that the immobile activator, while pressing against the teeth, was responsible for the treatment effects. Later EMG studies by Ahlgren (32) demonstrated that passive tension in the muscles persists while sleeping, and that contraction of the tongue and jaw muscles transmit intermittent forces during REM sleep. He concluded that the activator gives rise to both continuous and intermittent forces during sleep with the continuous forces being the dominant factor.

2. APPLIANCE DESIGN

Since the original introduction of the activator by Andresen, at that time called the "Norwegian system" (3), many different appliance designs have been developed for use in functional jaw orthopedics.

The original Andresen activator was designed to be used only at night and the vertical opening was within the normal freeway space. The sagittal advancement was limited to between 3 and 5 mm and the lower incisors were supported by the appliance only on the lingual and occlusal.

Modifications of this original appliance have since been used in more recent functional appliance designs. Most appliances now have either acrylic over the lower incisors or a labial bow to prevent excessive tipping of the lower incisors. To reduce the bulkiness of the appliance a cross palatal wire has been used to substitute for the acrylic as well. Other functional appliances have been designed with jackscrews to actively expand the maxillary arch. The Bionator, designed by Balters (33), includes a modified maxillary labial archwire that extends posteriorly to relieve cheek pressure on the posterior teeth and allow for passive expansion of the dental arches.

The function regulator, as designed by Fränkel (34), also uses the concept of passive expansion to an even greater extent. The appliance further incorporates interproximal wires in the maxillary arch to fix the appliance to the maxillary teeth. The appliance includes buccal and labial shields to prevent lip and cheek pressure from restricting transverse development of the dental arches. To maximize this effect the shields are extended deep into the vestibule in order to stretch the vestibular mucosa and its underlying periosteum. Fränkel believes that this periosteal stretching will help develop the underlying basal bone.

Functional appliances have also been developed with separate maxillary and mandibular components. The twin block appliance by Clark (date) is a modification of an appliance originally introduced by Schwarz (35). The maxillary portion has a block of acrylic covering the posterior occlusion up to the second bicuspid, while the mandibular portion has occlusal coverage over the bicuspids. The lack of occlusal coverage on the mandibular molars allows for vertical and anterior eruption of the molars. Both the maxillary and mandibular appliance components have inclined planes that brings the mandible into an anteriorly displaced position. A more recent modification of the twin block appliance incorporates attracting rare earth magnets into the inclined planes.

The use of the activator in combination with a headgear is another recent advancement in dentofacial orthopedics. Initially this appliance combination allowed the headgear to be used either together with the functional appliance, or independently, as the individual case required. (36) A cervical headgear was used in combination with the activator by Pfeiffer and Grobety (37-39), but that system was later modified by Teuscher

(37-42). Teuscher developed an occipital pull headgear activator appliance which incorporates a high pull headgear through tubes placed in the acrylic adjacent to the deciduous molars. It functions as a one piece appliance and by placing the headgear tubes into the acrylic the tendency to distal tipping of maxillary first molars, as is seen when the headgear forces are directed through these teeth, is prevented. Anterior torquing springs are incorporated into the acrylic to control the tendency for the maxillary incisors to tip lingually during activator treatment. The direction of pull of the headgear is guided between the center of resistance of the maxilla and the maxillary dentition to avoid any undesirable tipping of the maxillary occlusal plane.

Fixed postural or functional interarch appliances are another recent addition to functional jaw orthopedics. One of the more popular appliances of this type is the "Herbst appliance", whch did not gain wide recognition or popularity until it's reintroduction by Pancherz (43). The appliance consists of a tube and plunger mechanism that holds the lower jaw forward and it is attached to the maxillary first molars and mandibular first bicuspids. This telescoping mechanism forces a forward positioning of the mandible as the teeth are brought into contact. A variety of different designs have now been developed on the same principle.

3. TREATMENT EFFECTS

The treatment effects of functional appliances has been the topic of much controversy. A centerpiece of this debate is whether these appliances have an effect on condylar growth. Charlier (4), Stöckli and Willert (5), Petrovik (6), Elgoyhen (10), and McNamara (7-9) have all reported stimulated condylar growth in animal models. Charlier (4) conducted a study on adolescent *Sprague-Dawley* rats and reported that hyperpropulsion of the mandible brought about additional growth of the condylar cartilage by stimulating the prechondroblastic zone of cells. Elgoyhen (10) conducted a study on rhesus monkeys in which a protrusive mandibular position was achieved by placement of onlays on the teeth. He reported a statistically significant increase in the rate and amount of condylar growth that occurring during the first three months of the experiment. The vertical displacement of the maxilla was inhibited as was the vertical and anterior eruption of the maxillary teeth. He also found mesial migration of the buccal segments of the mandibular dentition. Stöckli (5) also conducted a study which involved a protrusive mandibular position in monkeys and reported that in the experimental animals the posterior region of the condylar head the condylar cartilage increased to several times its normal thickness. However, after 120 days the histological appearance of the condyles did not differ from the controls and no histopathology was detected.

Increased condylar growth produced by a protrusive mandibular position has not been definitively demonstrated in humans, however. McNamara (44), Creekmore and Radney (45), and Righellis (46) have reported statistically significant increases in condylar growth using the function regulator. Robertson (12) and Gianelly et al (13), on the other hand, did not find an increase in condylar growth, and Gianelly (13) ascribed the differences in amounts of condylar growth to mandibular posturing.

The treatment effects of functional appliances have been shown not to be merely limited to growth of the mandible. In one of the first prospective studies of functional appliances, Harvold and Vargervik (11) and Vargervik and Harvold (14) described the skeletal and dental effects of the Harvold activator. Their findings included statistically significant changes in the following areas; reduction of the forward growth of the maxilla, uprighting of the maxillary incisors, decrease in the overjet, and leveling of the mandibular occlusal plane. During treatment the sagittal molar relationship improved and they reported a relocation of the glenoid fossa downward and forward, with advancement of all mandibular structures, and an increase in the lower face height. Jakobsen and Paulin (47) reported that females demonstrated a decreased ANB angle due to restriction of maxillary growth while the males showed a decreased ANB angle primarily due to increased mandibular growth. Anterior rotation of the mandible was less common in the activator group than in the control group with the condylar growth in the activator group being in a superior-posterior direction, and total mandibular length was increased more in the activator group. Luder (48) also reported on two types of reaction to activator treatment. He found that males showed increased condylar growth that was redirected posteriorly, while females just showed redirected growth. In both groups the displacement of the maxilla was not influenced by the activator appliance, but there was a pronounced inhibition of vertical dentoalveolar development. Luder also reported that the angulation of the upper and lower occlusal planes changed significantly in males but did not in females. At the initiation of treatment the males had deeper bites and therefore needed higher construction bites for the activator. He concluded that a higher construction bite leads to more mandibular and less maxillary response to activator treatment.

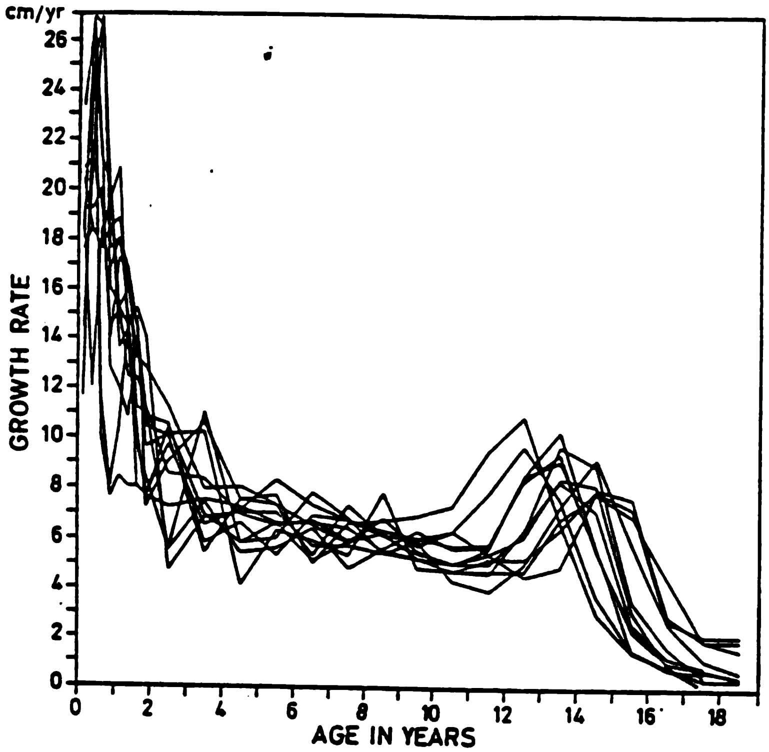
Studies of the treatment effects of the activator-high pull headgear appliances have also been conducted. Lagerstrom and Nielsen et al (49) looked at the skeletal and dental contributions to CL II correction in patients treated with a high-pull headgear-activator appliance. They found that the correction was obtained by a slight distal repositioning of the maxillary molars (mean 0.07 mm) and a mesial repositioning of the mandibular molars (mean 3.3 mm). Perhaps more importantly, they reported a wide range of variation in the treatment effects between individuals.

B. SOMATIC GROWTH

One of the first studies on the course of general body growth was conducted by Count Philibert Gueneau de Montbeillard in 1759-1777 (50). He measured his son's height measurements systematically from birth to the age of 18. He found that postnatal growth rate was highest during the first year and then gradually diminished until the age of 14 when a marked acceleration of growth occurred. This acceleration would later be known as the adolescent or pubertal growth spurt. After this spurt the growth rate fell off gradually until adult stature was reached.

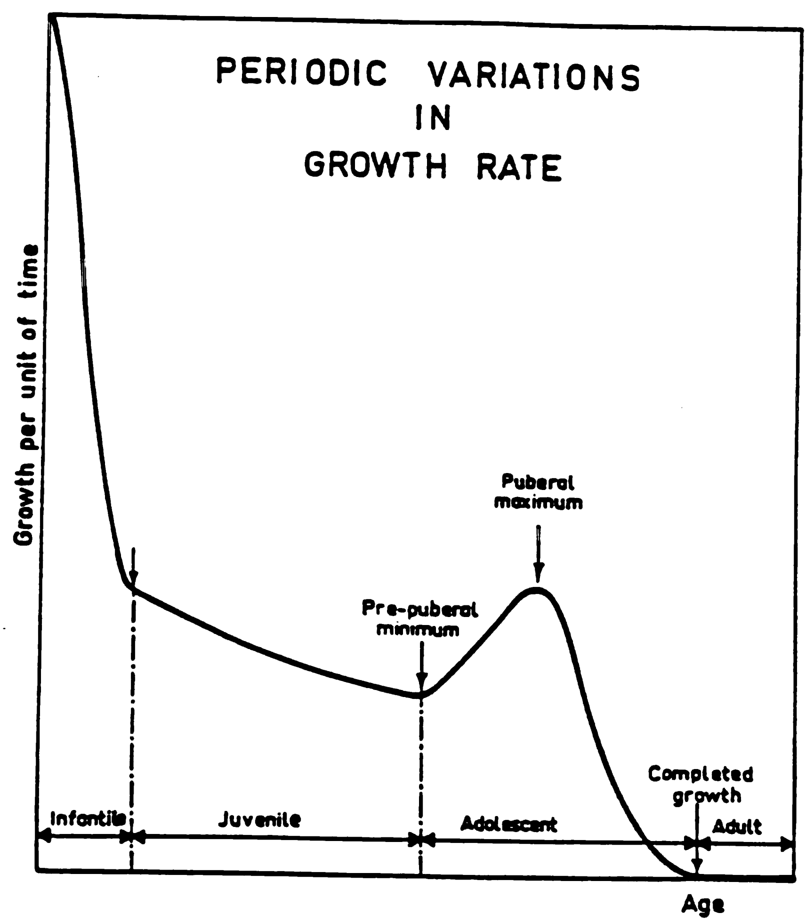
Since that time numerous studies have been conducted to determine the timing of the pubertal growth spurt as it has been considered an important time period for orthodontic treatment. Studies by Björk (15, 17, 51, 52) showed a peak in growth velocity in females at 12.5 years and 14.5 years in males. Examples of typical growth curves are shown in Figure 1 and a mean growth curve is shown in Figure 2. Björk's studies also demonstrated a pre pubertal growth minimum which in males occurs 2.5-3.0 years prior to the growth peak. Houston (53, 54) reported that peak growth velocity in stature on average was seen at 12 years in females and 14 years in males with a

Figure 1. Curves For Growth Rate in Body Height for 12 Boys*



*** After Björk (1972)**

Figure 2. Periodic Variations in Growth Rate**



**** After Björk (1966)**

standard deviation of 1 year in both populations. Tarranger (55) found that in both sexes the peak height velocity (12.0 years females, 14.1 years males) occurs on average two years after the onset of the spurt.

C. FACIAL GROWTH AND SOMATIC GROWTH

The timing of the peak growth period of the maxilla and the mandible as related to the timing of peak somatic growth has been studied by numerous investigators. It has been reported that the peak in growth of the facial structures directly coincides with that of body height. Hunter (56), Brown(57), Thompson (58), and Houston (53) have all reported that the timing of peak facial growth coincides with that of peak growth in body height. Hunter (56) reported that of all his measurements Ar-Po showed the most consistent relationship with growth in height. Thompson (58) reported that in females that took part in the Burlington Growth Center study, mandibular length reached its maximum velocity at the same time as body height.

Peak growth in the maxilla and mandible has also been reported to occur after peak somatic growth. Nanda (59) found that in subjects from the Child Research Council at the University of Colorado there was a tendency for circumpubertal maximums in facial dimensions to occur slightly later than that for body height. Bhamba (60, 61) reported that the time of maximum velocity in facial growth usually occurs a few months after the spurt in body height. He found that in 66% of the individuals had their maximum facial growth spurt after the spurt in body height and that in 67% of the individuals the maximum facial growth occurred within 6 months of that of body height. He also reported that individual cases may deviate considerably in almost every parameter from the average growth changes. The metallic implant studies of Björk (51, 52, 62, 63) showed that the cranial sutures (Figure 3) and the mandibular condyles (Figure 4) have the same characteristic growth velocity curve as that of height and are closely associated in time (Figure 5).

It seems well established based on previous studies that the timing of maximum peak growth rate in the craniofacial structures occurs at, or slightly after, the time of maximum peak growth in stature.

Figure 3. Sagittal Sutural Growth Boys (After Björk1966)

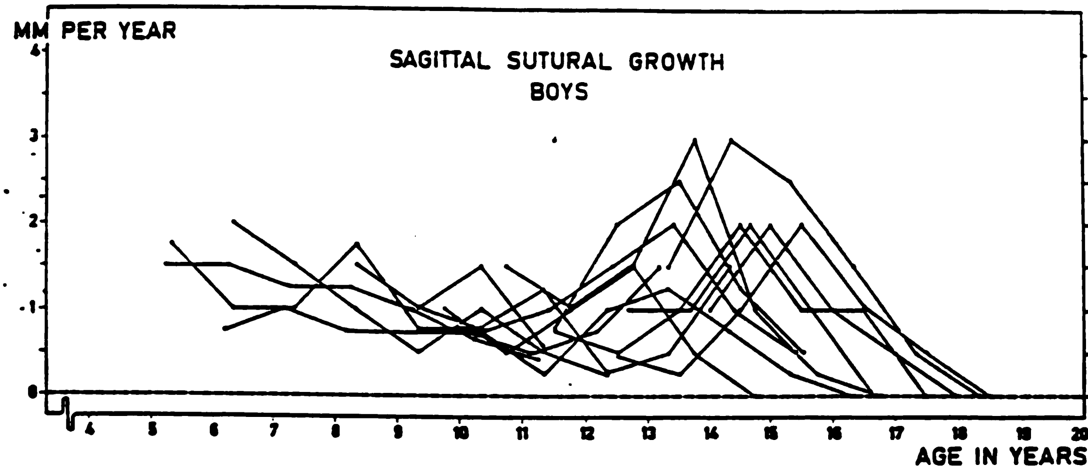


Figure 4. Curves for Growth Rate of the Mandibular Condyles (After Björk 1966)

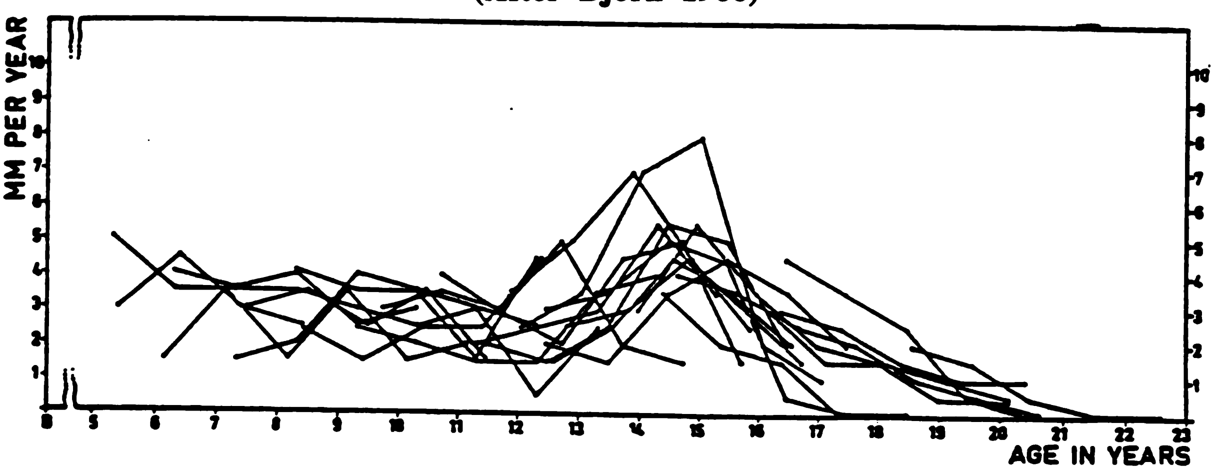
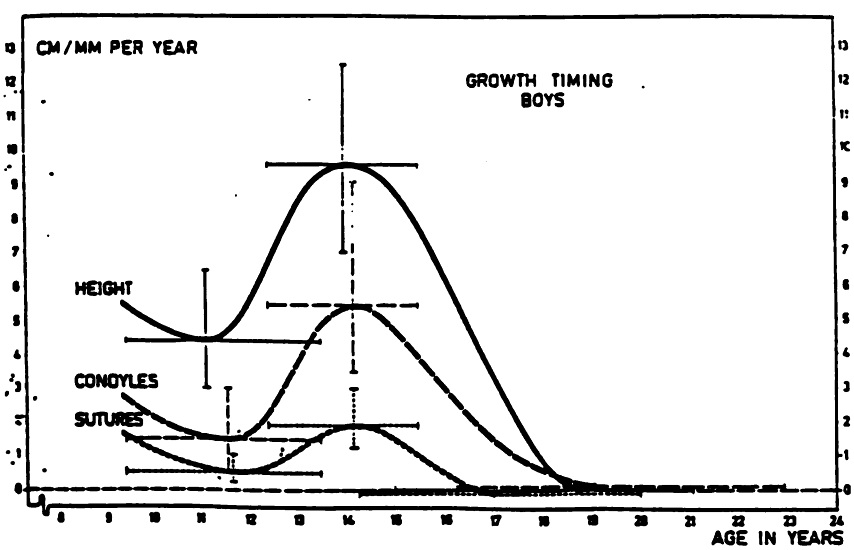


Figure 5. Growth Timing for Boys (After Björk 1966)



III. MATERIALS AND METHODS

A. SUBJECTS

The materials used for this study included a subset of cases from a previous prospective clinical study of functional appliance treatment conducted by Harvold and Vargervik (11, 14). The aim of their investigation was to study the skeletal and dental effects of an activator appliance designed to recruit masticatory and facial musculature and to control eruption of teeth. The number of subjects included in the original study by Harvold and Vargervik was 120 (64 males and 56 females). Their selection criteria included a class II malocclusion in the mixed dentition stage. The subjects were recruited into the study by answering an add placed in a local San Francisco newspaper. To further qualify they needed to use the appliance at least 8 out of every 24 hours, primarily at night.

For inclusion in this present retrospective study the subjects must have complied with the protocol of the original study and had cephalometric headfilms taken at the time of treatment start, end of treatment, and one year post treatment. Fifty nine patients fulfilled this criteria (31 females and 28 males). The headfilms and height measurements were taken on the same day at six month intervals (+/- 7 days).

B. APPLIANCE DESIGN

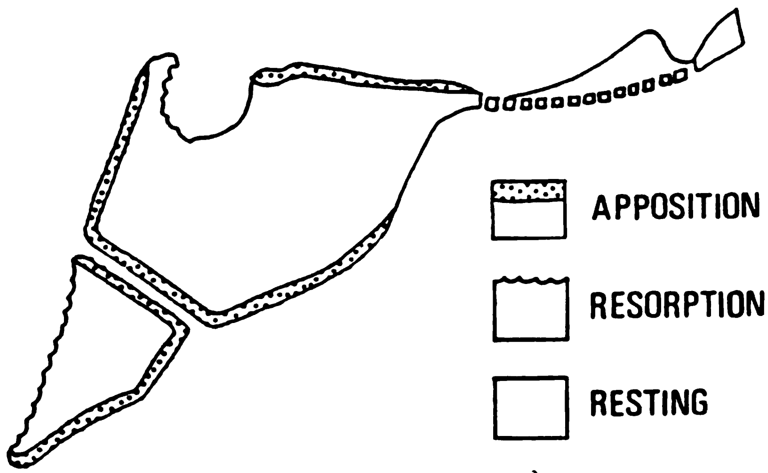
The appliance was designed with a wax bite taken in an edge to edge incisor relationship with a minimum opening of 5-6 mm beyond the freeway space. The activator was trimmed so that occlusal contact was maintained on the maxillary molars and the mandibular molars and bicuspids were free to erupt. No guide planes to promote mesial migration of the lower buccal segments were used in the appliance. Acrylic was removed from the lingual surfaces of the maxillary and mandibular incisors. Coverage of the incisal edges was maintained.

C. CEPHALOMETRIC ANALYSIS

The headfilms were all taken on the same cephalostat by the same 2 technicians. The serial headfilms for each subject were traced in succession at one sitting by one investigator on standard acetate paper using a fine lead pencil (0.5 mm HB). All double contours were bisected to minimize landmark location error (64).

The technique for limiting the tracing and superimpositional errors was twofold. The first step in this process involved critically appraising the acetate tracings to ensure all structures were correctly located by matching them to the headfilms. The tracings were then superimposed on stable structures of the anterior and median cranial base (anterior contour of sella turcica, the cribiform plate, median border of the orbital roof, and the ethmoid bones) as shown by Melsen (65) (Figure 6). The nasion sella line (NSL) and the nasion sella perpendicular (NSP) were then carried forward to the subsequent films in a series. When an aberrant landmark location or a suspected rotational error in a given tracing was noted, that acetate tracing was placed back on the headfilm to check for errors in landmark identification. In the case of an error in landmark identification the corrected position was marked.

Figure 6. Anterior Cranial Base



*After Melsen (1974)

The second step was to critically appraise the computerized TIOPS™ superimpositions. The software overlays the headfilms on the digitized sella-nasion line registered at sella. The nasion point located on the first film was carried forward to the subsequent films after superimposition on the stable structures of the cranial base. The serial headfilms were then superimposed simultaneously to see if a logical sequence of growth changes was achieved (66). The problems associated with the conventional technique of superimposing headfilms is that any vertical displacement in the identification of nasion will result in significant errors in the antero-posterior positioning of landmarks in the midface and the mandible. Baumrind (67), Moore (68), Nelson (69), and Knott (70) have all shown that nasion has a high degree of variability in the vertical dimension with growth. Baumrind (67) reported the standard deviation in the location of nasion in the vertical plane is 1.33 mm. Baumrind (71) has also shown that the farther a given landmark is from the center of rotational error, the greater the potential displacement of that landmark. This accounts for the significant amount of antero-posterior error in the location of landmarks in the midface and mandible when vertical errors in the location of nasion are present. Much of this problem was eliminated by using the above mentioned method of superimposition.

To reduce these possible sources of error, all the tracings for a given patient were digitized and the superimposition evaluated on the computer screen. Once again, the superimposition was evaluated for aberrant landmark location or a suspected rotational error in a given tracing. In the case of an error in the digitization of a landmark, that landmark was redigitized from the tracing. In the case of nasion showing a superior or inferior growth vector relative to the anterior cranial base, the tracings for that patient were superimposed on the stable structures of the anterior cranial base and nasion became a constructed point for digitizing purposes.

The TIOPS™ software digitizes the landmarks on the tracings relative to two fiducial points placed on the tracing paper. The magnification of the headfilms was 9.8%. No correction of the magnification was done due to the fact that the information sought was incremental changes of linear measurements and angular measurements. Thirty three hard and soft tissue reference points were digitized using the TIOPS™ software (Figures 7,8 and Table 1). Reference lines were located relative to these points (Figures 9,10 and Table 2) and were then used to calculated the angular measurements use in this study (Table 3).

The technique of mandibular superimposition (Figure 11) is based on the Björk method of landmark identification for mandibular superimposition (66). This technique, developed by Björk from metallic implant studies, recommends superimposing on 1) the anterior contour of the chin, 2) the inner cortical structures of the inferior border of the symphysis, 3) any distinct trabecular pattern in the symphysis, 4) the contour of the mandibular canal, 5) the lower contour of the molar germ from the time of initiation of mineralization to just before root formation.

Table 1. Reference Points on the Lateral Cephalometric Headfilm

Cranial Base Landmarks

ar	*Articulare.* The intersection between the contour of the external cranial base and the dorsal contour of the condylar head or neck.
ba	*Basion.* The most postero-inferior point on the clivus.
n	*Nasion.* The most anterior point of the frontonasal suture.
s	*Sella.* The center of sella turcica.
sa	*Sella Anterior.* The intersection between the anterior contours of sella turcica and the anterior clinoid process
ts	Tuberculum sellae

Maxillary Landmarks

ans	*Anterior Nasal Spine.* The apex of the anterior nasal spine.
pm	*Pterygomaxillare.* The intersection between the nasal floor and the posterior contour of the maxilla.
pr	*Prosthion.* The most antero-inferior point on the upper alveolus margin
ss	*Subspinale.* The most posterior point on the anterior contour of the upper alveolar arch.

Table 1 (cont.) Reference Points on the Lateral Cephalometric Headfilm

Mandibular Landmarks

gn	*Gnathion*. The most inferior point on the mandibular symphysis.
id	*Infradentale*. The most antero-superior point on the lower alveolar margin.
ma1	*Mandibular Reference 1.*
ma2	*Mandibular Reference 2.*
pg	*Pogonion*. The most anterior point on the mandibular symphysis.
pgn	*Prognathion*. The point on the mandibular symphysis farthest from cd.
sm	*Supramentale*. The most posterior point on the anterior contour of the lower alveolar arch.

Dental Landmarks

ai	*Apex of lower central incisor.*
as	*Apex of upper central incisor.*
clm	*Mesial cusp of lower first molar.*
cum	*Upper molar mesial cusp.*
ii	*Incisal edge of lower central incisor.*
is	*Incisal edge of upper central incisor.*
mlm	*Mesial of lower first molar crown.*
mop	*Molar occlusal point.*
mum	*Mesial of upper first molar crown.*
pop	*Premolar occlusal point.*
rlm	*Lower molar root point.*
rum	*Upper molar root point.*

Table 2. Reference Lines on the Lateral Headfilm

CL	*Chin line*. The line joining *id* and *gn* .
ML	*Mandibular line*. The tangent to the lower border of the mandible through *gn* and *mlp* .
MRL	*Mandibular reference line*. The line joining *ma1* and *ma 2*.
NL	*Nasal line*. The line through *ans* and *pm*.
NSL	*Nasion sella line*. The line through *n* and the center of *s* on the first film.
NSP	*Nasion sella perpendicular*. The perpendicular line to *NSL* through *s* .
OL_f	*Functional occlusal plane*. The line joining *pop* and *mop*.
OL_i	*Lower occlusal plane*. The line joining *ii* and *clm*.
OL_s	*Upper occlusal plane*. The line joining *is* and *cum*.

Table 3. Angular Measurements on the Lateral Headfilm

CL/ML	*Mandibualr alveolar prognathism*
ML-OL_i	*Mandibular incisor inclination*
NL-OL_s	*Maxillary incisor inclination*
NL/ML	*Vertical jaw relationships*
NSL/ML	*Mandibular inclination*
NSL/NL	*Maxillary inclination*
OL_f/NSL	*Occlusal plane inclination*
OL_i/ML	*Mandibular zone*
OLs/NL	*Maxillary zone*
pr-n-ss	*Maxillary alveolar prognathism*
s-n-pg	*Mandibular prognathism*
s-n-sm	*Mandibular prognathism*
s-n-ss	*Maxillary prognathism*
ss-n-pg	*Sagittal jaw relationship*
ss-n-sm	*Sagittal jaw relationship*

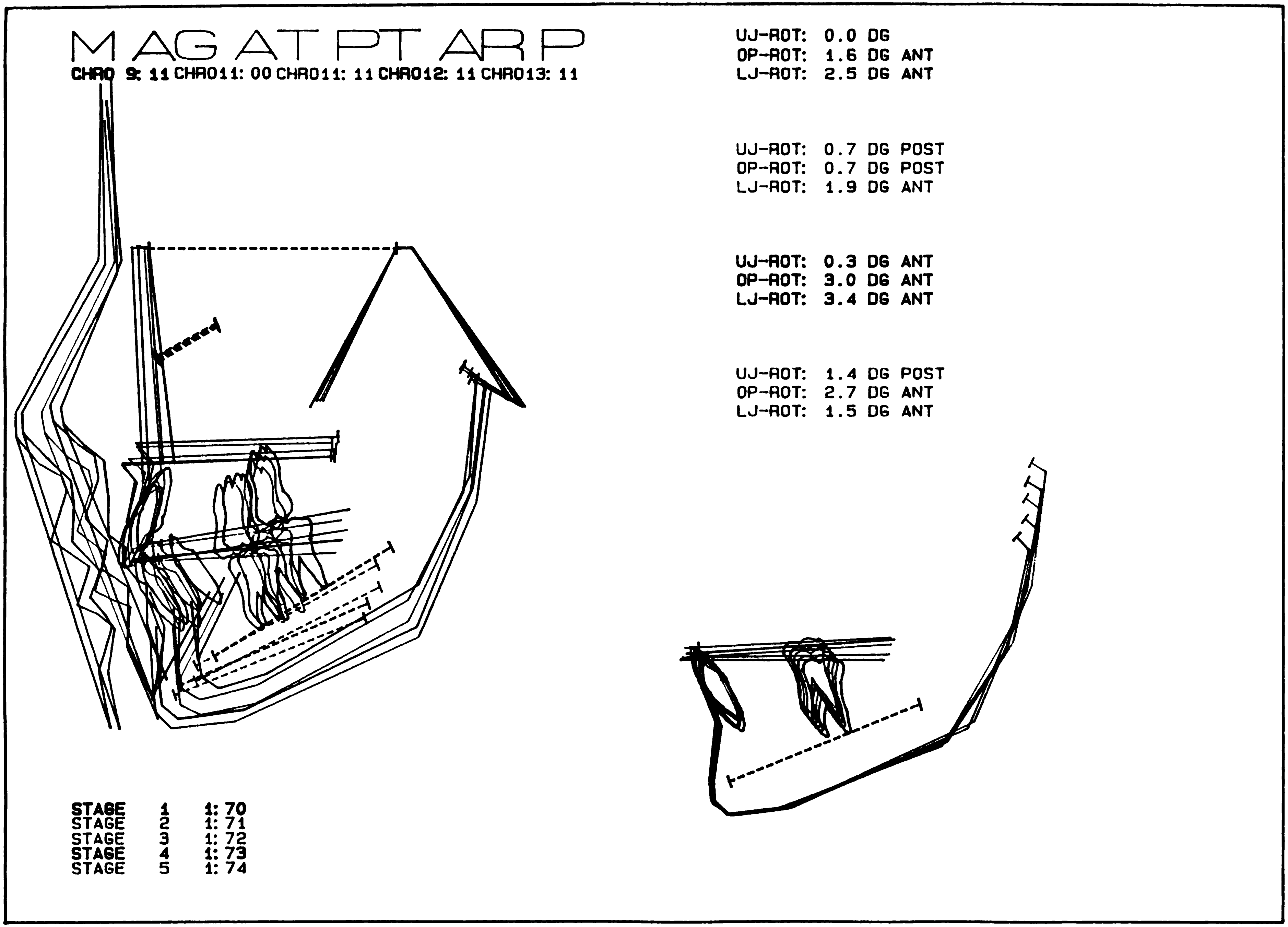

MAGATPTARP
CHRO 9: 11 CHRO11: 00 CHRO11: 11 CHRO12: 11 CHRO13: 11
UJ-ROT: 0.0 DG
OP-ROT: 1.6 DG ANT
LJ-ROT: 2.5 DG ANT
UJ-ROT: 0.7 DG POST
OP-ROT: 0.7 DG POST
LJ-ROT: 1.9 DG ANT
UJ-ROT: 0.3 DG ANT
OP-ROT: 3.0 DG ANT
LJ-ROT: 3.4 DG ANT
UJ-ROT: 1.4 DG POST
OP-ROT: 2.7 DG ANT
LJ-ROT: 1.5 DG ANT
STAGE 1 1: 70
STAGE 2 1: 71
STAGE 3 1: 72
STAGE 4 1: 73
STAGE 5 1: 74

Figure 8. Cephalometric Landmarks*

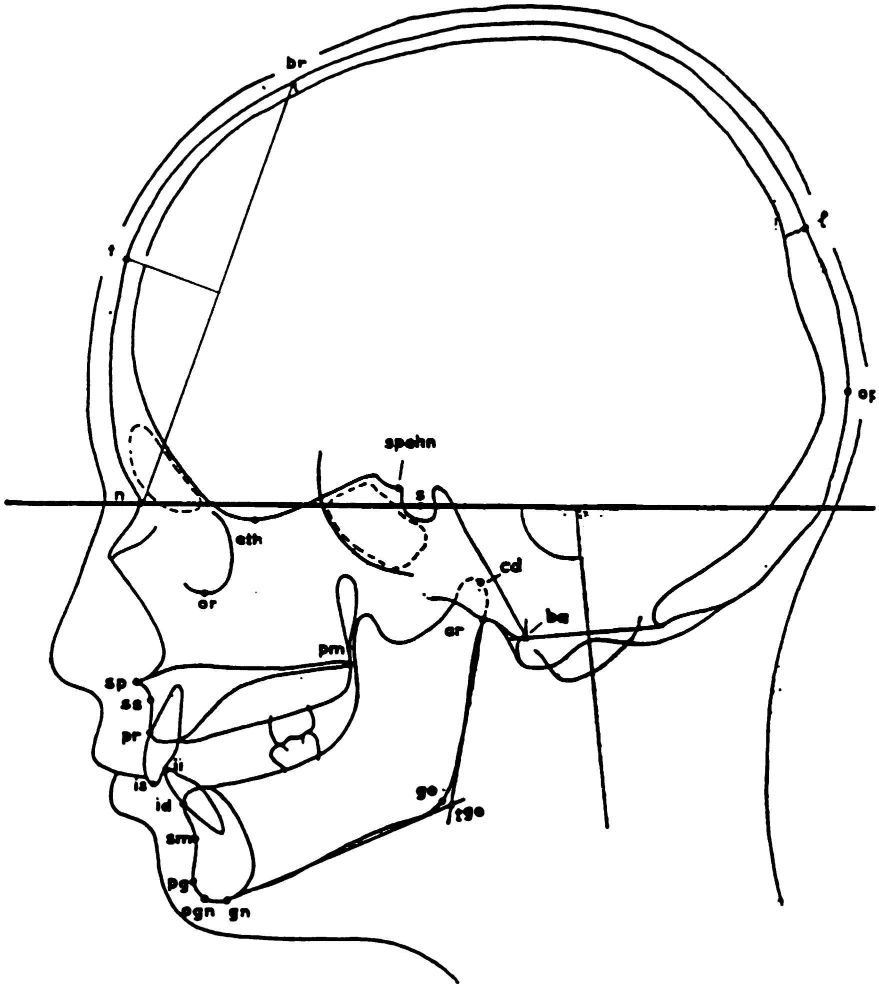
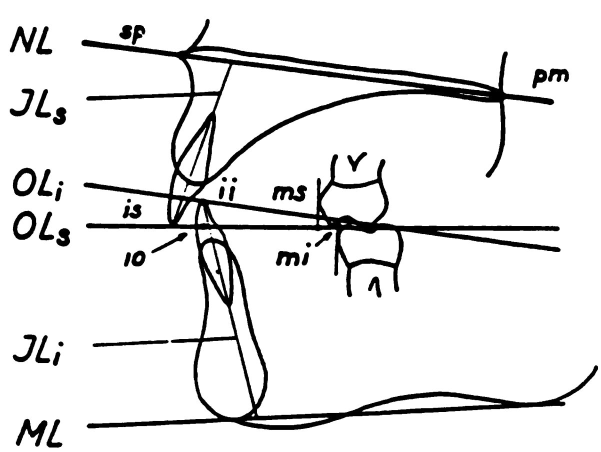


Figure 9. Cephalometric Reference Lines I*



*After Björk (1960)

Figure 10. Cephalometric Reference Lines II (After Björk 1960)

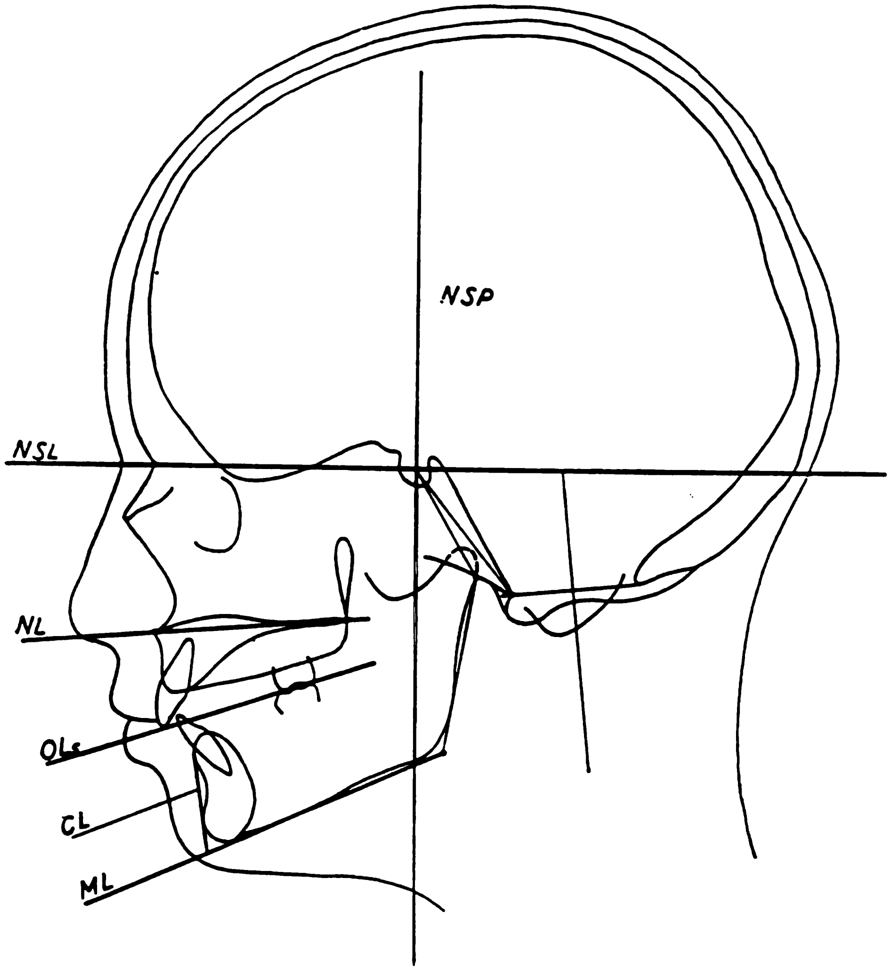
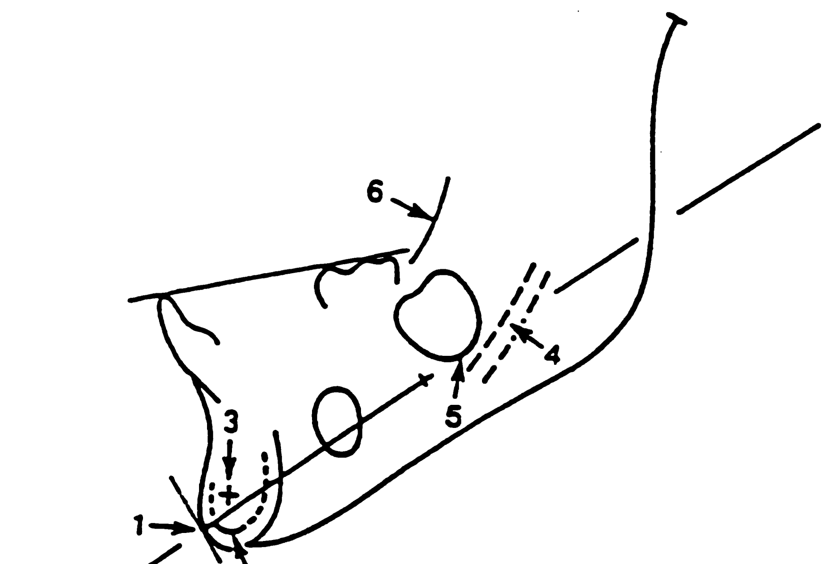


Figure 11. Landmarks for Mandibular Superimposition (After Björk 1983)



Several measurements were made directly from the acetate tracings themselves. The Nasion-Sella line and Nasion-Sella perpendicular registered at Sella were traced on the first headfilm. Subsequent headfilms were superimposed on the stable structures of the cranial base and these reference lines were transferred. The measurements were made to the nearest 0.5 mm. Reference points for horizontal measurements were measured relative to NSP (Figure 12, Table 4), while the reference points for vertical measurements were made relative to NSL (Figure 13, Table 5). Reference points used to determine mandibular tooth eruption (Table 6) were made relative to the mandibular reference line. Mandibular length was measured from Articulare to Pogonion.

Table 4. Points Used for Linear Measurements on the Headfilm
(Measurements Made Relative to NSPerp)

ii	*Incisal edge of mandibular central incisors.*
is	*Incisal edge of maxillary central incisors.*
L6	*Mesial of mandibular first molars.*
pg	*Pogonion.*
ss	*Subspinale.*
U6	*Mesial of maxillary first molars.*

Table 5. Reference Points Used for Linear Growth Measurements and Anterior Face Height on the Tracings
(Measurements Made Relative to SN)

gn	*Gnathion.*
is	*Incisal edge of maxillary first incisors.*
ss	*Subspinale.*
U6	*Mesial cusp tips of maxillary first molars.*

Table 6. Reference Points Used for Mandibular Tooth Eruption on the Tracing
(Measurements Made Relative to Mandibular Reference Line)

L6	*Lower molar mesial cusp tip.*
ii	*Incisal edge of lower central incisor.*

Figure 12. Reference Points for Horizontal Measurements (After Lagerström and Nielsen et al 1990)

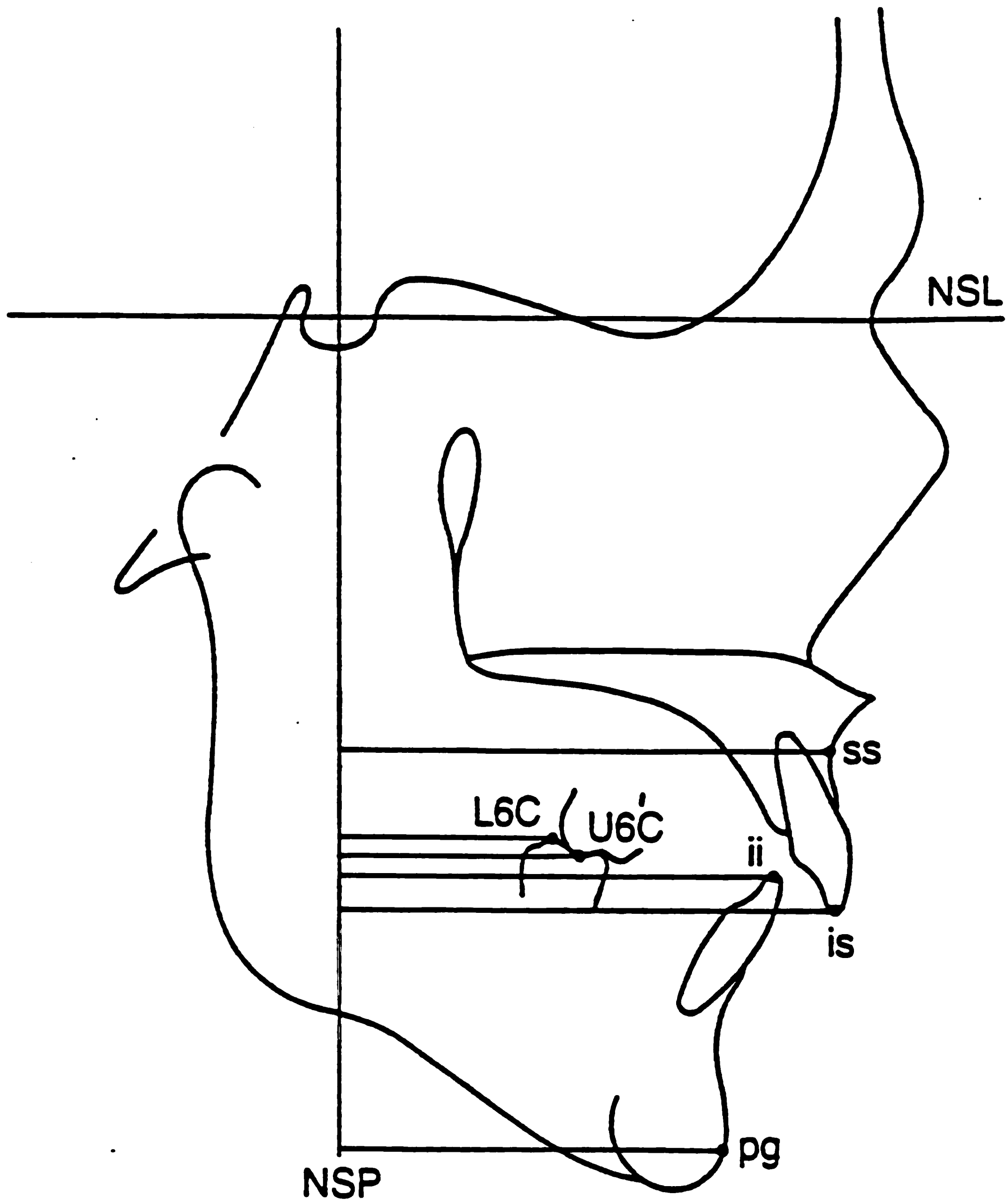
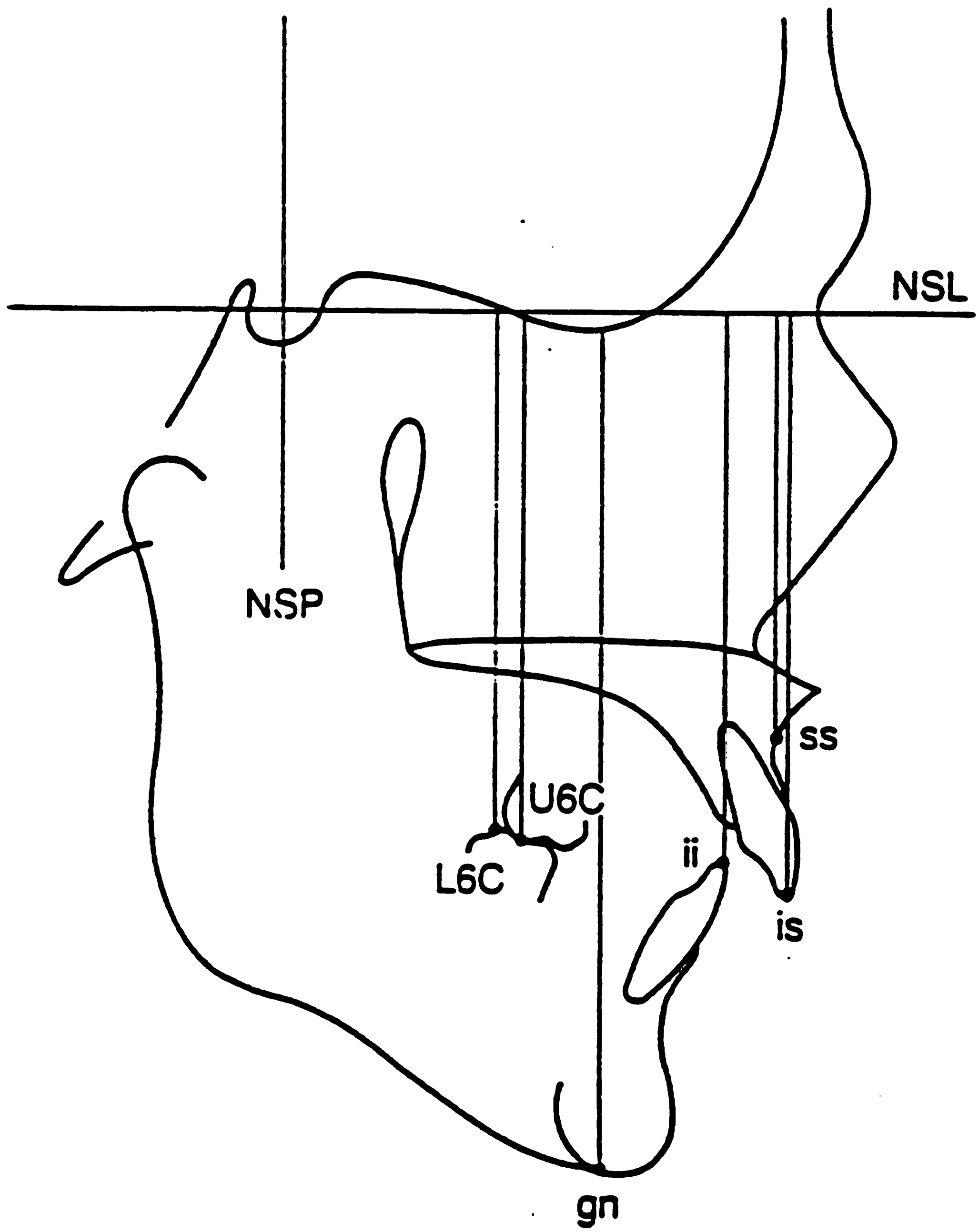


Figure 13. Reference Points for Vertical Measurements (After Lagerström and Nielsen et al 1990)



D. ERROR OF THE METHOD

The method error represents the uncertainty and error associated with the individual observations of a variable. These errors have several possible sources. There is the systematic error in all headfilms which is due to the magnification effect of the x-ray beam itself. There are also human errors involved which include: tracing the headfilm, identifying the landmark, digitizing the landmark correctly, and accurately inputing the data into the computer. Superimposing the headfilms also has inherant error involved in the technique.

When analyzing the results of a study involving superimposition of cephalometric headfilms one must consider the inherent errors in the technique as pointed out by Baumrind (71) He showed that superimpositional errors have both a rotational component and a translational component and that the total displacement of a given landmark is the sum of it's rotational displacement plus the translational displacement. The translational source of error is uniform for all landmarks, whereas the size of the rotational error sources will vary as a function of each given landmark's distance from the center of rotation.

The superimpositional error based on anterior cranial base or sella nasion registration, according to Baumrind (71) yields an average antero-posterior positioning error at pogonion of 1.5 mm. Baumrind therefore recommends making multiple tracings of each headfilm and multiple independent replications of each act of superimpositioning , as one way to reduce the error.

In this study, the superimpositions for each patient were checked twice, once at the level of the individual superimposed tracings and again at the level of the computerized superimpositions to reduce the error as much as possible. This served the dual purpose of getting the most accurate superimposition possible as well as checking for accuracy in landmark identification.

The act of tracing and superimposing serial headfilms of the same subject (5 to 7 per patient) taken at one year intervals show a natural growth progression, which reduces the errors associated with the superimposition of only two headfilms, which has been the case in many published studies.

Several other factors also aid in the reduction of errors. All films were taken by the same two technicians under standardized conditions using the same cephalostat. The large number of headfilms analyzed (approx. 350) helps to randomize measurement errors as well.

The method errors s(i) for this study were determined by means of duplicate tracing and digitizing of ten randomly selected headfilms. The selected headfilms were traced and digitized on two separated occasions by the same investigator. The statistical analysis was performed using the StatView 4.51 program (Abacus Concepts, Inc. Berkeley, CA) on a Macintosh computer. The method error was calculated by the formula: $\sqrt{\Sigma (x_a - x_b)^2 / 2N}$, where x_a is the first measurement of a variable, x_b is the duplicate measurement of the same variable and N is the total number of duplicate measurements (in this case 10). The results of the method error s(i) for 25 angular and linear measurements and the corresponding data from other studies are shown in Tables 7 and 8.

Baumrind (67) reported on the causes of error in landmark identification. He stated that the precision of landmark identification is a function of how sharply the edge of the landmark folds in the region of the point being estimated. Therefore, when the edge is a gradual curve, for example ss and sm, the errors are larger. The errors found for ss and sm shown in Tables 7 and 8 are in agreement with the results reported by Baumrind (67), as well as those reported by Midtgard (72) and Richardson (73).

The method error for the maxillary and mandibular incisors is primarily due to the inherant inaccuracy of locating the apex of these teeth. The error found for the lower incisor inclination, which is primarily due to location of the apex of these teeth. coincides with results published by Strabrum (74)who reported the location of apex inferior was not located with confidence by observers in 75% of cases. Baumrind (67) also reported that location of the apex of the mandibular incisor was the least reliable landmark to identify.

The method error was also calculated for the skeletal age assessments determined from analyzing the handwrist films. Ten randomly selected handwrist films were reanalysed at a later date. The same formula was used to calculate the s(i) for the skeletal age of the patients and it was determined to be a mean of .36 years.

The findings of the reproducibility of identifying bone stages on the hand wrist film agree with those of Wenzel and Melsen (75). They found that the differences in agreement between the first and second readings never exceeded one stage and the second scores were distributed symmetrically above and below the first assessments. Their overall replicability between stages ranged from 82-100% and the average deviation in skeletal ages was 0.11 years.

TABLE 7. Method Error (Angular Measurements)

Variable	Current Study	Bjork* (1947)	Werner* (1955)	Lysell & Flipsson* (1958)	Brown* (1965)	Solow* (1966)	Jakobsson (1990)
NSL/NL	.18				1.36	1.00	.46
NSL/ML	.46		.39	.54	.53	.54	.69
NL/ML	.46	.99			1.13	.84	.46
s-n-ss	.29		.39	.58	1.17	.63	.54
s-n-pg	.24	.68	.37	.47	.80	.62	
s-n-sm	.25		.39	.50		.52	.44
ss-n-pg						.43	
ss-n-sm			.24	.51		.41	.57
pr-n-ss	.30						
IL_s/NL	.83					1.78	.47
IL_i/ML	1.18		.80			1.52	.41
CL/ML	1.01	.92		.80	.54	.79	
OLs/NL	.67	1.27			1.19	1.20	
OLi/ML	1.07					1.01	

* after Solow (1966)

TABLE 8. Method Error (Linear Measurements)

U6 I-NSP	.22
L6 I-NSP	.52
is I-NSP	.25
ii-NSP	.22
sm-NSP	.43
pg-NSP	.67
U6 II-NSL	.27
is II-NSL	.34
sm-NSL	1.36
gn-NSL	1.36
ii-MRL	.22
clm-MRL	.19
ar-pg	.30

E. STATISTICAL ANALYSIS

The statistical anlaysis of the data was performed using the StatView® 4.51 (Abacus Concepts, Berkeley, CA) program. A paired T test was performed on the pretreatment cephalometric values of girls and boys to determine possible differences between the two groups. A paired T test was also used on the posttreatment values to determine any significant differences between the groups. The skeletal and dental changes during treatment were analysed and regression analyses were performed to determine the association beteween specific pretreatment parameters and the changes during treatment. Analysis of variance (ANOVA) was used to determine possible associations beween the skeletal and dental changes during treatment and the individual subjects growth intensity.

IV. RESULTS

A. Timing of Treatment Relative to the Pubertal Growth Spurt

The records of treatment were evaluated to determine the age of the subject at the time treatment was started, how long the treatment lasted, and the timing of the subject's growth spurt based on the individual patient's growth velocity curve. The mean values as well as minimum and maximum values are seen in Table 9 and the individual subject's values are seen in Figures 14, 15.

Table 9. Mean Values for Timing of Treatment and Peak Growth

Boys (mean values)			
	Years	min	max
treatment start	10.5	7.5	12.9
treatment stop	13.6	11.0	15.5
treatment length	3.0	1.5	5.0
age at peak growth	13.5	12.0	16.7
Girls (mean values)			
treatment start	10.1	8.2	11.4
treatment stop	13.0	10.2	15.1
treatment length	2.9	1.8	5.0
age at peak growth	12.0	9.5	14.8

Figure 14. Timing of Treatment and Peak Growth of Boys (n=28)

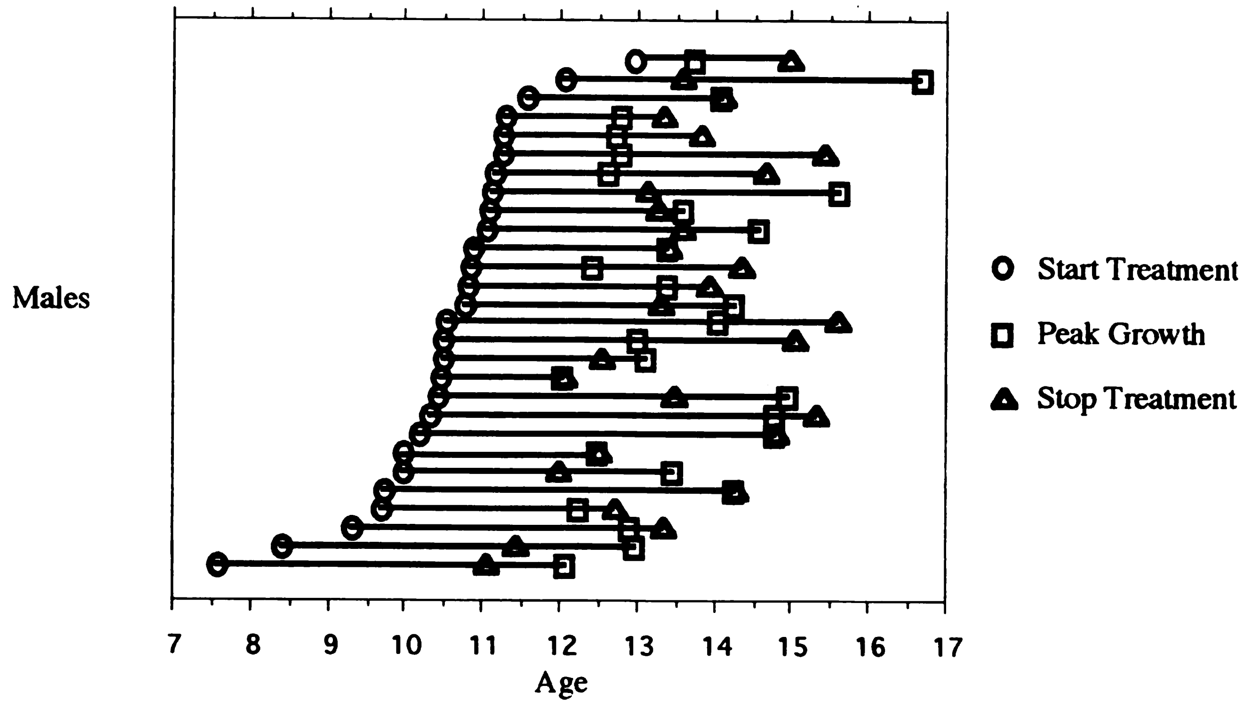
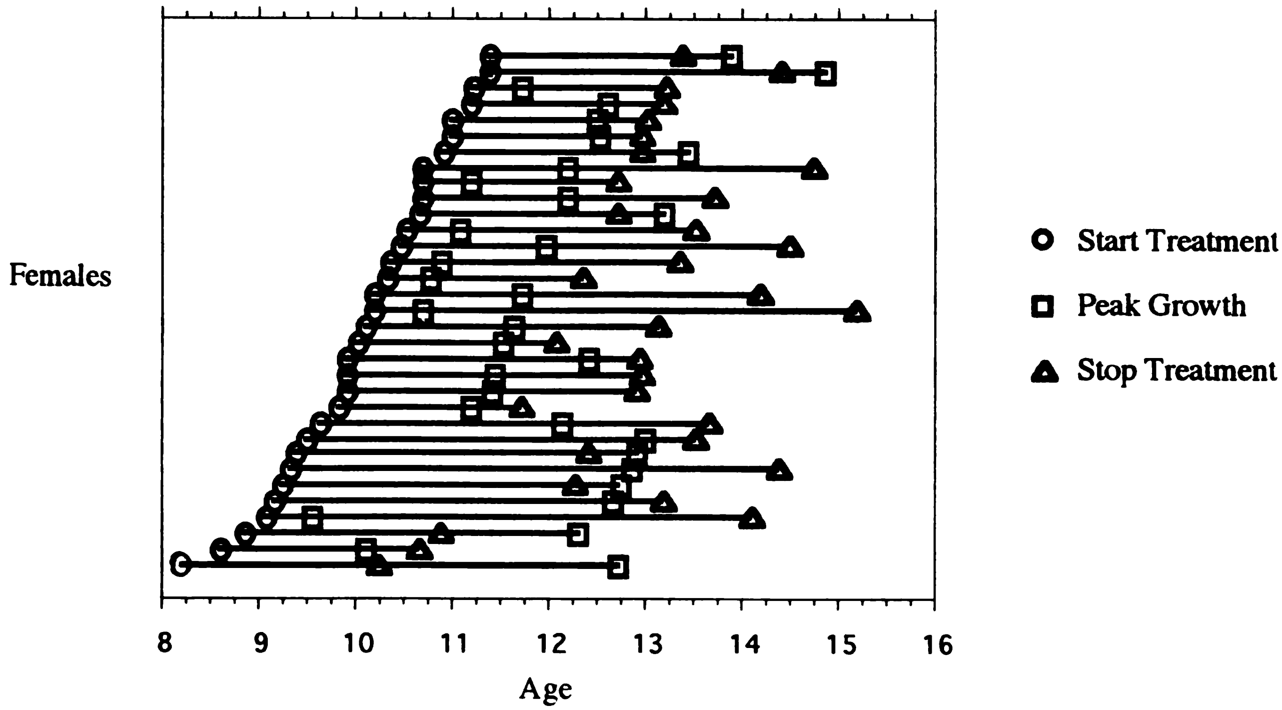


Figure 15. Timing of Treatment and Peak Growth of Girls (n=31)



The girls and boys started treatment nearly at the same chronologic age. In this sample, the average girls' peak growth spurt occurred about 2 years after the activator treatment was initiated while the average boys' peak growth occurred about 3 years after the beginning of treatment as determined by the height measurements and hand wrist films. The time of the girls' growth spurt coincides with values previously reported in the literature, however, the boys' growth spurt occurred earlier than reported in other studies. (15, 17, 57, 61, 76-80) The range of variation for the growth maximum shows the usual wide range. The average length of active treatment with the activator was almost identical for both groups, namely 3 years (range 1.5-5.0 yrs).

B. Pretreatment Facial Morphology

The pretreatment averaged tracings for girls and boys are seen in Figures 16 and 17 and the measured values are shown in Table 10. The skeletal measurements showed a sagittal jaw relationship discrepancy (ss-n-pg) of 5.5° for the girls and 4.4° for the boys. The discrepancy in both groups was due to mandibular retrognathism (s-n-pg) measuring 75.9° and 74.8° for the girls and boys, respectively. The boys also had a slightly decreased maxillary angulation (s-n-ss) of 79.3°.

The dentoalveolar measurements of both groups showed an increased overjet of over 8°. The maxillary incisors (NL-1/) and alveolus (pr-n-ss) were displastically proclined at 113° and 2.7°, whereas, the mandibular incisors (ML-/1) and alveolus (CL/ML) were compensatorily proclined at 95° and 73°, respectively. The vertical jaw relationship (NL/ML) was normal at 27° with a slightly decreased palatal plane angle

Figure 16. Mean Facial Morphology of Girls (n=31) Pretreatment

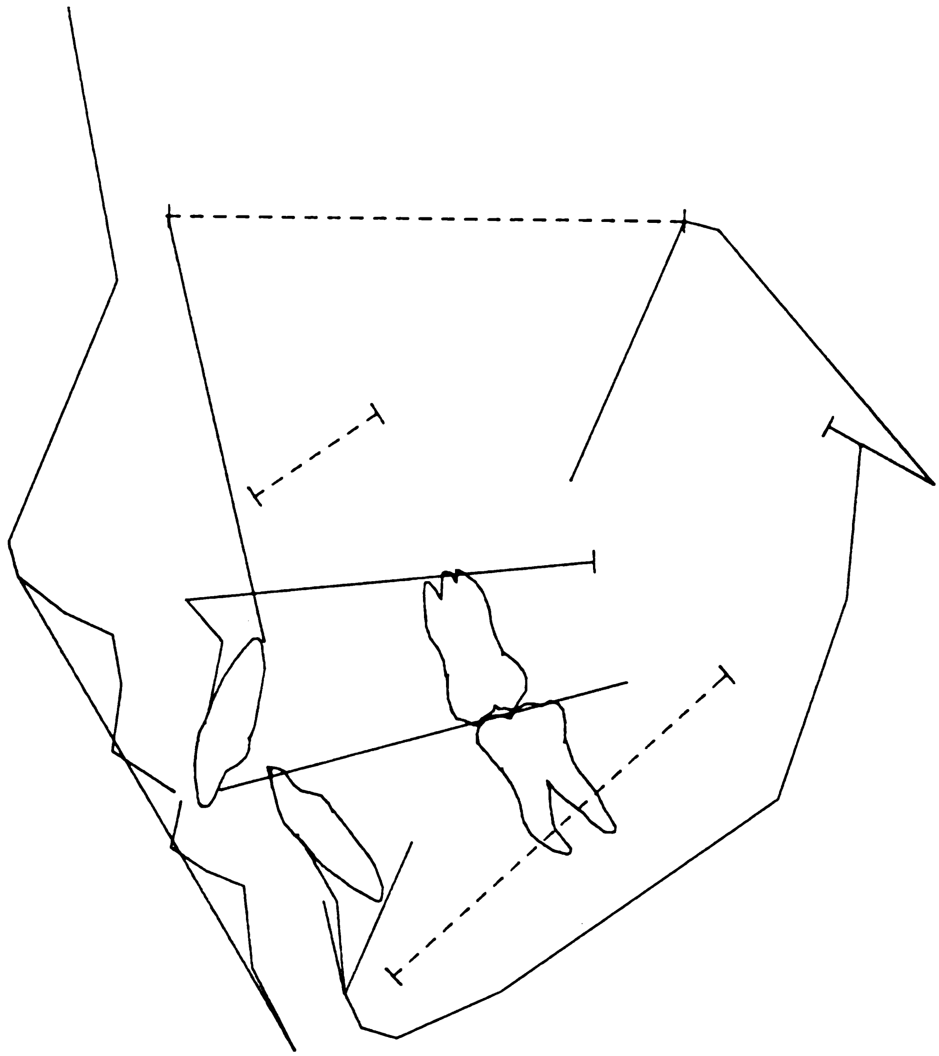


Figure 17. Mean Facial Morphology of Boys (n=28) Pretreatment

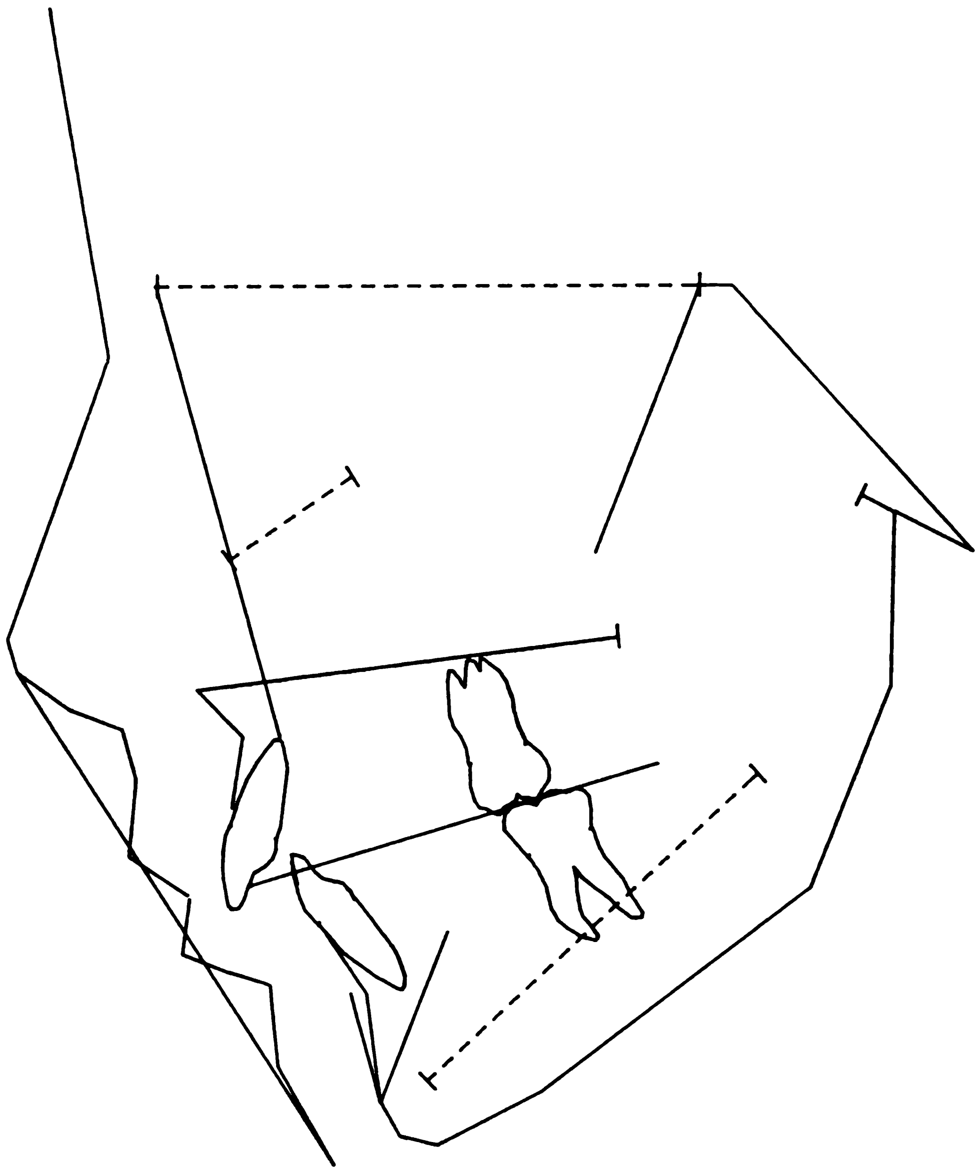


Table 10. Pretreatment Facial Morphology of Girls and Boys

Measurement	Girls (n=31)		Boys (n=28)		Mean Difference	Sign.
	Mean	S.D.	Mean	S.D.		
OB	2.22	1.88	3.81	1.80	1.59	*
OJ	8.70	2.55	7.99	1.51	.71	n.s.
pr-n-ss	2.71	1.16	2.70	.78	.01	n.s.
NL-1/	113.36	5.90	112.50	6.38	.86	n.s.
ML-/1	96.75	5.36	94.75	6.73	2.00	n.s.
CL/ML	73.67	4.86	73.23	4.96	.44	n.s.
SNA (s-n-ss)	81.36	3.96	79.26	3.32	2.10	n.s.
SNB (s-n-sm)	75.06	3.61	73.74	3.02	1.32	n.s.
SNPg (s-n-pg)	75.90	3.67	74.84	2.99	1.06	n.s.
ANB (ss-n-sm)	6.30	2.09	5.51	2.03	.79	n.s.
ANPg (ss-n-pg)	5.46	2.36	4.42	2.26	1.04	n.s.
ar-pg	100.09	4.23	103.41	4.38	3.32	**
NSL/NL	6.31	2.98	7.14	2.70	.83	n.s.
NSL/ML	33.93	5.18	34.77	4.96	.84	n.s.
NL/ML	27.62	5.22	27.63	4.05	.01	n.s.
$NL\text{-}OL_s$	11.35	3.80	12.46	3.49	1.11	n.s.
$ML\text{-}OL_i$	18.99	3.12	21.83	3.92	2.84	**

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

(NSL/NL) of 6.5° and a normal mandibular plane angle (NSL/ML) of 34°. The maxillary and mandibular zones (NL/OL_S, $ML\text{-}OL_i$) were both within normal limits in the girls, resulting in a normal overbite of 2°. However, these values were both increased in the boys which resulted in an increased overbite of 3.8°.

The pretreatment cephalometric measurements for the girls and boys (Table 10) were not significantly different. Only mandibular length (ar-pg), overbite, and mandibular zone ($ML\text{-}OL_i$) were significantly different. The girls had a smaller mandibular length than the boys and the boys had a deeper overbite a larger value for the mandibular zone than the girls.

The mean values for measurements of the pretreatment linear measurements are shown in Table 11. The groups did not have any significant pretreatment differences in the sagittal dimension. However, all the vertical parameters were significantly larger in the boys.

Increased lower facial height is usually associated with one of three morphologic types. One is characterized by increased mandibular and maxillary plane angles with an increased angulation to the occlusal plane. The second is characterized by an increased mandibular plane angle and a normal maxillary plane angle with marked dentoalveolar compensations. The third is also characterized by an increased mandibular plane angle but a normally inclined maxillary plane and lacking the dentoalveolar compensations in one or both arches which results in an anterior open bite. The mean morphology of the boys was not associated with an increased lower facial height, so the larger values for the boys in the vertical dimension were merely due to the fact that the boys were larger.

Table 11. Pretreatment Linear Measurements

Measurement	Girls (n=31)		Boys (n=28)		Mean Difference	Sign.
	Mean	S.D.	Mean	S.D.		
U6-NSP	34.11	4.58	34.59	4.16	.48	n.s.
L6-NSP	30.94	4.73	30.89	3.90	.05	n.s.
is-NSP	66.40	6.42	65.63	5.23	.77	n.s.
ii-NSP	58.15	5.29	58.98	5.55	.83	n.s.
sm-NSP	48.69	6.61	48.77	5.68	.08	n.s.
pg-NSP	47.24	7.42	47.05	6.68	.19	n.s.
ss-NSL	90.34	3.71	93.59	4.28	3.25	**
gn-NSL	108.34	5.06	113.61	5.07	5.27	***
U6-NSL	66.17	3.62	69.50	3.33	3.33	***
is-NSL	78.05	4.44	82.45	3.91	4.40	***
L6-mand ref	17.44	1.91	19.02	1.95	1.58	**
ii-mand ref	31.77	2.67	34.18	2.25	2.41	***

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

C. Posttreatment Facial Morphology

The post treatment averaged tracings and measured values are seen in Figures 18, 19 and Table 12. The skeletal measurements showed an average sagittal jaw relationship (ss-n-pg) of 3.3° for the girls and 2.4° for the boys. The mandibular retrognathism measured 77.3° and 76.3° in the girls and boys, respectively. Both groups also had decreased maxillary angulation (s-n-ss) with the girls at 80.6° and the boys 78.8°. The sagittal dentoalveolar measurements showed a decrease in the overjet to 4.7 mm in the girls and 4.1 mm in the boys. The maxillary incisors (NL-1/) in both groups were inclined slightly to the lingual at 108° and the maxillary alveolus (pr-n-ss) had a normal angulation. The mandibular anterior alveolus (CL/ML) was compensatorily proclined at 74° in both groups, however, only the females had proclined mandibular incisors (ML-/1) at 96.3°.

The vertical skeletal and dentoalveolar measurements (vertical jaw relationship, palatal plane angle, mandibular plane angle, maxillary zone, mandibular zone, and overbite) were normal for both the males and females. The pretreatment values for maxillary zone, mandibular zone, and overbite for the girls remained within normal limits while these pretreatment values in the boys all decreased to become within normal limits posttreatment.

The posttreatment comparison of girls and boys in Table 12 shows the differences were similar to those seen pretreatment. The mean value for overbite in boys decreased to 2.2 mm which is not a value that is significantly different than the females. The mandibular length (ar-pg) was still significantly larger for the males (113.3 mm) than the females (107.7 mm) and the mandibular zone (ML-OL_i) for males (19.8°) was also significantly larger than the females (18.4°).

The values of linear measurements are shown in Table 13. Once again, there were no significant differences in the sagittal dimension between the girls and boys while all of the parameters measured in the vertical dimension were significantly larger in the male sample. It should be noted, however, that even though the differences in the sagittal dimension did not change significantly with treatment, everyone of them increased. This indicates that the male patients had larger increments of growth in the sagittal direction, but not enough to be statistically significant.

A comparison of the mean differences between males and females (Table 12) demonstrates a general trend towards normalization of the values after treatment. The only parameters which showed an increase in the mean difference between males and females were the vertical jaw relationship (NL/ML), mandibular plane angle (NSL/ML), and mandibular length (ar-pg).

Figure 18. Mean Facial Morphology of Girls (n=31) Posttreatment

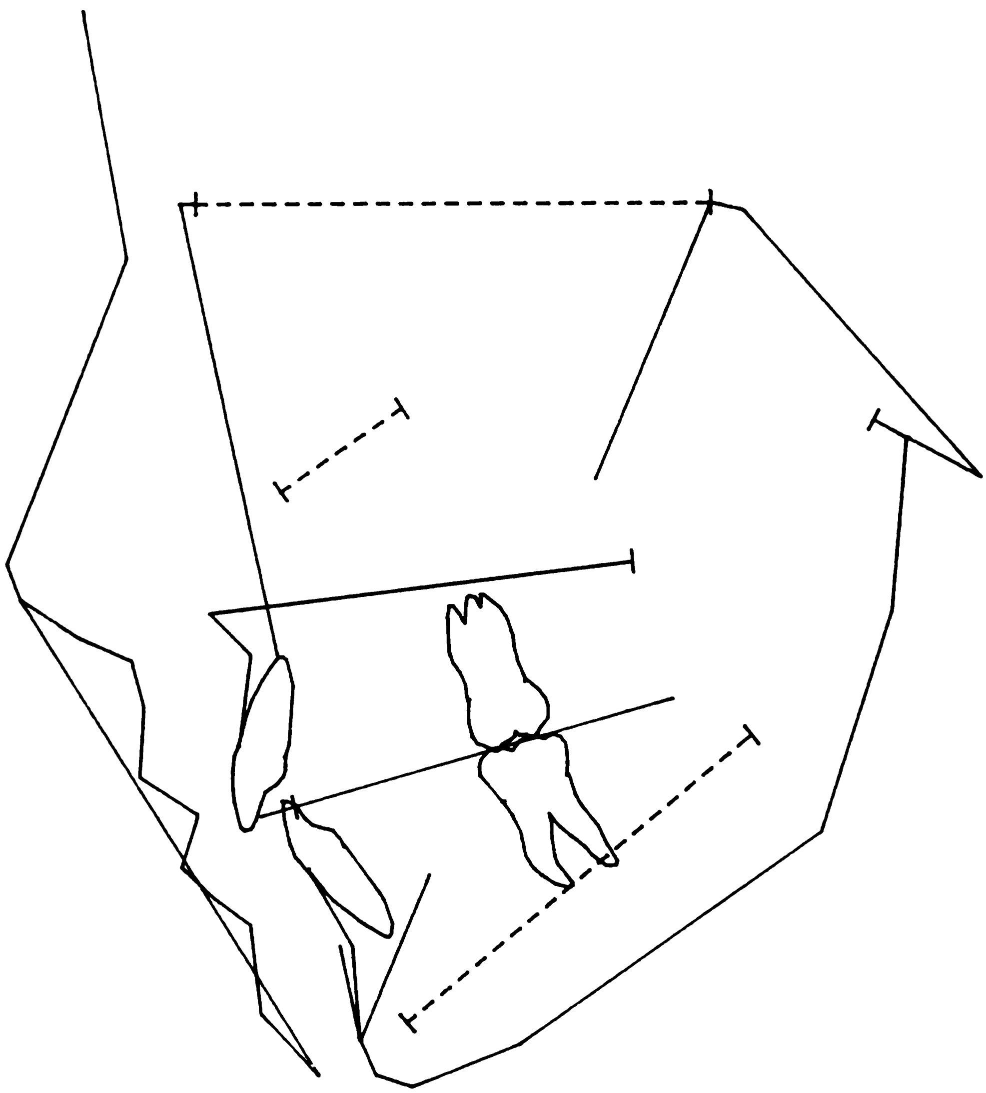


Figure 19. Mean Facial Morphology of Boys (n=28) Posttreatment

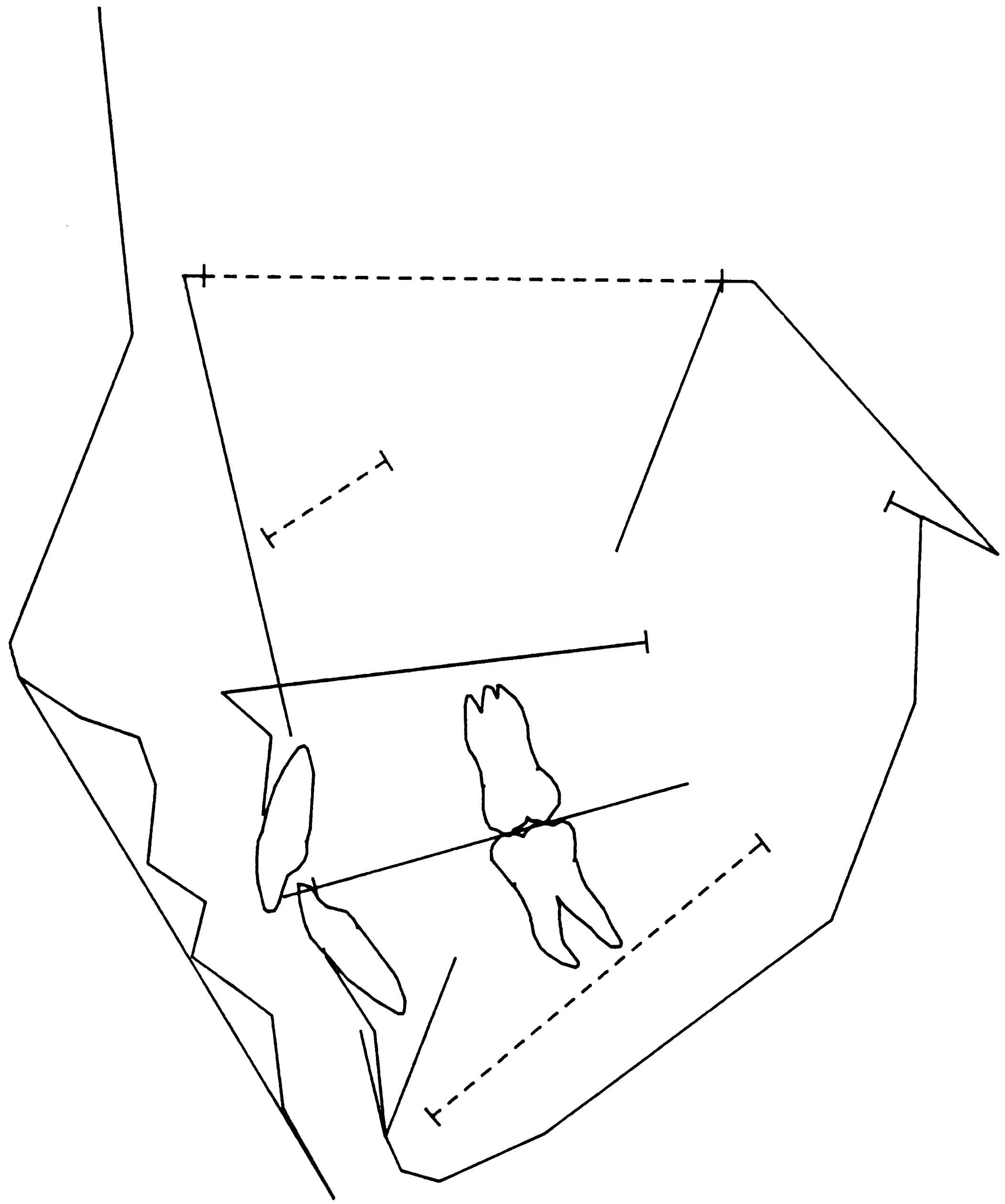


Table 12. Posttreatment Facial Morphology of Girls and Boys

Measurement	Girls (n=31)		Boys (n=28)		Mean Difference	Sign.
	Mean	S.D.	Mean	S.D.		
OB	1.87	1.30	2.15	1.27	.28	n.s.
OJ	4.69	1.77	4.09	1.70	.60	n.s.
pr-n-ss	2.57	1.16	2.54	.77	.03	n.s.
NL-1/	108.96	5.17	108.67	6.28	.29	n.s.
ML-/1	96.27	5.75	95.52	6.89	.75	n.s.
CL/ML	74.43	5.01	74.62	4.87	.19	n.s.
SNA (s-n-ss)	80.55	4.30	78.76	3.32	1.79	n.s.
SNB (s-n-sm)	76.44	3.91	75.38	3.61	1.06	n.s.
SNPg (s-n-pg)	77.26	4.03	76.34	3.63	.92	n.s.
ANB (ss-n-sm)	4.11	1.88	3.39	2.27	.72	n.s.
ANPg (ss-n-pg)	3.29	2.31	2.44	2.61	.85	n.s.
ar-pg	107.69	4.51	113.30	6.30	5.61	***
NSL/NL	7.16	3.23	7.34	2.98	.18	n.s.
NSL/ML	33.26	5.49	34.50	5.89	1.24	n.s.
NL/ML	26.10	4.88	27.16	5.13	1.06	n.s.
$NL\text{-}OL_s$	10.84	3.22	10.98	3.27	.14	n.s.
$ML\text{-}OL_i$	18.39	3.78	19.76	3.92	1.37	*

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

Table 13. Posttreatment Linear Measurements

Measurement	Girls (n=31)		Boys (n=28)		Mean Difference	Sign.
	Mean	S.D.	Mean	S.D.		
U6-NSP	35.24	5.65	36.70	5.82	1.46	n.s.
L6-NSP	34.81	5.77	36.07	5.52	1.26	n.s.
is-NSP	64.92	6.80	65.86	6.38	.94	n.s.
ii-NSP	60.74	5.93	62.50	6.29	1.76	n.s.
sm-NSP	50.95	7.64	51.59	7.69	.64	n.s.
pg-NSP	49.65	8.60	50.16	8.60	.51	n.s.
ss-NSL	97.58	4.56	104.20	6.47	6.62	***
gn-NSL	116.50	5.61	124.98	7.71	8.48	***
U6-NSL	71.22	4.22	76.30	4.65	5.08	***
is-NSL	82.53	4.41	87.70	4.50	5.17	***
L6-mand ref	20.92	2.14	23.91	2.92	2.99	***
ii-mand ref	33.31	2.50	36.64	2.93	3.33	***

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

D. Treatment Changes in Subjects

The average general facial growth changes as well as the maxillary and mandibular treatment changes are seen in Figure 20 in girls and Figure 21 in boys, respectively. The values for the comparison of treatment effects between the girls and boys are seen in Table 14. The girls and boys, in general, showed similar changes during treatment with the activator.

However, maxillary prognathism showed a significantly greater reduction in the girls (0.8°) than in the boys (0.5°). Mandibular prognathism (s-n-pg) increased significantly in both the girls and the boys with an increase of 1.4° for the girls and 1.50° for the boys. These values account for the reduction in the sagittal jaw relationship seen in both groups. The sagittal jaw relationship (ss-n-pg) was decreased by 2.2° in the girls and 2.1° in the boys.

Overjet and the inclination of maxillary incisors (NL-1/) were also significantly reduced in both groups. The reduction in these values, along with the increase in mandibular prognathism the most striking results of treatment with the activator. The 4 mm decrease in overjet seen in both groups was due to a combination of the decreased sagittal jaw relationship mentioned above and to the decrease seen in the inclination of the maxillary incisors. The girls had a decrease of 4.4° in the inclination of the maxillary incisors while the boys had a decrease of 3.8°.

Neither the group showed significant changes in mandibular plane angle, mandibular incisor inclination, and maxillary alveolar prognathism.

The remainder of the cephalometric measurements showed significant differences between the growth of the girls and boys. Both groups showed an increase in the palatal plane (NSL/NL), but only the girls showed a significant increase of 0.9°. Both groups also showed a decrease in mandibular plane angle (NSL/ML), but only the girls showed

Figure 20. Mean Facial Morphology of Girls (n=31) Superimposition of Pretreatment (Green) and Posttreatment (Brown) Headfilms

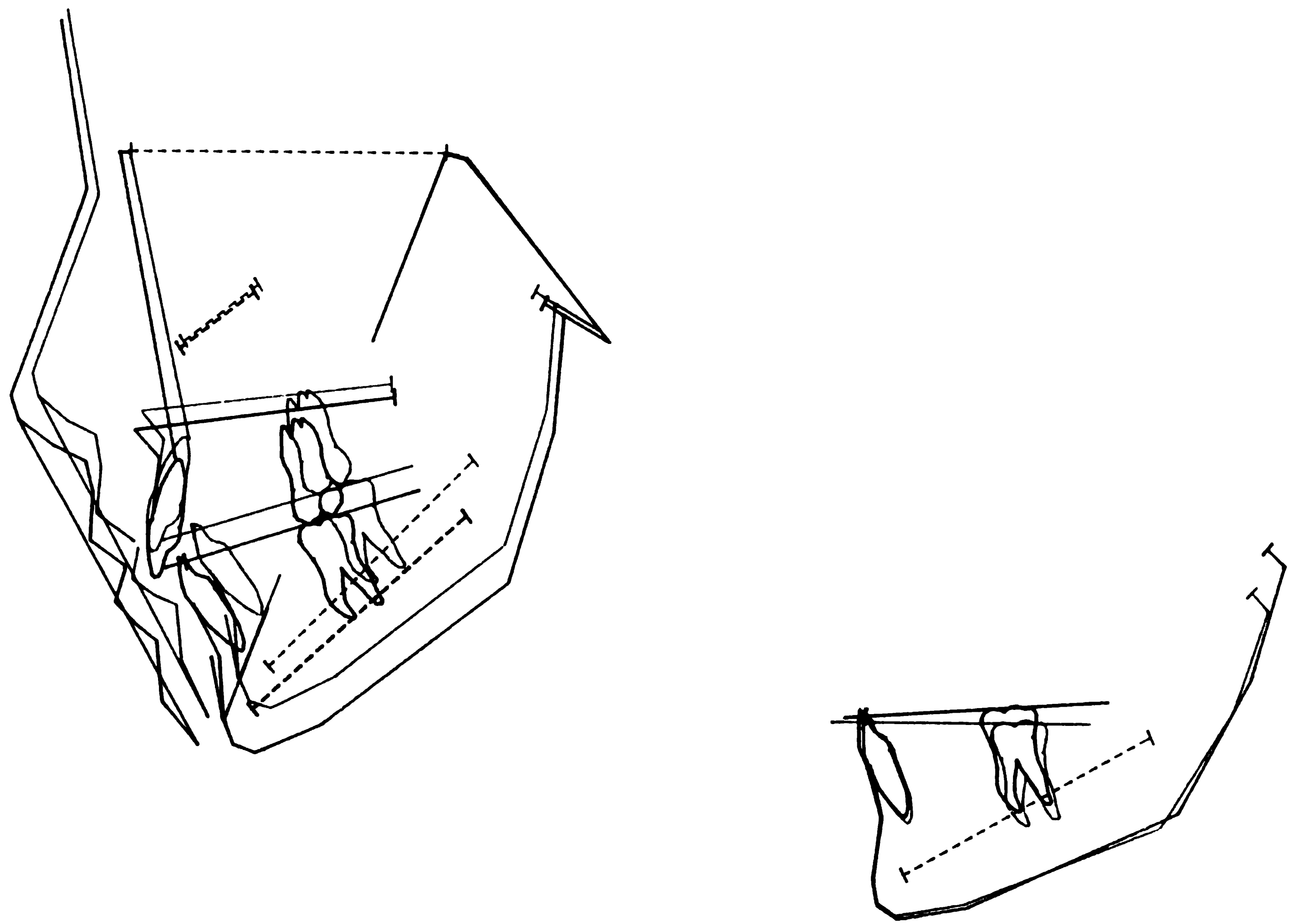


Figure 21. Mean Facial Morphology of Boys (n=28) Superimposition of Pretreatment (Blue) and Posttreatment (Red) Headfilms

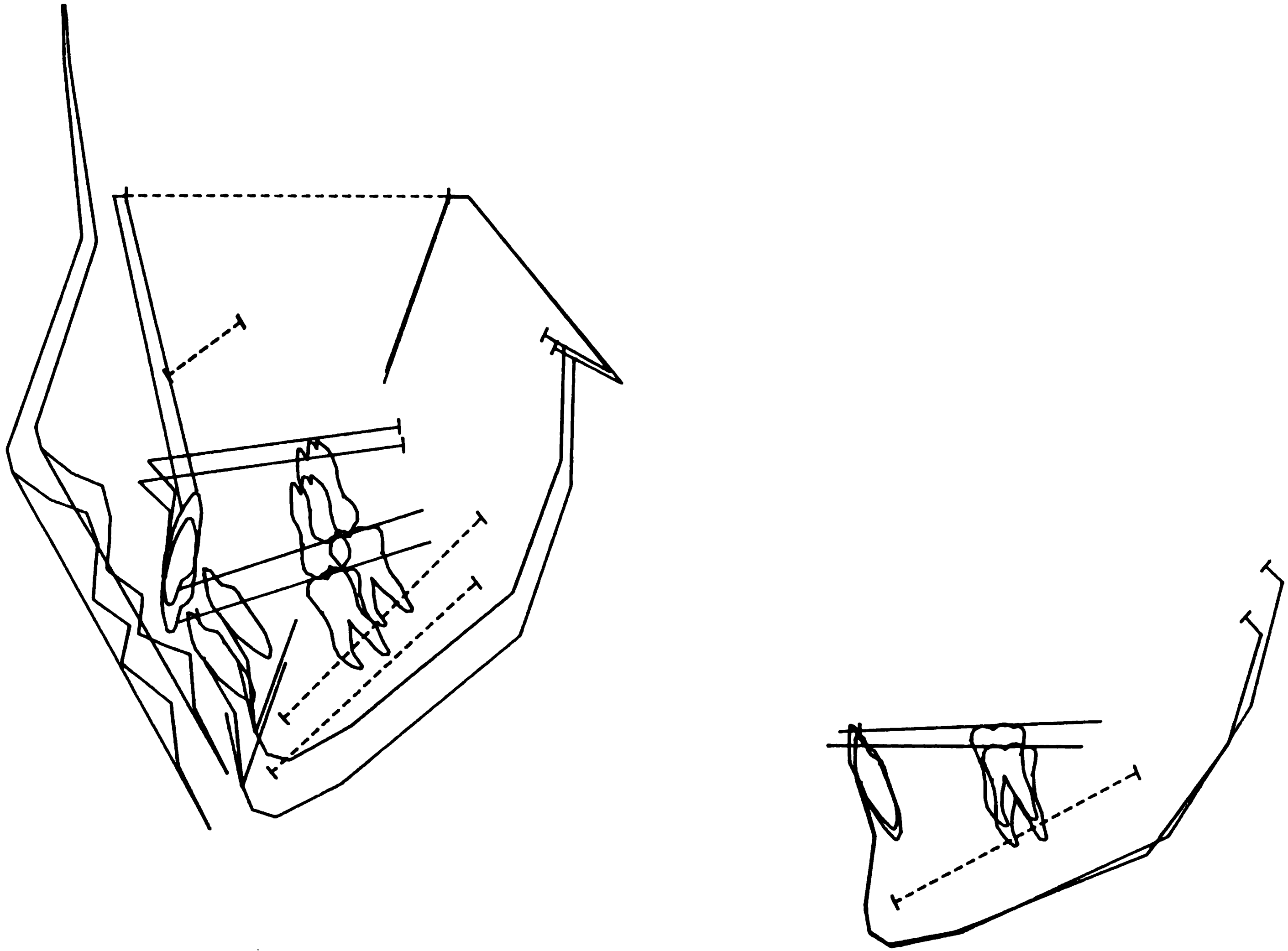


TABLE 14. Comparison of Growth and Treatment Changes Between Girls and Boys

Measurement	Girls (n=31)				Boys (n=28)			
	Pre Tx	Post Tx	Change	Sign.	Pre Tx	Post Tx	Change	Sign.
OB	2.22	1.87	-.35	n.s.	3.81	2.15	-1.66	***
OJ	8.70	4.69	-4.01	***	7.99	4.09	-3.90	***
NSL/NL	6.31	7.16	.85	***	7.14	7.34	.20	n.s.
NSL/ML	33.93	33.26	-.67	n.s.	34.77	34.50	-.27	n.s.
NL/ML	27.62	26.10	-1.52	***	27.63	27.16	-.47	n.s.
s-n-ss	81.36	80.55	-.81	**	79.26	78.76	-.50	n.s.
s-n-pg	75.90	77.26	1.36	***	74.84	76.34	1.50	***
s-n-sm	75.06	76.44	1.38	***	73.74	75.38	1.64	***
ss-n-pg	5.46	3.29	-2.17	***	4.42	2.44	-1.98	***
ss-n-sm	6.30	4.11	-2.19	***	5.51	3.39	-2.12	***
pr-n-ss	2.71	2.57	-.14	n.s.	2.70	2.54	-.16	n.s.
NL-1/	113.36	108.96	-4.40	***	112.50	108.67	-3.83	**
ML-/1	96.75	96.27	-.48	n.s.	94.75	95.52	.77	n.s.
CL/ML	73.67	74.43	.76	n.s.	73.23	74.62	1.39	**
OL_s/NL	11.35	10.84	-.51	n.s.	12.46	10.98	-1.48	**
OL_i/ML	18.99	18.39	-.60	n.s.	21.83	19.76	-2.07	***

*P< 0.05; **P< 0.01; ***P< 0.0001

a significant decrease of 1.5°. The girls showed a significant decrease in maxillary prognathism (s-n-ss) of 0.8° while the boys showed a significant increase in mandibular alveolar prognathism (CL/ML) of 1.4°. As stated previously, the boys showed a significant decrease in overbite of 1.7 mm, which was associated with significant decreases in both the maxillary (OL_s/NL) and mandibular (OL_i/ML) zones. The girls also showed decreases in overbite, maxillary zone, and the mandibular zone, however, none of these decreases was significant.

The linear measurments seen in Table 15 show the growth and treatment effects as measured on the pre and posttreatment tracings. Most of these measurements showed significant increases but with no significant differences between the girls and the boys. This is to be expected due to the fact that these values are all linear measurements that are going to increase with growth. The only significant difference was seen in the horizontal change of the maxillary central incisors relative to nasion-sella perpendicular (is-NSP). Here the girls showed a significant decrease of 1.5 mm while the boys showed an increase of 0.2 mm. This is associated with the fact that the girls had a significantly greater decrease in maxillary prognathism as well a significantly greater lingual inclination of the maxillary central incisors.

TABLE 15. Comparison of Measurements of Growth and Treatment Changes in Girls and Boys

Measurement	Girls (n=31)				Boys (n=28)			
	Pre Tx	Post Tx	Change	Sign.	Pre Tx	Post Tx	Change	Sign.
U6-NSP	34.11	35.24	1.13	*	34.59	36.70	2.11	***
L6-NSP	30.94	34.81	3.87	***	30.89	36.07	5.18	*
is-NSP	66.40	64.92	-1.48	**	65.63	65.86	.23	n.s.
ii-NSP	58.15	60.74	2.59	***	58.98	62.50	3.52	***
sm-NSP	48.69	50.95	2.26	***	48.77	51.59	2.82	***
pg-NSP	47.24	49.65	2.41	***	47.05	50.16	3.11	***
U6-NSL	66.17	71.22	5.05	***	69.50	76.30	6.80	***
is-NSL	31.77	82.53	50.76	***	34.18	87.70	53.52	***
sm-NSL	90.34	97.58	7.24	***	93.59	104.20	10.61	***
gn-NSL	108.34	116.50	8.16	***	113.61	124.98	11.37	***
ii-MRL	31.77	33.31	1.54	***	34.18	36.64	2.46	***
L6-MRL	17.44	20.92	3.48	***	19.02	23.91	4.89	***
ar-pg	100.09	107.69	7.60	***	103.41	113.30	9.89	***

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

E. Evaluation of Treatment Effects of Subgroups Relative to Their Growth Spurt

The girls and boys were each subdivided into four groups. The division of these groups was based upon the timing of the individual subject's growth spurt relative to the time that their activator treatment was initiated. The boys and the girls differed due to the fact that the girss, on average, were treated closer to the time of their peak growth than the boys. The timing of peak growth was based on the subject's individual growth velocity curve. The number of subjects in each of these subgroups is shown in Table 16.

Table 16. Subdivision of Subjects in Relation to Maximum Pubertal Growth

Group	Number of Girls	Number of Boys
A: Peak at treatment start	7	0
B: Peak 1 year post treatment start	10	5
C: Peak 2 years post treatment start	6	9
D: Peak 3 years post treatment start	8	6
E: Peak 4 years post treatment start	0	8

Tables 17-20 show the results of the cephalometric measurements of the treatment effects on the subgroups (A-E) of girls and boys. An ANOVA analysis was conducted to determine if there were any significant differences between the subgroups of girls. This comparison of subgroups showed no significant differences for any of the cephalometric measurements. None of the subgroups showed any significant differences between them for any of the parameters measured. The same analysis was conducted on the sample of

Table 17. Cephalometric Comparison of Treatment Changes (Girls) By Group

Measurement	Group A (n=7)		Group B (n=10)		Group C (n=6)		Group D (n=8)		Sign.
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	
OB		1.90	-.39	1.55	-.83	1.86	-.25	1.99	n.s.
OJ	-4.63	1.08	-3.99	3.10	-3.17	1.89	-4.15	2.74	n.s.
pr-n-ss	-.59	.85	-.11	1.41	.50	.52	-.25	1.26	n.s.
1/NL	-6.54	2.99	-4.77	6.41	-3.68	3.45	-2.63	6.99	n.s.
1/ML	1.19	2.52	-1.46	4.26	-2.02	2.13	.43	6.11	n.s.
CL/ML	.66	4.12	.02	2.41	-.43	1.28	2.68	2.44	n.s.
SNA (s-n-ss)	-.23	1.03	-.82	1.36	-1.68	1.38	-.65	1.60	n.s.
SNB (s-n-sm)	1.53	2.00	1.36	1.25	1.03	1.39	1.55	1.70	n.s.
SNPg (s-n-pg)	1.81	2.04	1.32	1.10	1.02	1.29	1.27	1.68	n.s.
ANB (ss-n-sm)	-1.76	1.56	-2.18	1.90	-2.72	1.65	-2.20	2.00	n.s.
ANPg (ss-n-pg)	-2.04	1.31	-2.14	1.57	-2.70	1.69	-1.92	2.11	n.s.
ar-pg	7.29	3.29	8.35	2.17	6.79	2.93	7.63	3.47	n.s.
NSL/NL	.86	1.35	1.14	1.31	.28	.68	.90	.73	n.s.
NSL/ML	-1.71	1.73	-.33	2.57	.30	1.58	-.91	3.10	n.s.
NL/ML	-2.57	1.04	-1.47	1.79	.02	1.49	-1.81	2.68	n.s.
OL_s/NL	.10	2.36	-1.31	2.33	.25	2.23	-.59	3.07	n.s.
OL_i/ML	-1.74	2.57	-.95	2.07	-.28	2.15	.60	5.24	n.s.

*P< 0.05

Group A: peak at treatment start
Group B: peak 1 year post treatment start
Group C: peak 2 years post treatment start
Group D: peak 3 years post treatment start

Table 18. Cephalometric Comparison of Treatment Changes (Boys) By Group

Measurement	Group B (n=5)		Group C (n=9)		Group D (n=6)		Group E (n=8)		Sign.
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	
OB	-1.94	1.34	-1.62	2.36	-1.40	1.26	-1.74	1.55	n.s.
OJ	-4.26	1.86	-2.90	2.11	-4.20	.95	-4.72	1.75	n.s.
pr-n-ss	-.36	.98	-.06	.32	-.30	.60	-.01	.65	n.s.
1/NL	-4.44	8.73	-1.28	5.65	-3.96	4.15	-5.46	6.52	n.s.
1/ML	1.60	10.79	-1.19	5.56	.34	5.71	3.05	5.74	n.s.
CL/ML	1.16	1.64	.37	1.89	1.90	1.92	2.81	2.45	n.s.
SNA (s-n-ss)	-1.00	2.28	-.60	2.23	-.26	1.44	-.08	1.13	n.s.
SNB (s-n-sm)	1.14	1.19	1.42	1.71	1.66	1.67	2.39	1.14	n.s.
SNPg (s-n-pg)	.64	.60	1.53	1.70	1.40	1.54	2.21	1.35	n.s.
ANB (ss-n-sm)	-2.14	1.78	-2.02	1.96	-1.92	1.55	-2.46	.72	n.s.
ANPg (ss-n-pg)	-1.64	1.80	-2.13	1.80	-1.66	1.51	-2.29	.72	n.s.
ar-pg	9.60	4.71	10.50	3.95	9.20	4.32	10.25	5.34	n.s.
NSL/NL	.24	1.14	.27	.95	.36	1.17	-.04	1.04	n.s.
NSL/ML	-.10	.51	-.11	2.80	-.66	2.48	-.14	1.59	n.s.
NL/ML	-.34	1.37	-.38	3.08	-1.02	1.81	-.10	2.09	n.s.
OL_s/NL	-1.58	2.79	-2.42	2.52	-1.00	1.21	-.79	2.69	n.s.
OL_i/ML	-2.76	3.09	-1.14	3.22	-2.10	1.58	-2.75	3.31	n.s.

*$P < 0.05$

Group B: peak 1 year post treatment start
Group C: peak 2 years post treatment start
Group D: peak 3 years post treatment start
Group E: peak 4 years post treatment start

Table 19. Cephalometric Comparison of Linear Treatment Changes (Girls) By Group

Measurement	Group A (n=7)		Group B (n=10)		Group C (n=6)		Group D (n=8)		Sign.
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	
U6-NSP	2.21	1.93	.80	1.92	-.42	4.67	1.75	2.09	n.s.
L6-NSP	4.71	2.36	2.95	2.71	3.50	2.00	4.56	2.37	n.s.
is-NSP	-1.57	1.64	-2.25	3.22	-1.42	1.56	-.50	2.67	n.s.
ii-NSP	3.50	1.92	1.90	2.39	1.58	2.25	3.44	2.81	n.s.
sm-NSP	3.36	2.87	1.60	2.53	1.25	2.34	2.88	3.38	n.s.
pg-NSP	4.00	3.91	1.65	2.55	1.50	2.19	2.63	3.70	n.s.
ss-NSL	7.07	3.16	8.10	2.93	5.57	3.70	7.75	2.49	n.s.
gn-NSL	7.93	3.85	8.95	2.14	7.57	3.12	7.88	2.60	n.s.
U6-NSL	5.00	2.43	5.70	1.44	3.79	2.56	5.38	2.50	n.s.
is-NSL	4.29	2.06	4.65	1.67	3.36	2.16	5.44	2.64	n.s.
L6-mand ref	3.93	1.31	3.40	2.09	2.86	.75	3.75	1.00	n.s.
ii-mand ref	1.71	.81	1.20	2.08	1.36	1.28	2.00	.85	n.s.

*P< 0.05

Group A: peak at treatment start
Group B: peak 1 year post treatment start
Group C: peak 2 years post treatment start
Group D: peak 3 years post treatment start

Table 20. Cephalometric Comparison of Linear Treatment Changes (Boys) By Group

Measurement	Group B (n=5)		Group C (n=9)		Group D (n=6)		Group E (n=8)		Sign.
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	
U6-NSP	-.20	2.86	3.06	2.89	1.90	1.92	2.81	2.45	n.s.
L6-NSP	3.20	3.44	5.11	2.38	5.60	2.30	6.63	2.93	n.s.
is-NSP	-1.50	3.26	1.11	2.30	-.60	1.98	1.25	2.84	n.s.
ii-NSP	2.40	1.92	3.78	2.88	3.20	2.66	4.69	4.25	n.s.
sm-NSP	1.60	2.46	2.72	3.81	2.40	3.05	4.31	2.24	n.s.
pg-NSP	1.60	2.66	3.22	3.98	2.40	3.45	4.69	2.84	n.s.
ss-NSL	10.40	5.56	11.78	5.73	10.20	4.21	10.19	5.37	n.s.
gn-NSL	11.40	6.39	12.61	5.86	10.60	4.81	10.94	5.55	n.s.
U6-NSL	6.40	3.94	7.56	3.69	6.40	3.99	6.88	4.22	n.s.
is-NSL	5.20	2.78	5.56	2.78	4.90	2.43	5.44	3.47	n.s.
L6-mand ref	4.50	3.18	5.22	1.66	5.40	1.78	4.75	1.89	n.s.
ii-mand ref	1.90	2.66	3.17	1.12	2.70	1.68	2.13	1.36	n.s.

*$P < 0.05$

Group B: peak 1 year post treatment start
Group C: peak 2 years post treatment start
Group D: peak 3 years post treatment start
Group E: peak 4 years post treatment start

V. DISCUSSION

Functional appliances have a long history of use for correction of dental malocclusions. They were first introduced in Europe in the early part of the century by Robin (1), but not until Andresen and Häupl (3) further developed their appliance did they gain widespread use, first in Europe and later in the United States. Since that time a variety of functional appliances have been designed, and much has been written about advantages and disadvantages of their use. Despite the many years these appliances have been used, many questions still remain unanswered with respect to the nature of the skeletal, dental, and functional changes that occur during treatment. Also the association between the timing of treatment and the changes that take place during treatment is still not clear.

The purpose of this present study was first, to investigate the skeletal and dental changes that occur during treatment with the Harvold activator appliance and if these changes are different in girls and boys and secondly, to determine if the observed treatment effects depend on the stage of maturation and growth intensity of the patient at the time of treatment. Our hope was also to use the information gained from this study to develop guidelines for the optimal time to start treatment.

The subjects for this study were divided by sex to determine possible differences in facial morphology before treatment and later in their response to treatment. The pretreatment facial morphology was very similar for the two groups. Both groups had increased overjet, dysplastically proclined maxillary incisors, and compensatorily proclined mandibular incisors. These findings are similar to those reported by Harvold and Vargervik (11, 14) in previous studies of this material. The differences in facial morphology between girls and boys were limited to a few parameters, for instance, boys had significantly greater overbites than girls. This overbite was associated with increased maxillary and mandibular zones, suggesting that the overbite was dentoalveolar in nature and due to overeruption of teeth. In addition, mandibular length in boys was also significantly greater than in the girls. We found that boys differed significantly from girls with respect to their vertical linear measurements, which were increased compared to girls. The observation of great similarity in facial morphology of girls and boys with Class II malocclusion is not new.(81)

When we compared the posttreatment facial morphology of girls and boys we found even fewer differences. The same difference in vertical linear dimensions observed prior to treatment also was present after treatment. Both groups showed a significant reduction in the overjet which was correlated with the decrease in proclination of the maxillary incisors, especially in the girls. Only the boys showed a significant reduction in overbite, whereas the girls showed only minimal change. This decrease in overbite, associated with decreases in the maxillary and mandibular zones, was due to a vertical increase of the buccal segments, i.e. eruption of the posterior teeth without corresponding vertical increase in the incisor region. The eruption is undoubtably a result of the removal of the acrylic over the posterior mandibular teeth. The sagittal skeletal change, on average, was a significant improvement in the jaw relationship of about 2°, which was primarily the result of forward growth of the mandible in combination with restriction of forward maxillary growth.

There were no significant changes in mandibular plane angle, mandibular incisor inclination, or maxillary alveolar prognathism. Other researchers have reported different findings. Earlier studies, including Harvold and Vargervik (11, 14), reported an increased mandibular plane angle with treatment. Several studies have also reported significant changes in incisor inclination with proclination of the mandibular incisors and retroclination of the maxillary incisors.

Many of the treatment effects found in this study coincide with those reported by other investigators. The decrease in overbite and overjet are similar to values reported by Ahlgren (82). Jakobsen (47) conducted a study on 31 girls and 22 boys from the ages of 8 to 14 years and found more restricted maxillary growth in the females and more mandibular growth in the males. The results of this study also show this general trend, but with considerable individual variations. Luder (48) reported that the boys in his study started treatment with deeper bites than the girls and therefore needed higher construction bite registrations for mandibular protrusion. He concluded that a higher construction bite leads to more mandibular growth and less maxillary reaction in response to activator treatment. The boys in our study started with greater overbite than the girls and similarly responded to treatment with more restriction of maxillary growth. The increase in the inclination of the palatal plane found in the girls also corresponds to results reported by Woodside (83), and may be the result of the greater restriction of the maxilla we observed in the girls. Our study found one of the primary treatment effects was in the retroclination of the maxillary incisors, with the mandibular incisors being relatively stable in their position, which is similar to results published by Weislander (49, 84, 85)

The samples of girls and boys, respectively, were subdivided based on the timing of their growth spurt relative to the time they started treatment. One of the groups (Girls: Groups A) was at peak growth at the time that treatment started. The other groups were prepubertal and reached their growth spurt 1-4 years after treatment started. Most of the subjects had a decrease in their growth velocity as they neared their prepubertal growth minimum. In some cases they were actually at minimum growth at the time treatment was started.

Several investigators have recommended the use of functional appliance therapy mainly during the pubertal growth spurt in order to take maximum advantage of the growth potential of the subject (82, 86, 87). Ahlgren (82) stated that treatment success was, "intimately related to the growth intensity of the jaws", however, no data were presented in his study to support this position.

Detailed investigations of functional appliance therapy vs. the timing of the peak growth spurt have been reported by Pancherz (18) and Hagg and Pancherz (19). They conducted studies of the treatment effects of the Herbst appliance and the timing of peak growth. Their results showed that sagittal condylar growth in subjects treated during their peak growth was twice that observed in subjects treated 3 years prior to or three years after peak growth. More specifically, they also reported that sagittal condylar growth in subjects treated one year prior to peak growth was considerably less than those treated at peak growth or one year after peak growth. Subjects treated three years post peak showed a change in incisor position twice that of subjects treated during peak growth.

While a Herbst appliance differs significantly from the Harvold activator in it's mode of action and time of use, these data do not exclude the possibility that subjects treated with functional appliances during their peak growth velocity can have more skeletal than dental changes, while those treated prior to peak or after peak growth respond with more pronounced dentoalveolar changes. In our study, Group A of the girls, who were in their peak growth at the time treatment was started, did not show any significant differences from the other three groups of girls. However, Group A was limited and only included 7 girls. This was due to the fact that the original proticol of this study called for subjects who had headfilms taken for at least one year posttreatment which limited the number of subjects taken from the original sample. By including the rest of the study sample from the original study a larger sample would fall in the Group A category, allowing a more definitive test to determine if there is a difference between treatment effects in subjects treated in the juvenile prepubertal period compared to those treated in the pubertal growth period.

The investigation of the subdivided groups of girls and boys did not demonstrate any significant differences in treatment effects between the groups. This sugests that during the juvenile growth period, up to and including the prepubertal growth minimum, it is not important when functional appliance therapy is initiated. The subjects in this investigation, on average, had similar treatment effects irrespective of when they were treated. These findings are similar to those reported by Demisch (88) who found no association between the stage of maturational development and the response to activator treatment in a study of girls and boys between the ages of 7.5 to 14 years who were treated for 14 months with a Herren activator. Freunthaller (89) also came to a similar conclusion. Our results are not in agreement with the recommendations of Björk (90) who felt there is a greater treatment effect at an earlier age, i.e. in the primary or mixed dentition, when compared to treatment in the permanent dentition. We found no correlation between the length of treatment and the age at which treatment was started in relation to peak growth. Successful treatment of subjects treated in their prepubertal minimum did not require longer treatment time than those treated prior to minimum growth or compared to those treated during peak growth.

This suggests that cooperation with consistent wear of the appliance may be a more important factor to the successful outcome of treatment than the timing of treatment prior to the growth spurt. The clinician should carefully evaluate the potential willingness of the patient to cooperate prior to initiating functional appliance therapy.

Most clinical studies of functional appliance therapy do not show an increase in the growth of the mandible with treatment. (84, 86, 90, 91) However, a few investigators have reported a significant increase in mandibular growth velocity during treatment. (92, 93)(McNamara, Rhigellis) Our findings regarding mandibular growth increments during the treatment period are similar to results originally reported by Harvold and Vargervik. (11, 14) They found an increase in mandibular growth velocity during the first year of activator therapy followed by a return to more normal growth intensity. The same results were found in this study in 6 out of the 8 groups of subdivided girls and boys. After the first year of treatment, the growth curves returned to normal values that coincided with the height velocity growth curves. These results agree with the animal studies conducted by Elgoyhen (10) and Stöckli (5) who noted an increased velocity in condylar growth during the first three months that their experimental monkeys were placed into protrusive mandibular position. One explanation for the initial growth intensity may be that the subjects were posturing forward into their accustomed bite due to muscle splinting. If the individual was posturing, it would give the appearance of increased mandibular growth velocity on the lateral headfilm.

In this study we found wide variabilities in treatment effects, which is similar to the findings of several previous studies. (49, 84, 88) The average treatment changes in the subjects of our study, however, do not allow us to make recommendations as to the type of patient that may be appropriate for treatment with an Harvold type activator because of the wide variations in response to treatment.

Our data showed that the timing of treatment prior to puberty does not have a significant effect on the successful outcome of treatment. If the clinician decides that functional appliance therapy is the proper treatment and the patient is obviously prepubertal then the treatment should be initiated when the patient is willing to cooperate with treatment.

VI. CONCLUSIONS

We have shown that the treatment effects of the Harvold activator are the result of varying contributions of skeletal and dentoalveolar changes, but with the retroclination of the maxillary incisors having the most significant effect on the reduction of overjet. The sagittal jaw discrepancy was decreased through restriction of maxillary growth and increased anterior growth of the mandible. Aside from the first year of treatment, the rate of mandibular growth was coincident with the growth rate that one might expect, based on the height velocity curves.

The majority of subjects were either in their juvenile prepubertal growth period or in their prepubertal growth minimum. The variability in treatment effects was large for all parameters measured, and no correlation was found between the stage of maturation of the subjects, the treatment effects, or the length of treatment. The cooperation of the patient with functional appliance therapy may be the most important factor in the success of treatment.

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VIII. APPENDIX ONE

Hand-wrist films

The original proticol of the study included the use of hand-wrist films to determine the stage of skeletal development of the subjects. Due to the fact that the headfilms were not routinely taken at the start of treatment, it was determined that the hand-wrist films were not appropriate for the use of determining the skeletal age of the subjects at the time of treatment start. The following is a literature review and and the method used for hand-wrist analysis in this study.

The timing of the adolescent growth spurt has long been of interest to orthodontists. It is felt that many orthodontic treatment modalities, especially those associated with growth modification, will have the best results if conducted during the time of peak growth intensity. Therefore, the timing of this peak growth is of primary importance. The problem faced by clinicians is accurately determining the timing of this peak growth for the individual child. The variation in the timing of the adolescent growth spurt is distributed in a range of plus or minus two years around the mean (94). This variation gives a possible four year range for when a given child may experience the peak.

Researchers have attempted to devise methods to more accurately determine when a given child can be expected to demonstrate peak growth. Hand wrist films have been used toward this end. Several different methods of determining the skeletal age of the patient have had popularity in the field of orthodontics. The two most notable are those of Tanner and Whitehouse (79) and Greulich and Pyle (80). The assumption underlying the analysis of hand wrist radiographs is that determination of skeletal age will be more accurate predictiing the time of the facial growth spurt than by chronologic age. The round and tubular bones of the hand and wrist include many primary ossification centers and therefore this region is regarded as a more sensitive indicator of skeletal development than other regions.

There are two basic methods of assessing hand wrist films: ossification events and bone stages. An ossification event is the progression from one bone stage to the next and thus its recognition requires serial radiographs. An ossification event is estimated to have occurred halfway between the last film on which the previous bone stage was evident and the first film on which the succeeding stage can be identified. Therefore, the accuracy of determining the timing of ossification events is dependent on the time interval between the serial radiographs.

Bone stages are arbitrary periods in the development of a bone and have been described in particular rating systems. Data from bone stages can not be extrapolated directly to ossification events because it is not possible to tell from a single bone stage when the associated ossification event occurred.

The utility of hand wrist films in orthodontics depends on whether or not skeletal age, as determined by the use of hand wrist films, is more accurate than chronologic age in determining the timing of the pubertal growth spurt.

Numerous studies have reported results indicating that hand wrist films have real clinical relevance and are valuable diagnostic tools in determining the timing of the pubertal growth spurt. Fishman (95) found that individual skeletal measurements were more accurate and therefore more clinically relevant than chronologic age. In this study only a small percentage of the individuals showed concurrence between skeletal and chronologic age with the females showing a greater amount of deviation in the timing of the growth velocity changes in cephalometric measurements than the males. Bergersen (96) found that using skeletal age to determine the timing of the pubertal growth spurt had 1/3 the variation of using chronologic age.

Other researchers have reported that hand wrist films are of little clinical value in determining the timing of the adolescent growth spurt. Houston (53, 54), using data collected in the Harpender Growth Study found that the method of determining bone age (RUS system) developed by Tanner et al (78) is more closely related to the timing of peak height velocity than carpal age. However, he also concluded that the uncertainty of predicting the timing of the peak height velocity from ossification events in hand wrist films is generally large and of limited value. He reported that the value of ossification events two years prior to peak height velocity are limited in their predictive capabilities and that single bone stages can not be used to predict peak height velocity.

Yet other researchers have found results that lie between the previous studies cited. Hunter (56) found the deviation in skeletal age in males was 1/2 of that found with chronologic age. In females, the skeletal age only had a slightly smaller deviation than that of chronologic age. He concluded that it was doubtful whether or not skeletal age would be helpful in determining the timing of the growth spurt in females. Similar results were reported by Smith (97) who reviewed the literature and came to the conclusion that hand wrist films may provide useful growth information on males but not females. Hagg (76, 77) reported that the peak and the end of the growth spurt, but not the beginning of the growth spurt could be assessed by hand wrist films. His findings showed great variation in the timing of the growth spurt. The early maturers reached the end of their growth spurt before the late maturers reached the onset of their growth spurt. He also found that the skeletal development at the beginning and peak of the growth spurt was more advanced in the females than males, but at the end of the growth spurt the skeletal development was more advanced in the males.

The hand-wrist films in this study were taken on two occasions separated by two years. Films on both the right and left hands of each individual were taken, however only the left hand films were analyzed for use in this study. The two left hand-wrist films for each subject were analyzed using the TW2 method of Tanner and Whitehouse (79). The RUS scoring system of bone stages was used. The RUS scoring system includes the radius, ulna, metacarpals I, III, V, proximal phalanges I, III, V, middle phalanges III, V, and distal phalanges I, III, V. This system scores these thirteen bone stages of the long bones in the hand which are then added together to determine the RUS maturity score.

(Tables 21,22) The score is compared to the graphs shown (Figures 69,70) to determine the skeletal age of the patient. The skeletal age can then be compared to another set of graphs (Figures 71,72) to determine the chronologic age of the patient.

The values of the skeletal ages (bone stages) from these two timepoints were averaged to estimate the patient's skeletal age at the time point midway between the times of the two handwrist films. This age was then used to determine the skeletal age at the time that treatment was initiated.

It was determined that the method of averaging the values of the skeletal ages (bone stages) from the two timepoints and then extrapolating back to determine the skeletal age at the time treatment was initiated was not accurate enough for the purposes of this study. The hand wrist data was not used for any of the results involving the stage of maturation of the patients. The annual height measurements were used for this purpose. This agrees with the protocol recommended by Hagg (76-78) who has reported that velocity curves of standing height are the most useful aids for estimation of the growth expectation of the mandible.

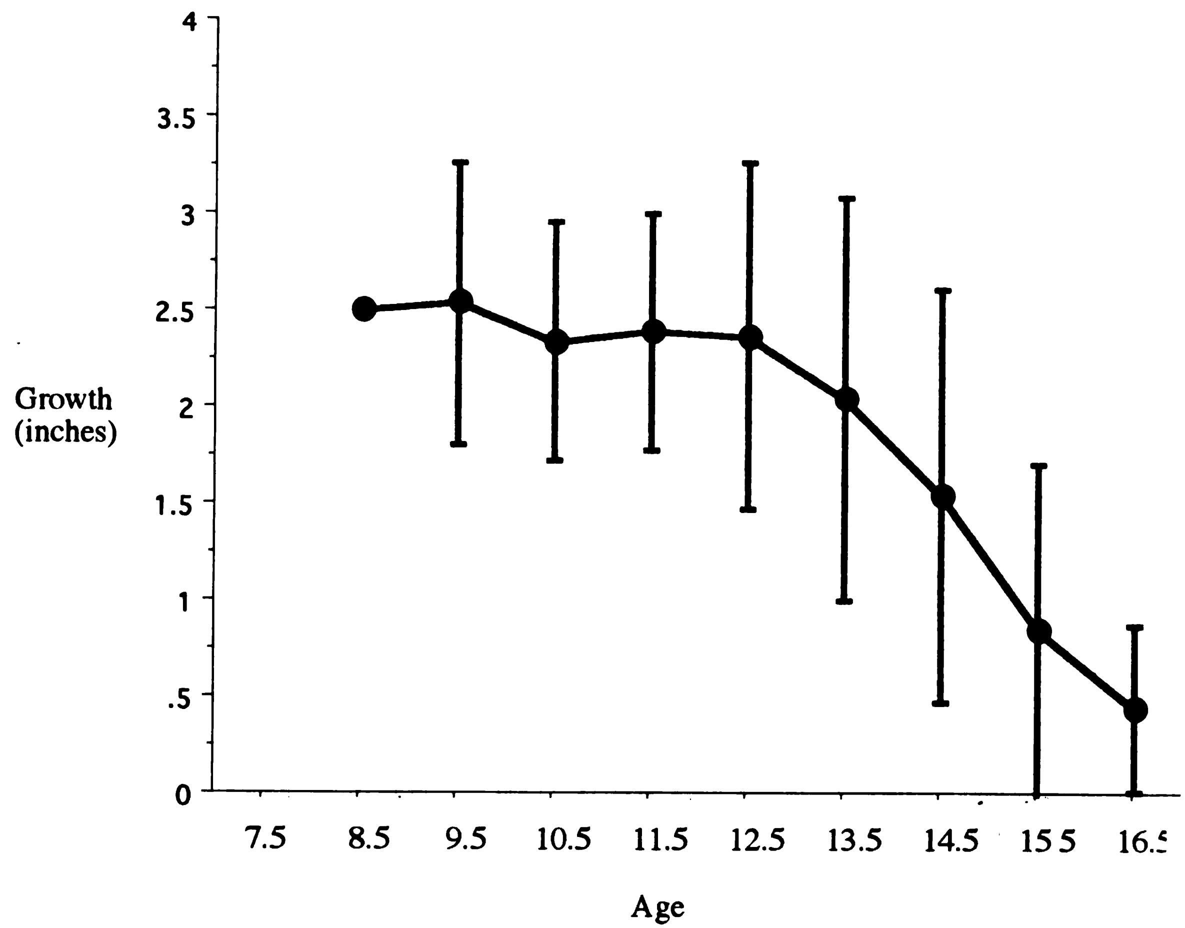


Figure 22. Girls (n=31) Growth Velocity Curve

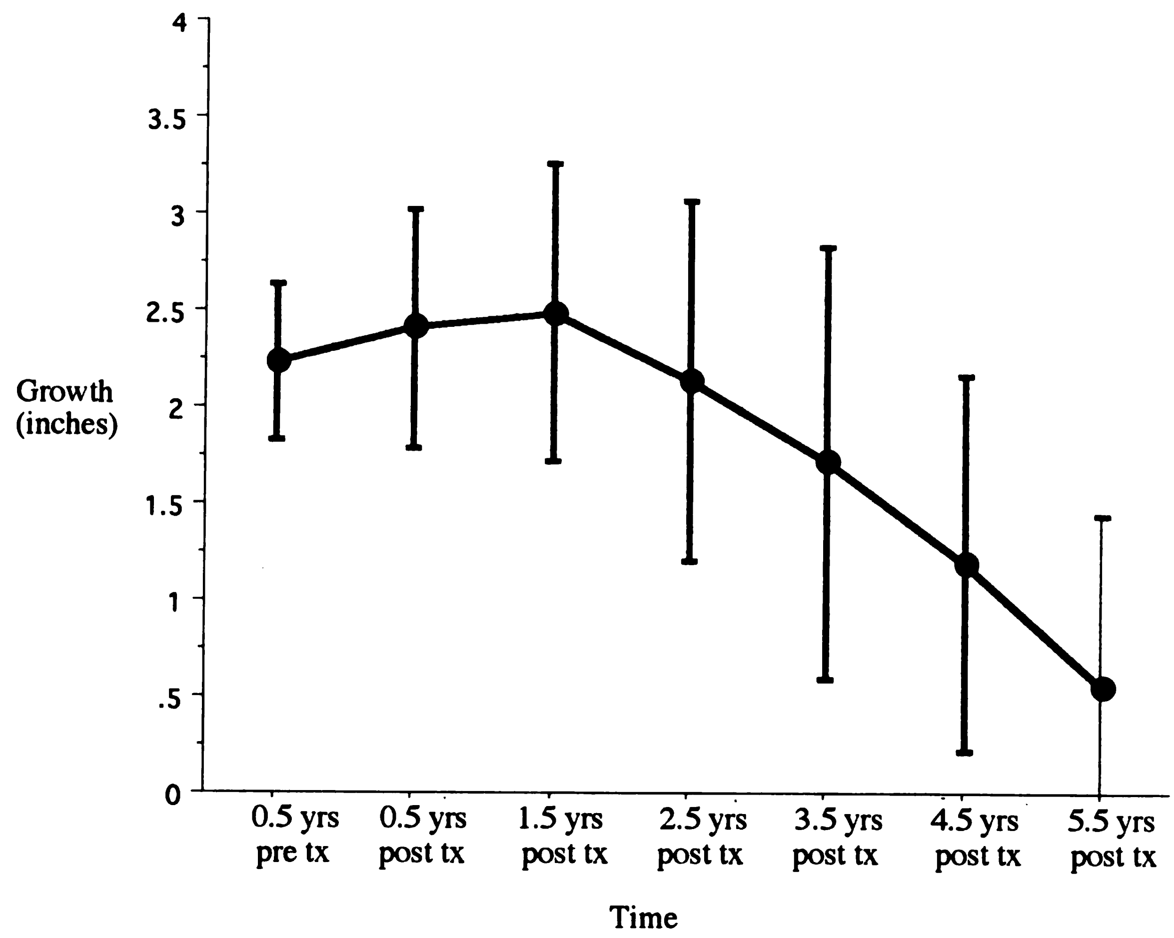


Figure 23. Girls (n=31) Growth Velocity Curve Relative to the Time of Treatment Start

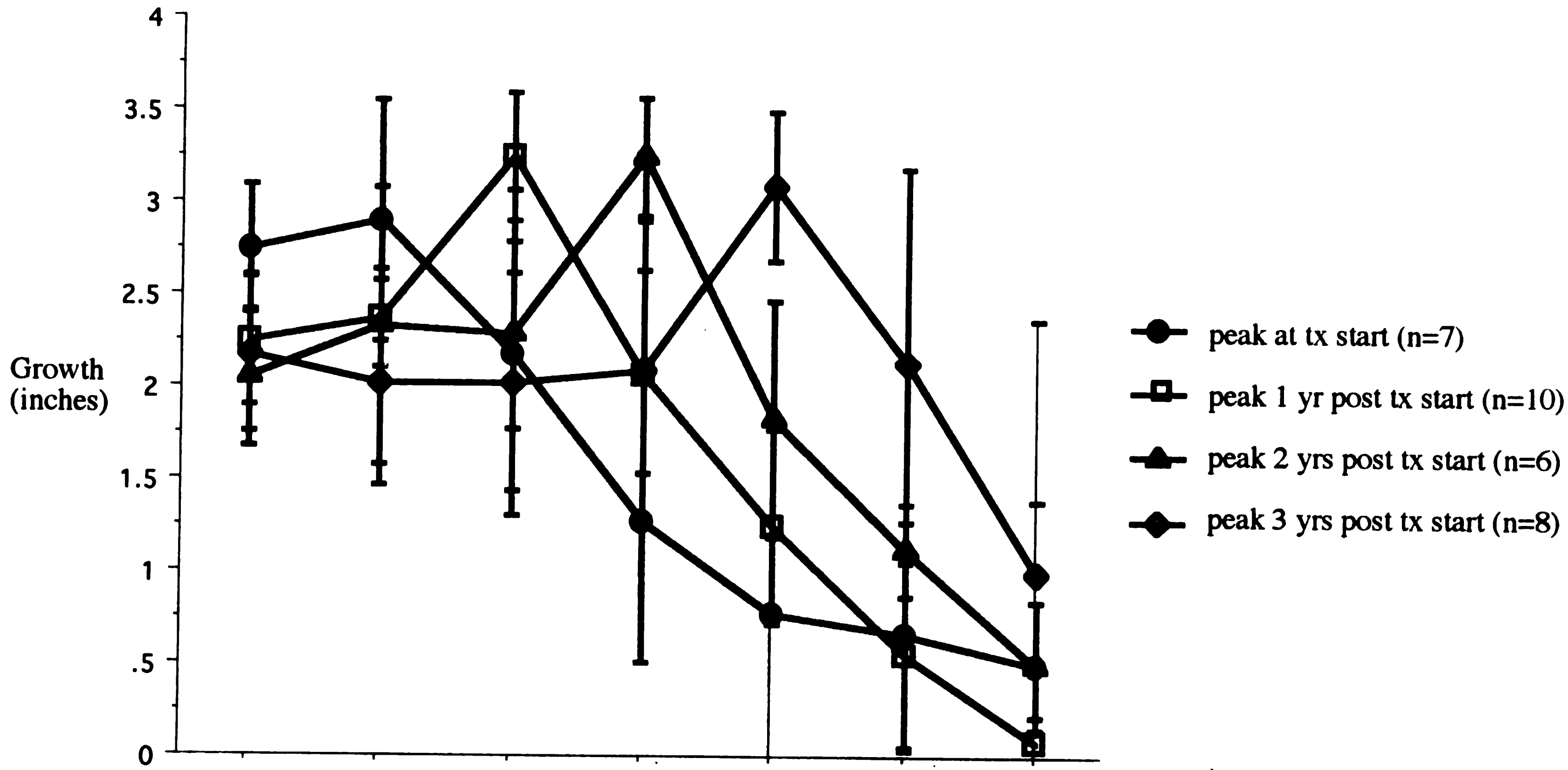


Figure 24. Subgrouped Girls (n=31) Growth Velocity Curve Relative to the Time of Treatment Start

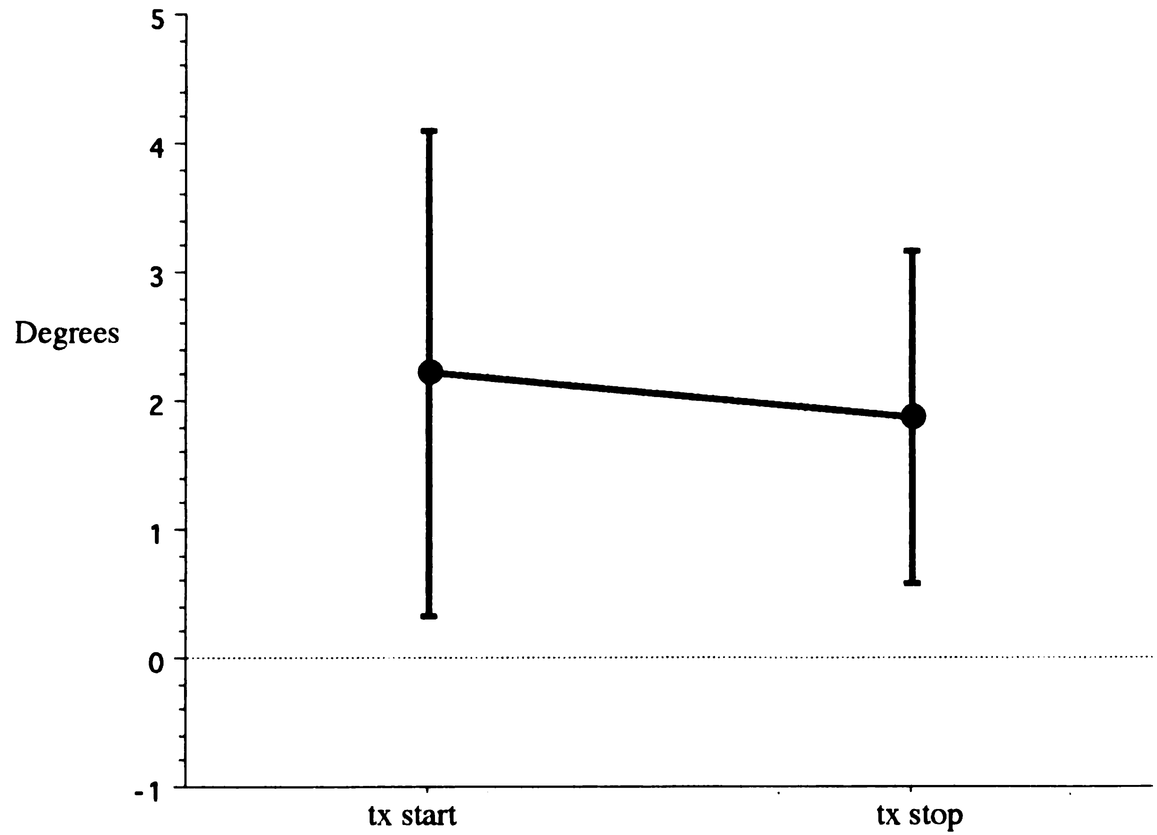


Figure 25. Girls (n=31) Change in Overbite

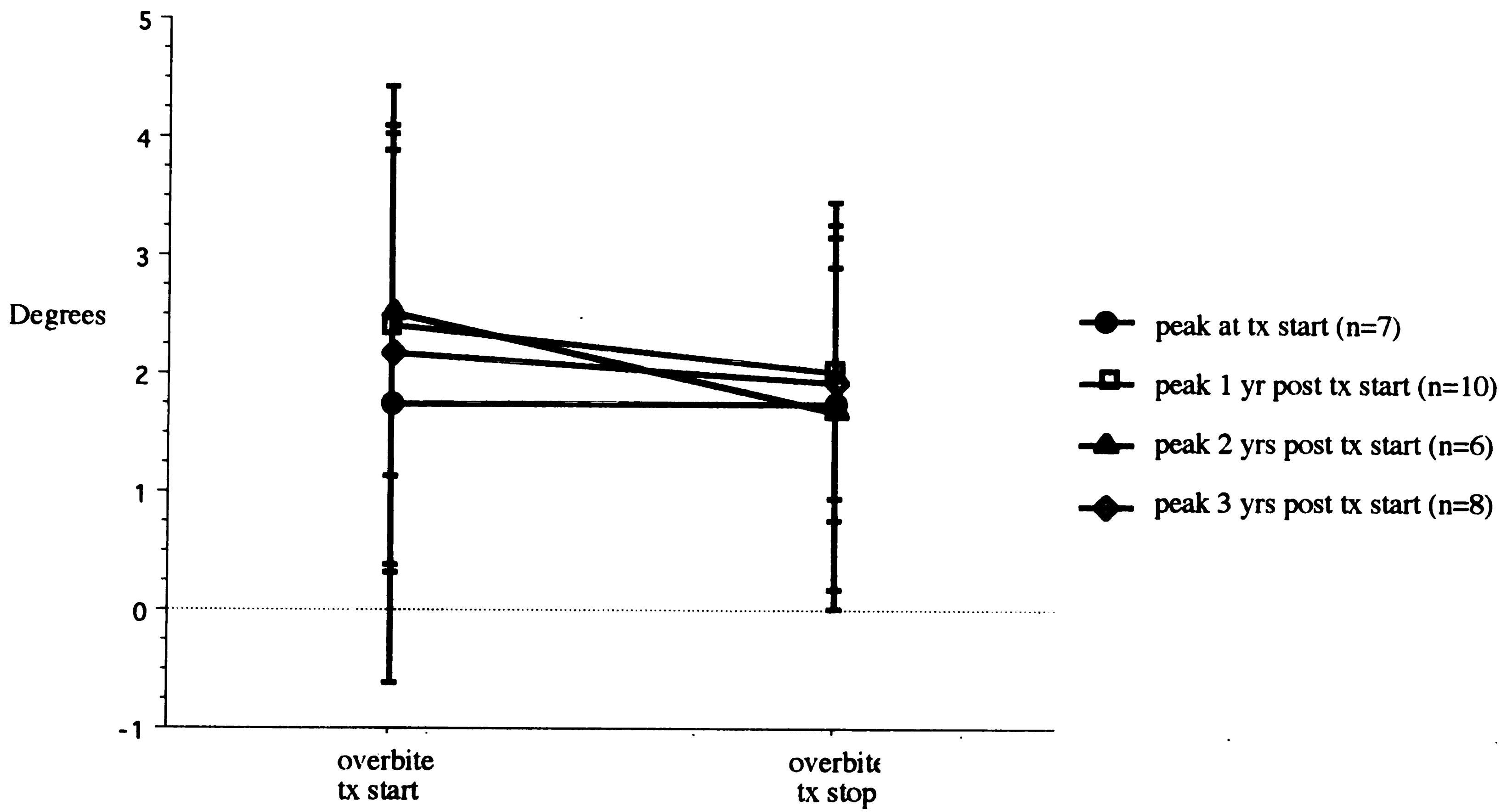


Figure 26. Subgrouped Girls (n=31) Change in Overbite

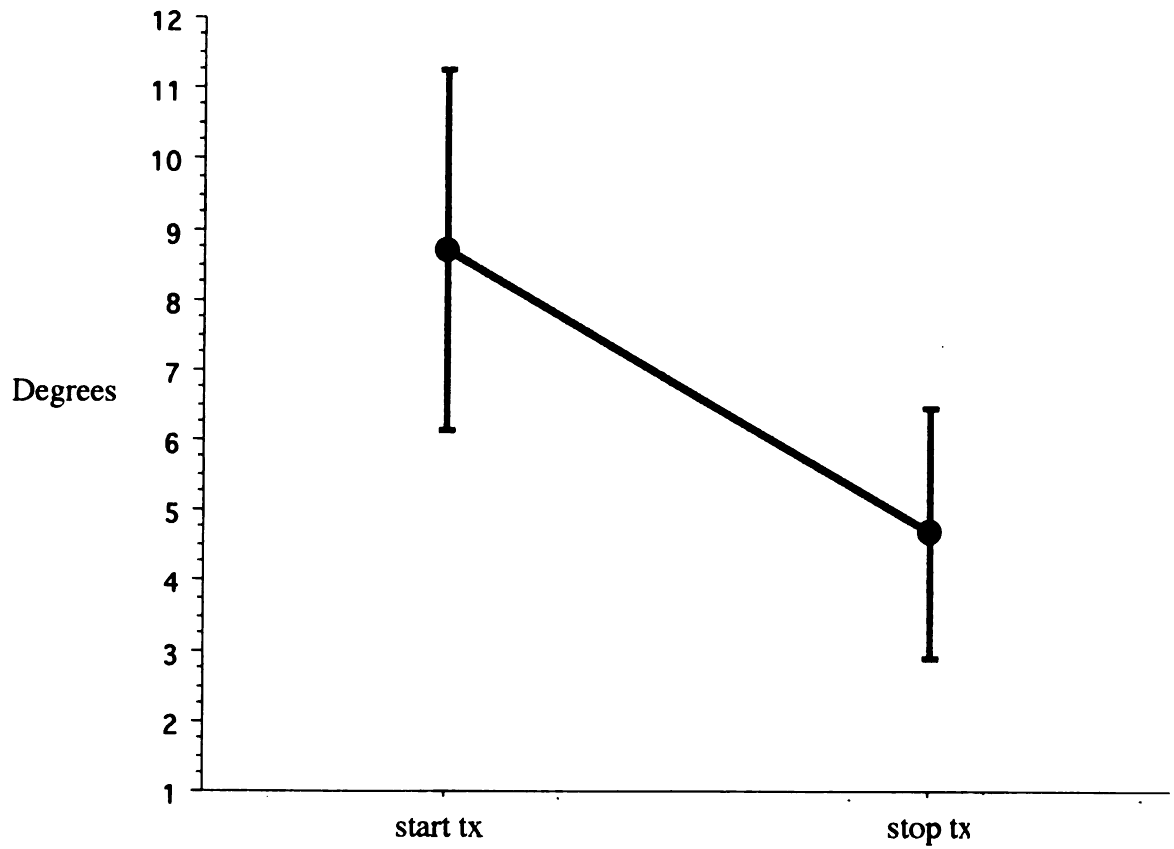


Figure 27. Girls (n=31) Change in Overjet

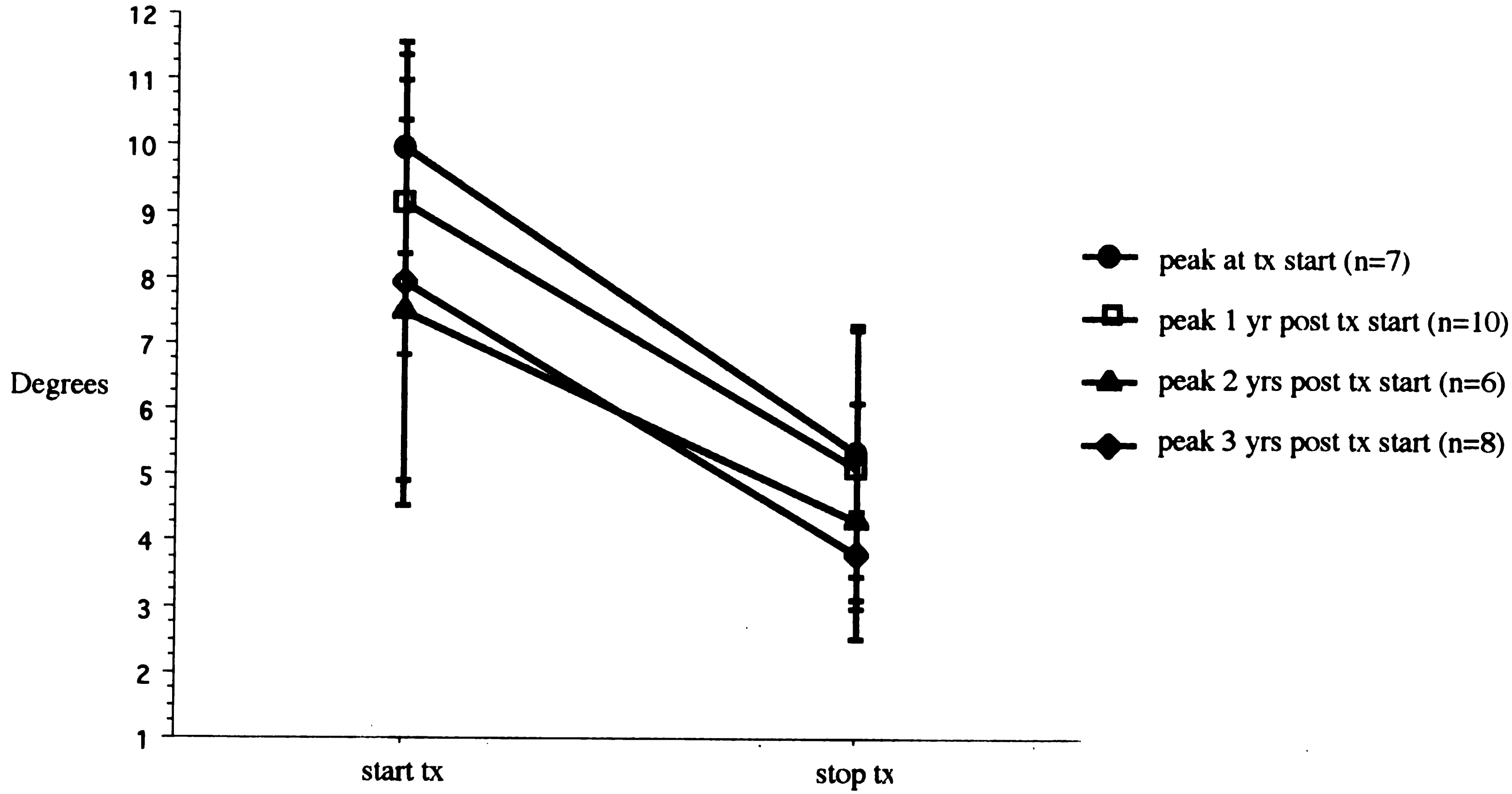


Figure 28. Subgrouped Girls (n=31) Change in Overjet

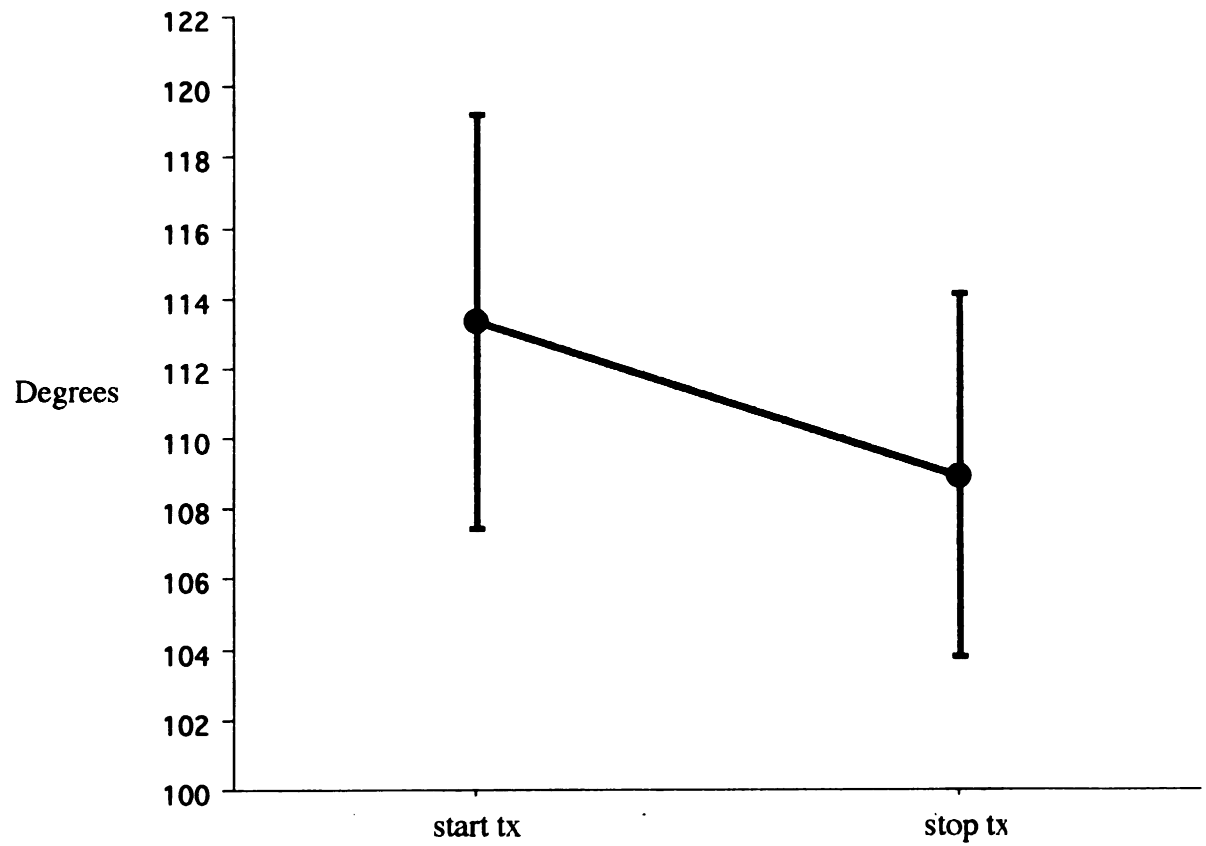


Figure 29. Girls (n=31) Change in Maxillary Incisor Inclination

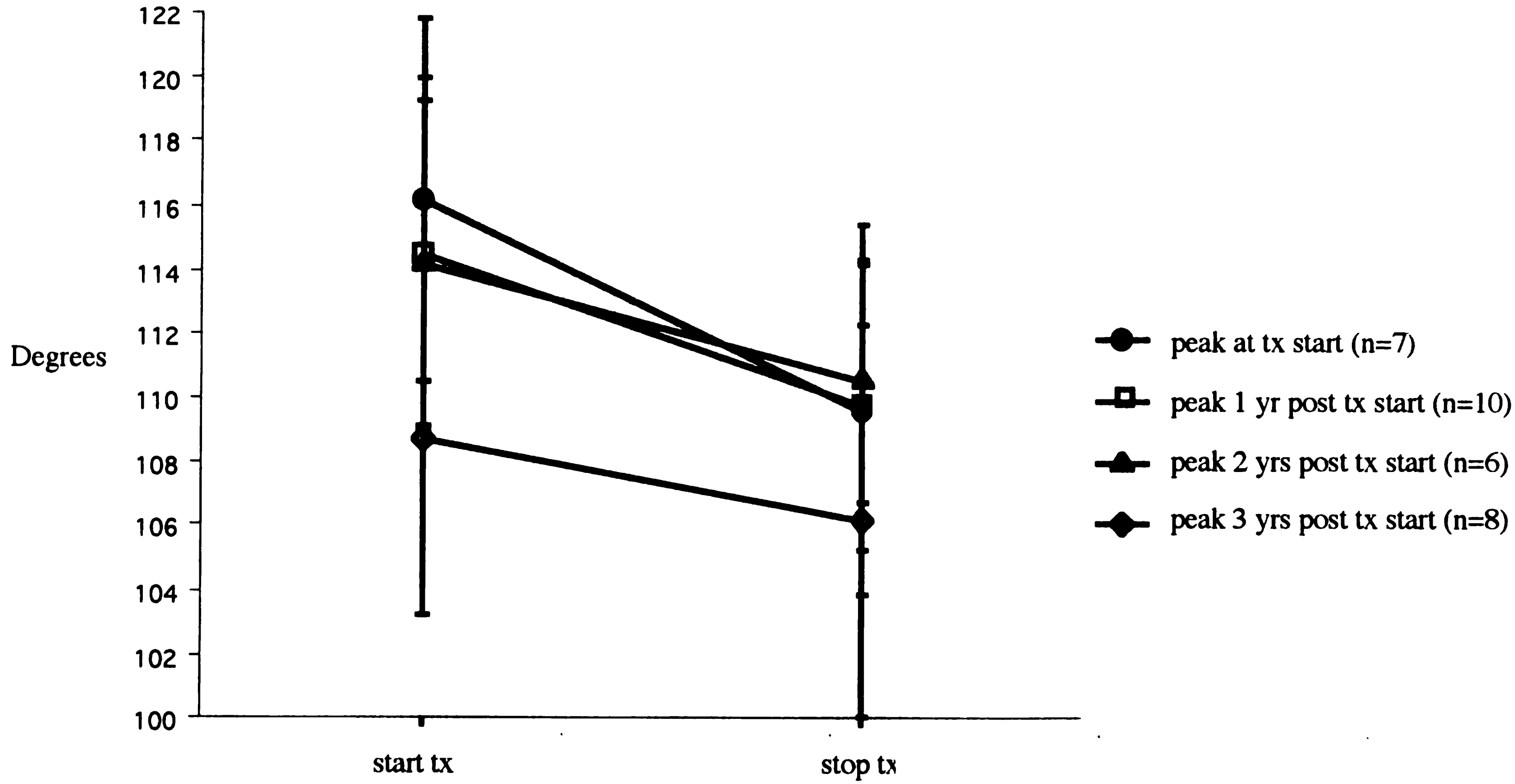


Figure 30. Subdivided Girls (n=31) Change in Maxillary Incisor Inclination

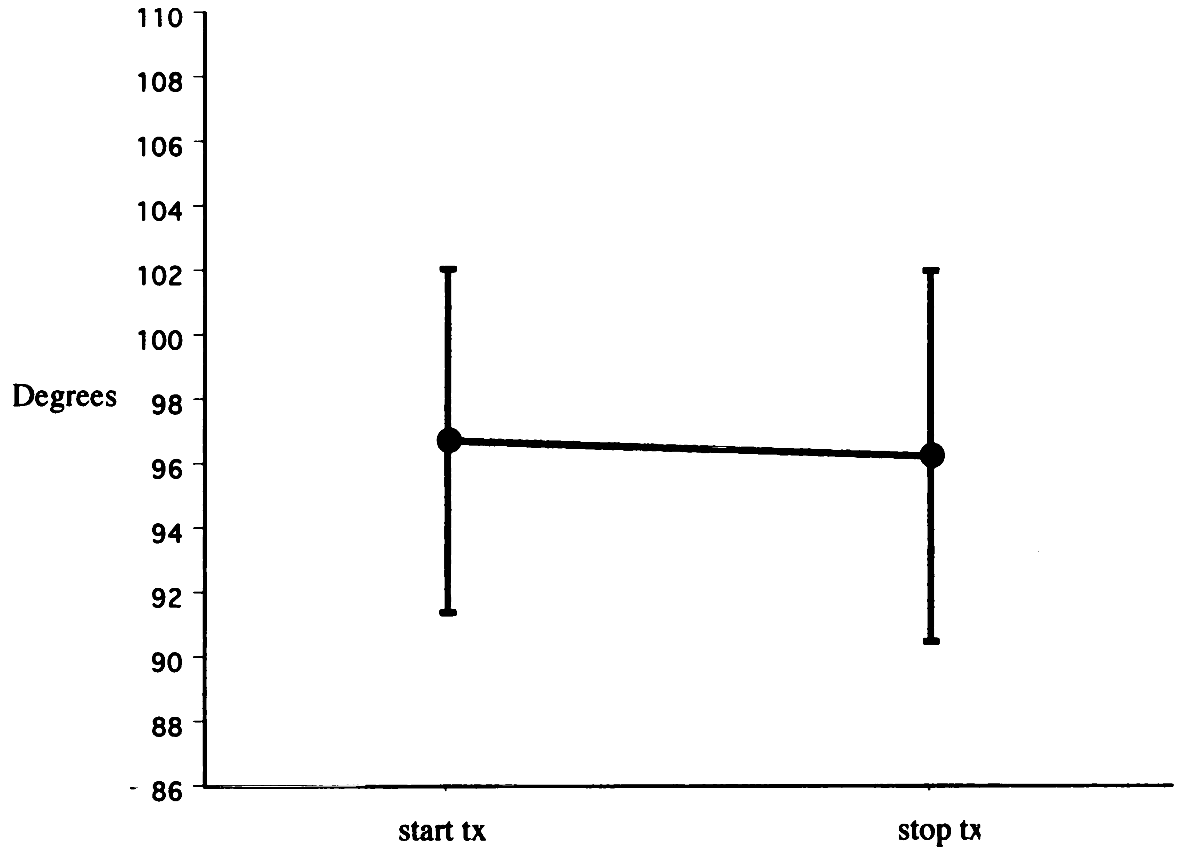


Figure 31. Girls (n=31) Change in Mandibular Incisor Inclination

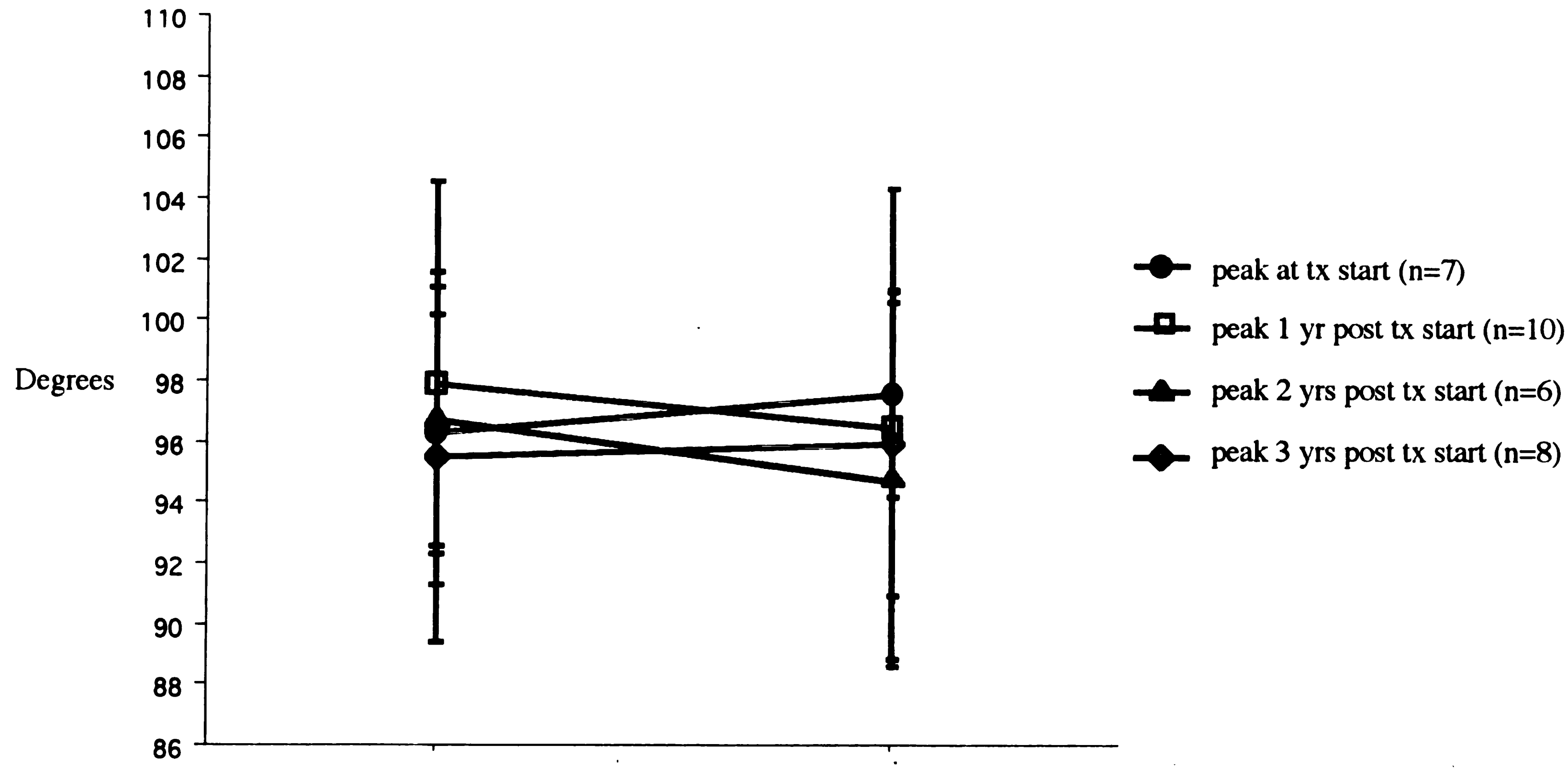


Figure 32. Subgrouped Girls (n=31) Change in Mandibular Incisor Inclination

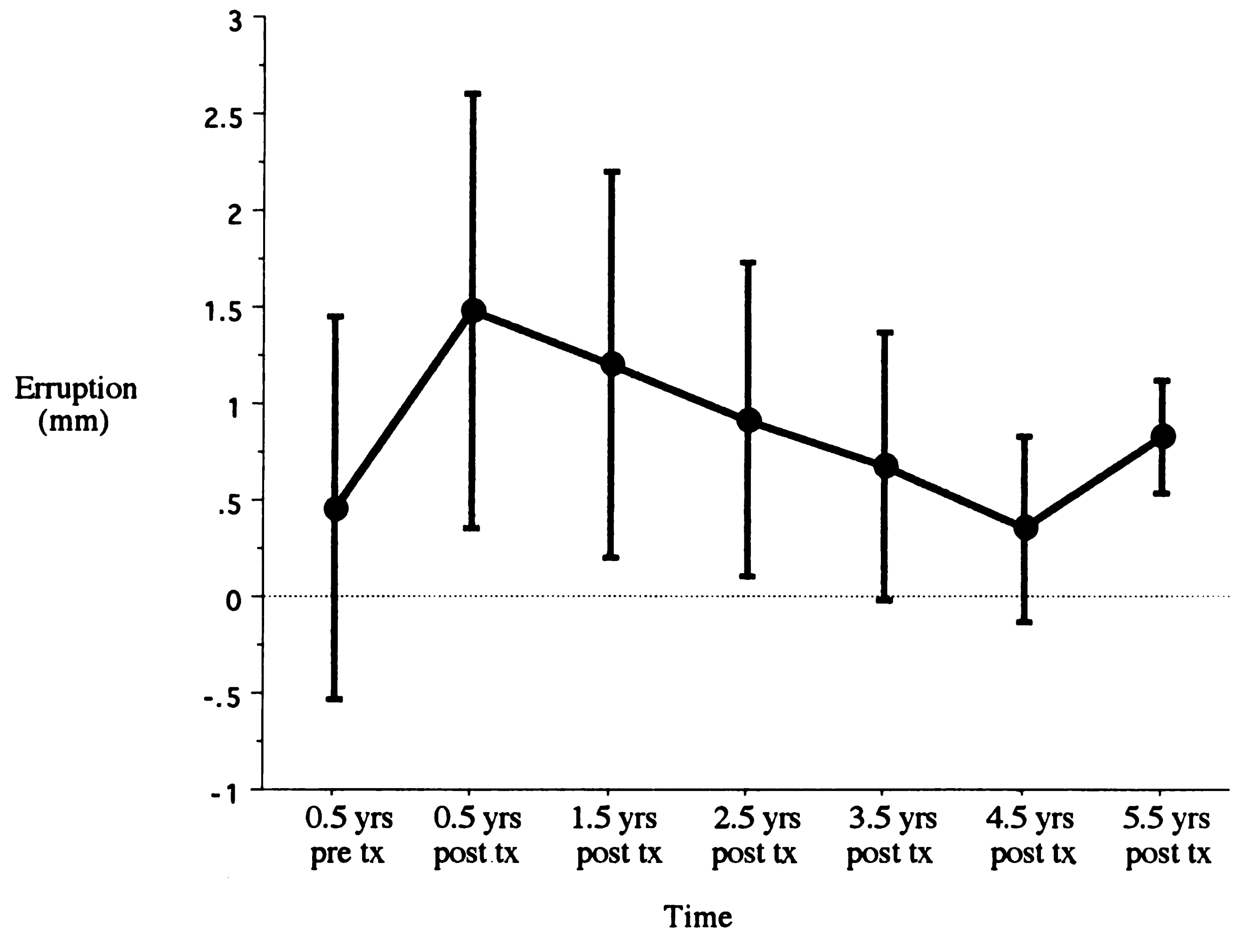


Figure 33. Girls (n=31) Eruption Velocity Curve for Mandibular Molars Relative to the Time of Treatment Start

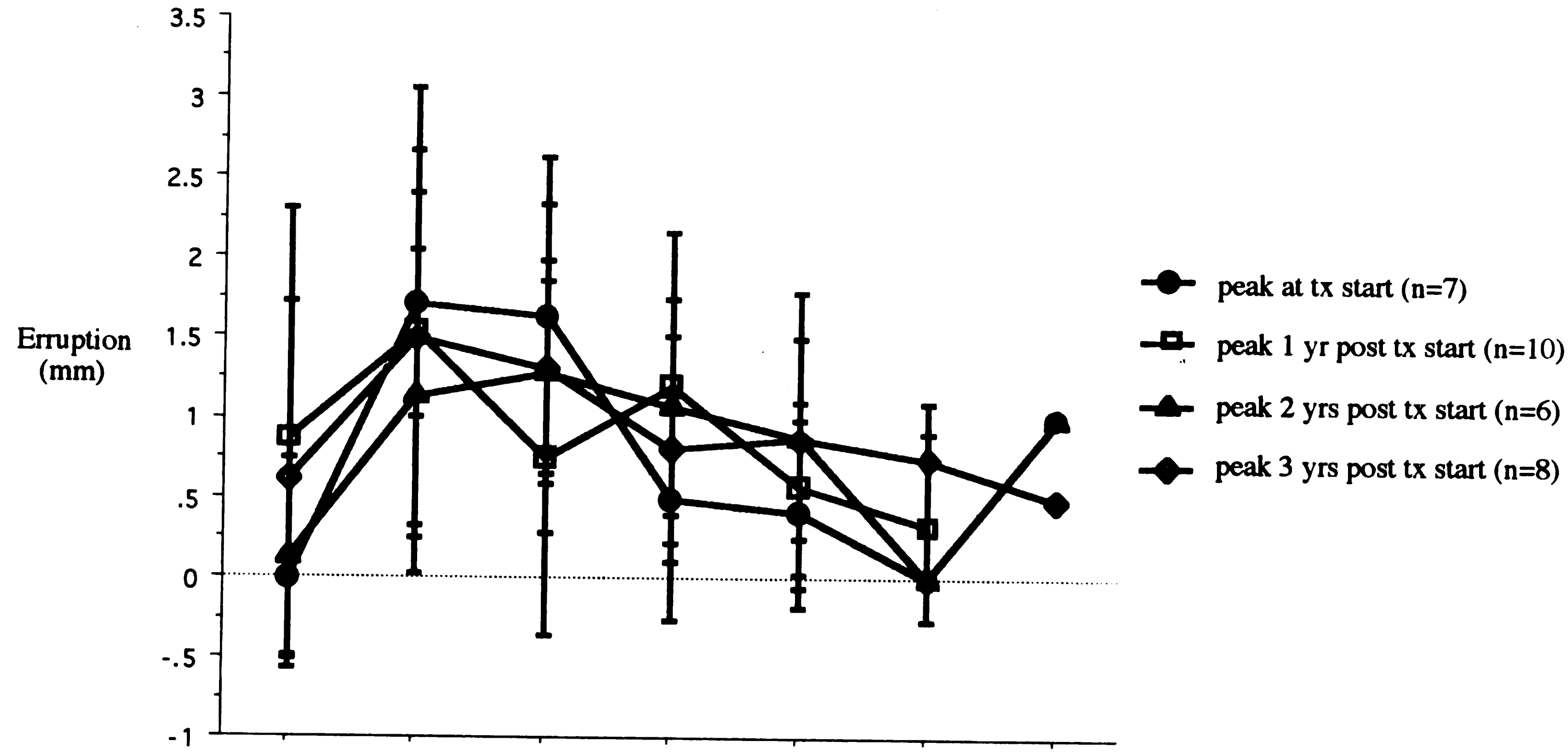


Figure 34. Subgrouped Girls (n=31) Eruption Velocity Curve for Mandibular Molars Relative to the Time of Treatment Start

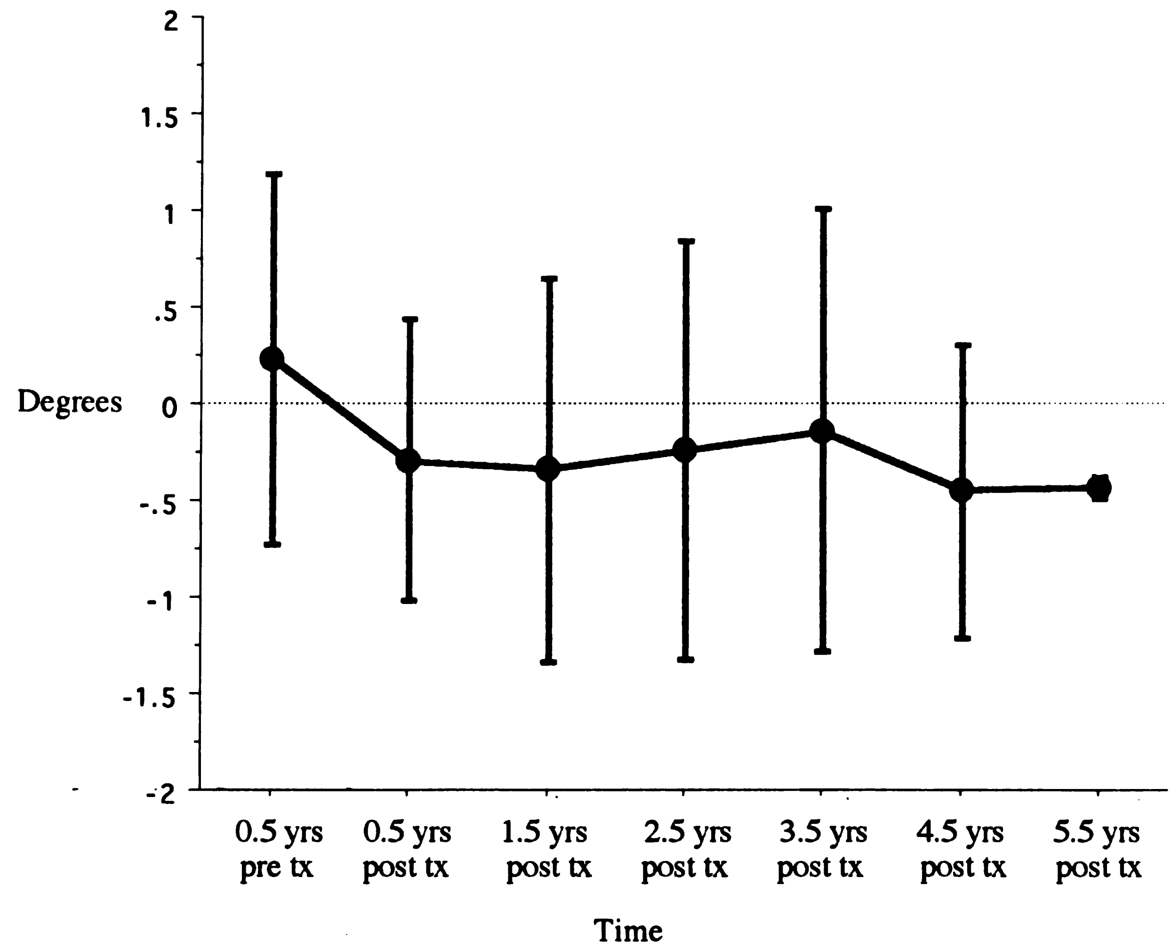


Figure 35. Girls (n=31) SNA Growth Velocity Curve Relative to the Time of Treatment Start

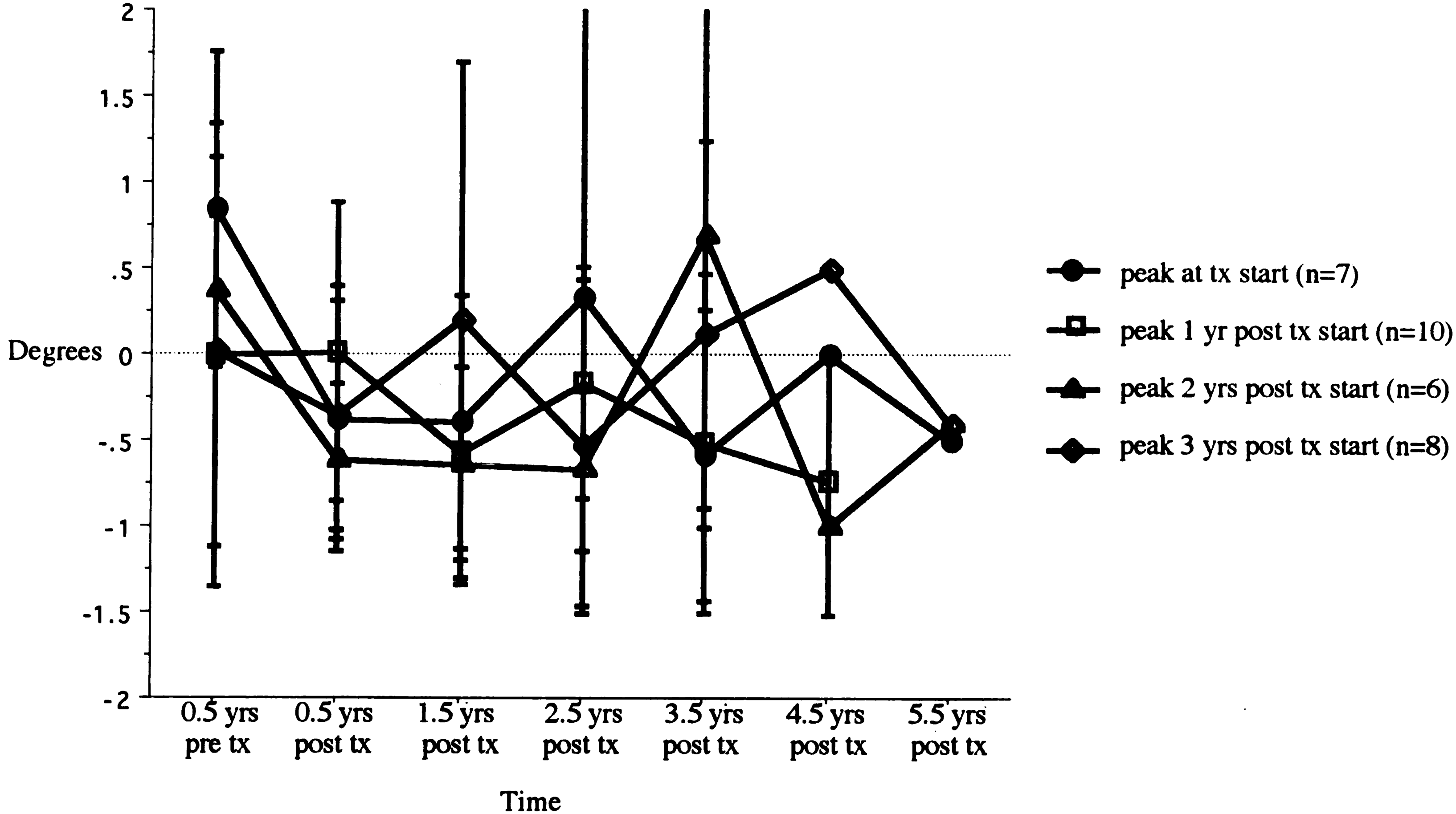


Figure 36. Subgrouped Girls (n=31) SNA Growth Velocity Curve Relative to the Time of Treatment Start

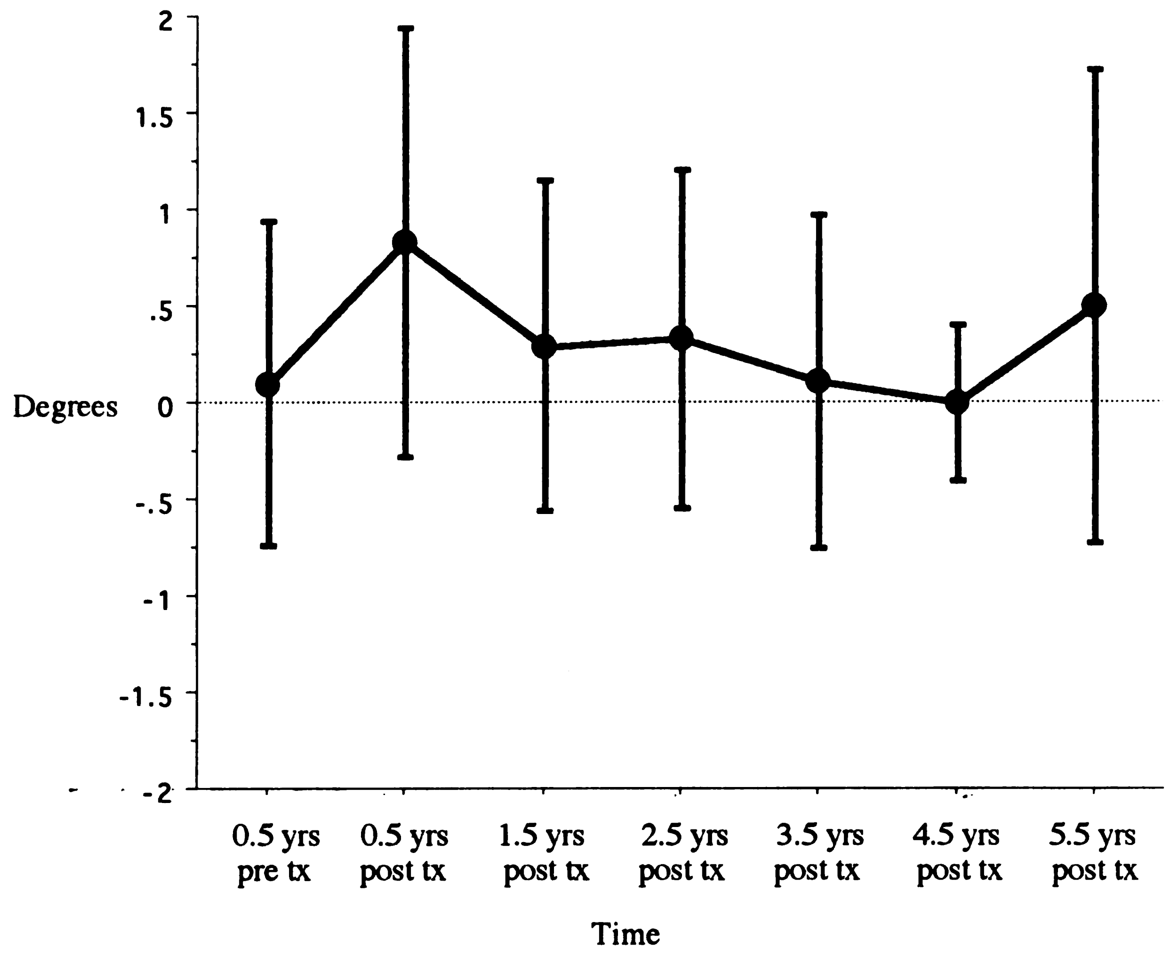


Figure 37. Girls (n=31) SNPg Growth Velocity Curve Relative to the Time of Treatment Start

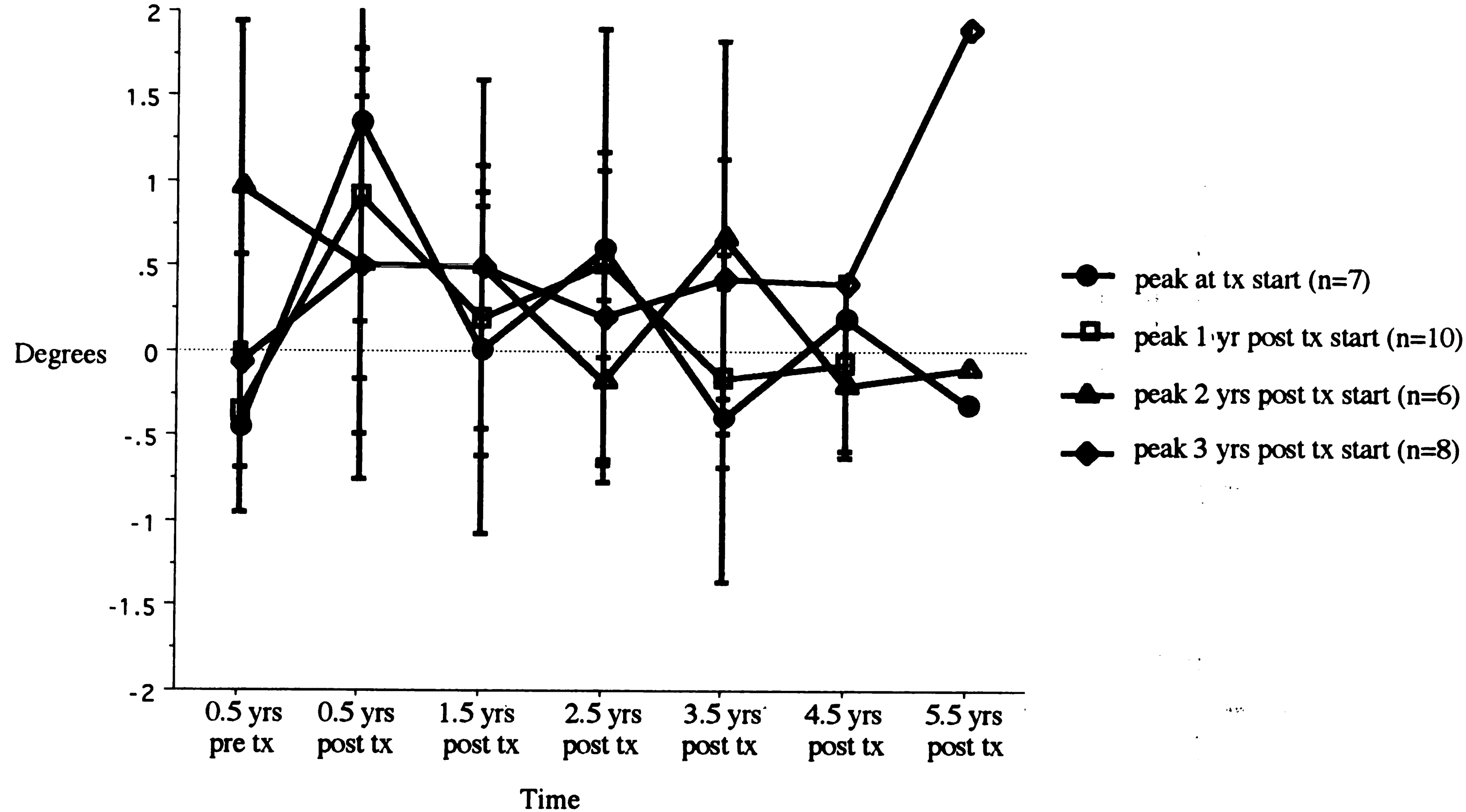


Figure 38. Subgrouped Girls (n=31) SNPg Growth Velocity Curve Relative to the Time of Treatment Start

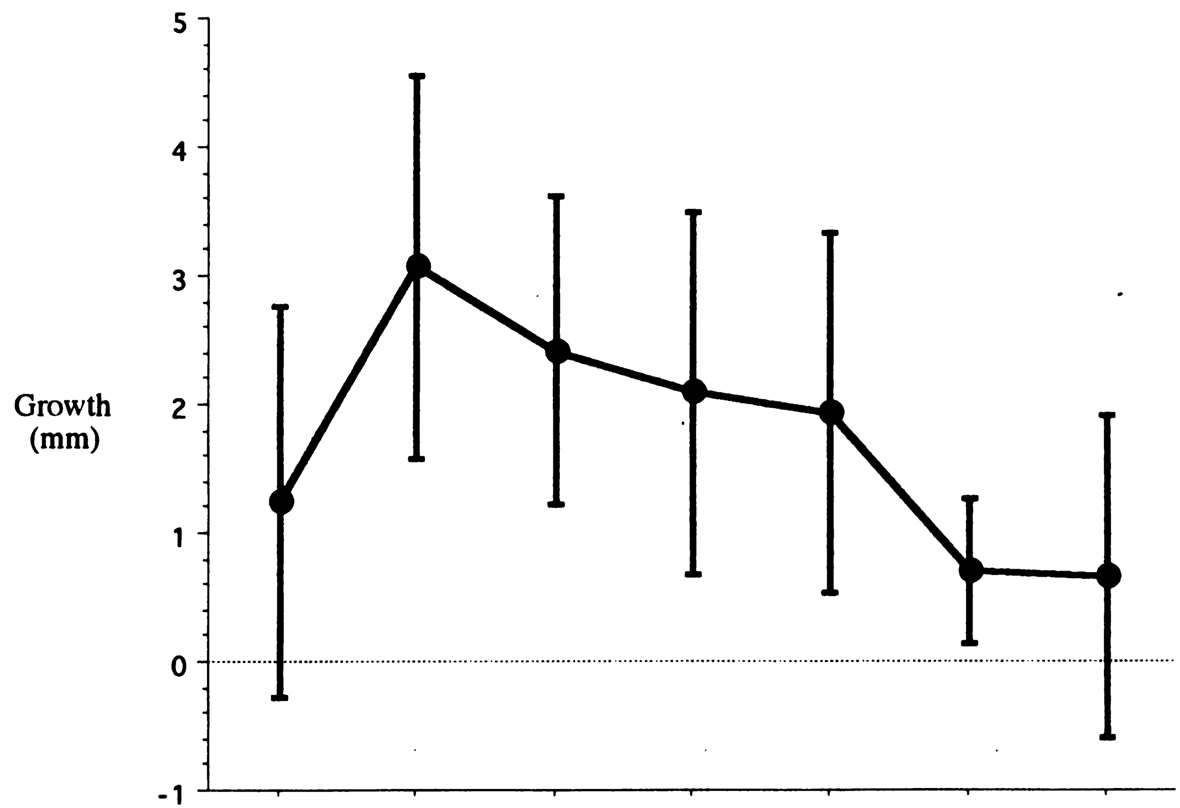


Figure 39. **Girls (n=31) ArPg Growth Velocity Curve Relative to the Time of Treatment Start**

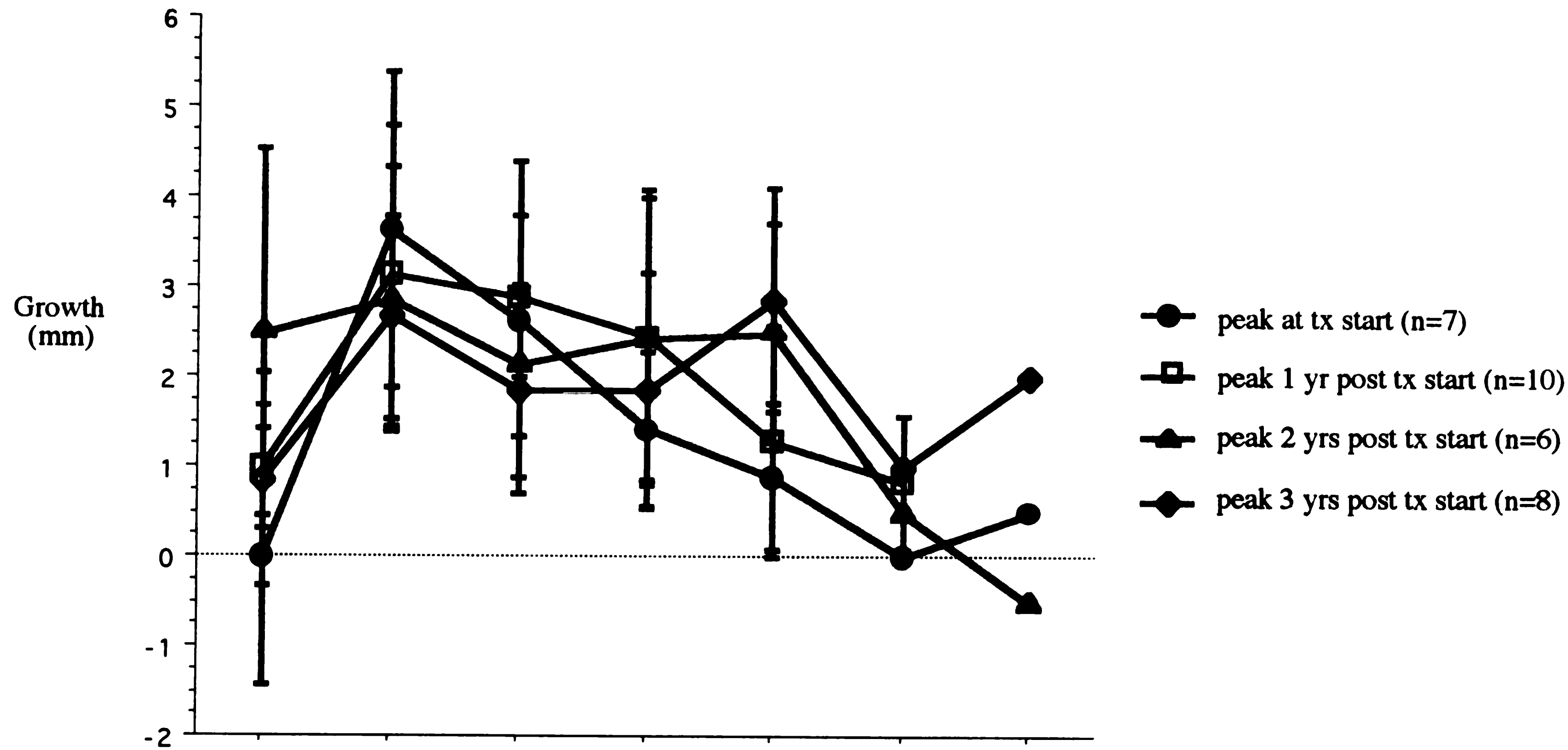


Figure 40. Subgrouped Girls (n=31) ArPg Growth Velocity Curve Relative to the Time of Treatment Start

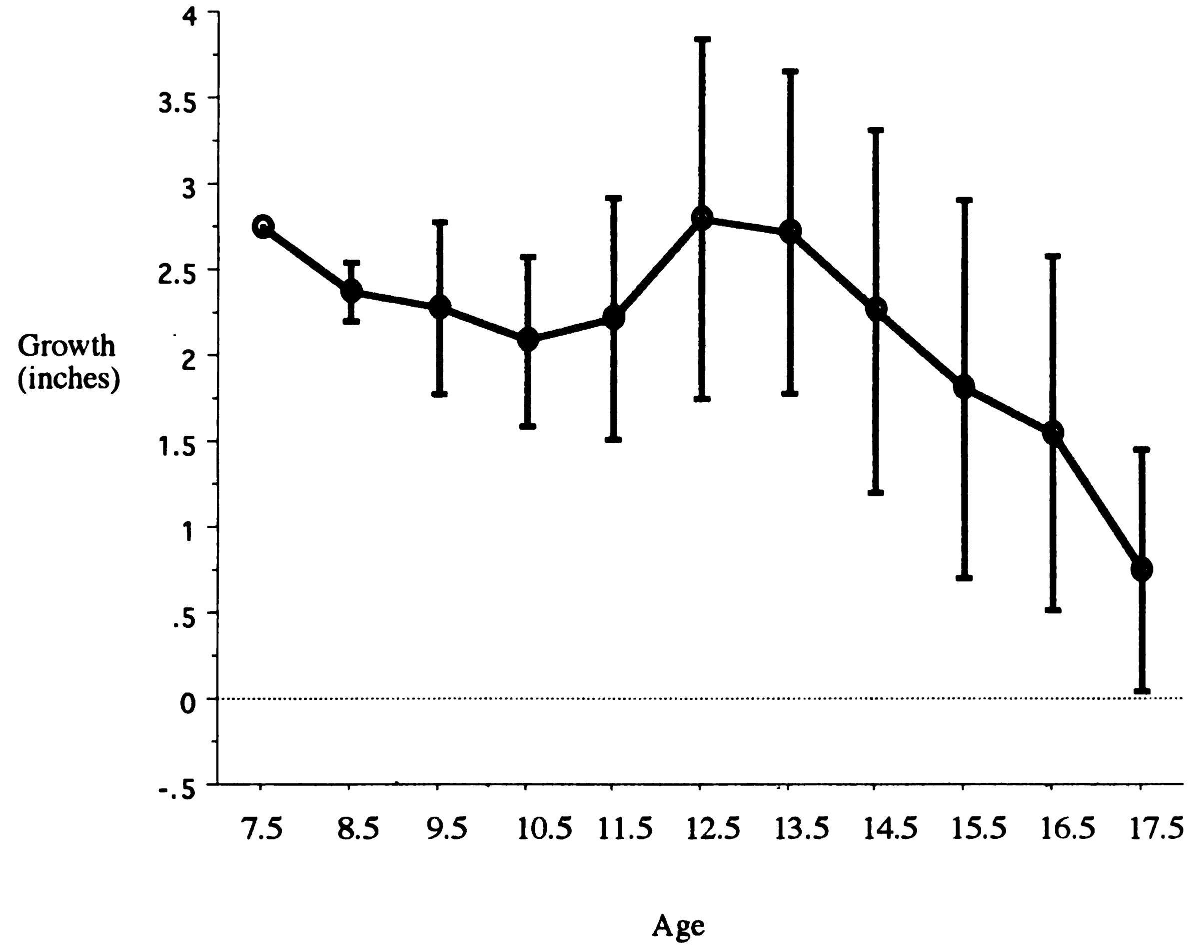


Figure 41. Boys (n=28) Growth Velocity Curve

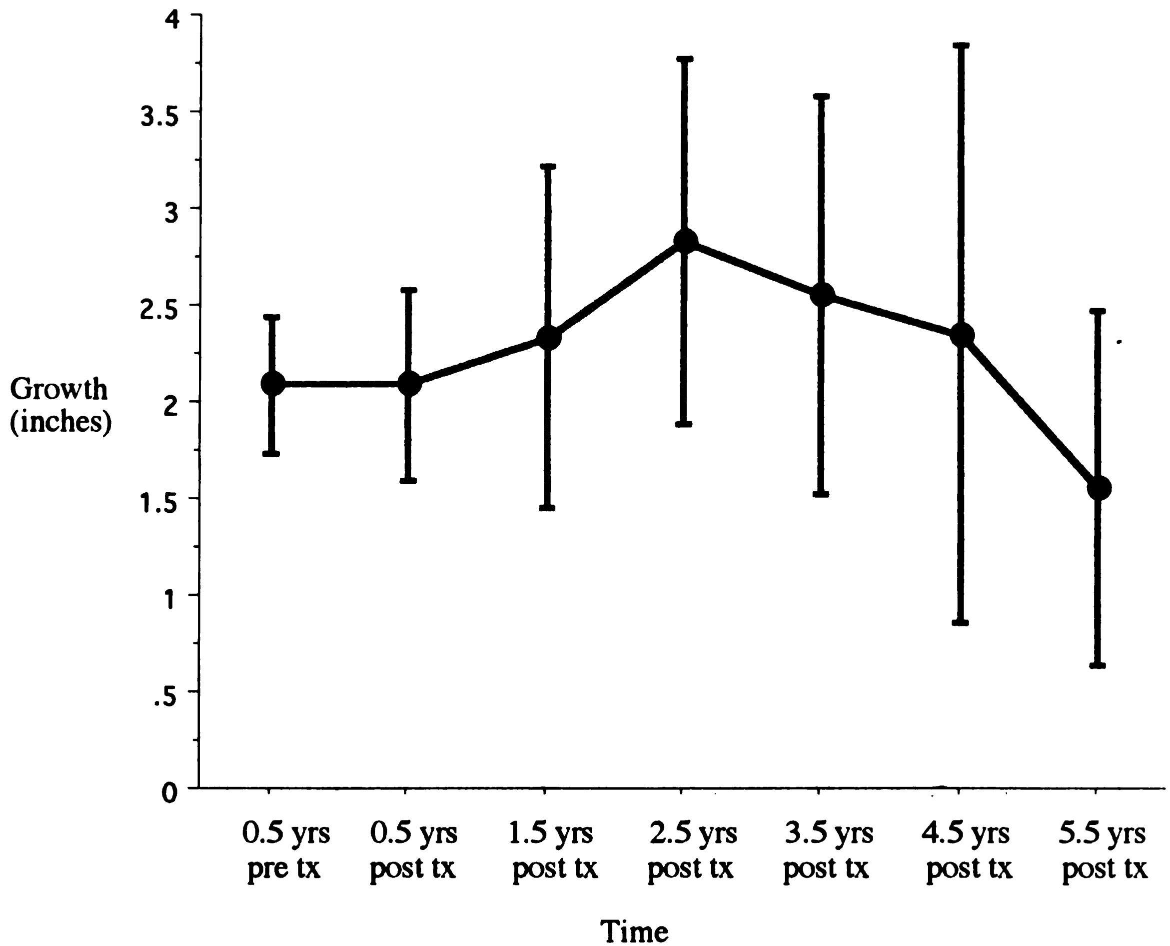


Figure 42. Boys (n=28) Growth Velocity Curve Relative to the Time of Treatment Start

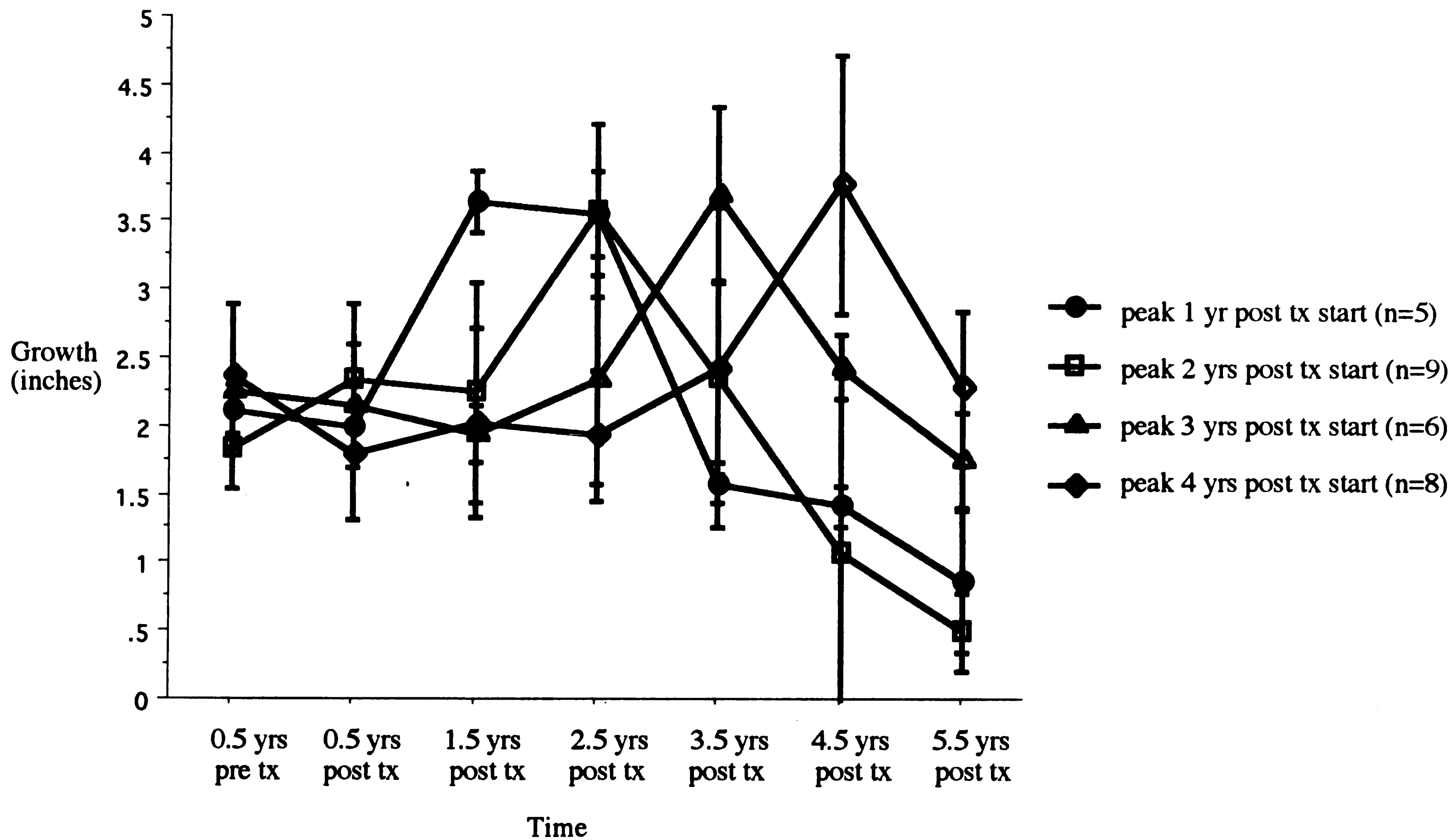


Figure 43. Subgrouped Boys (n=28) Growth Velocity Curve Relative to the Time of Treatment Start

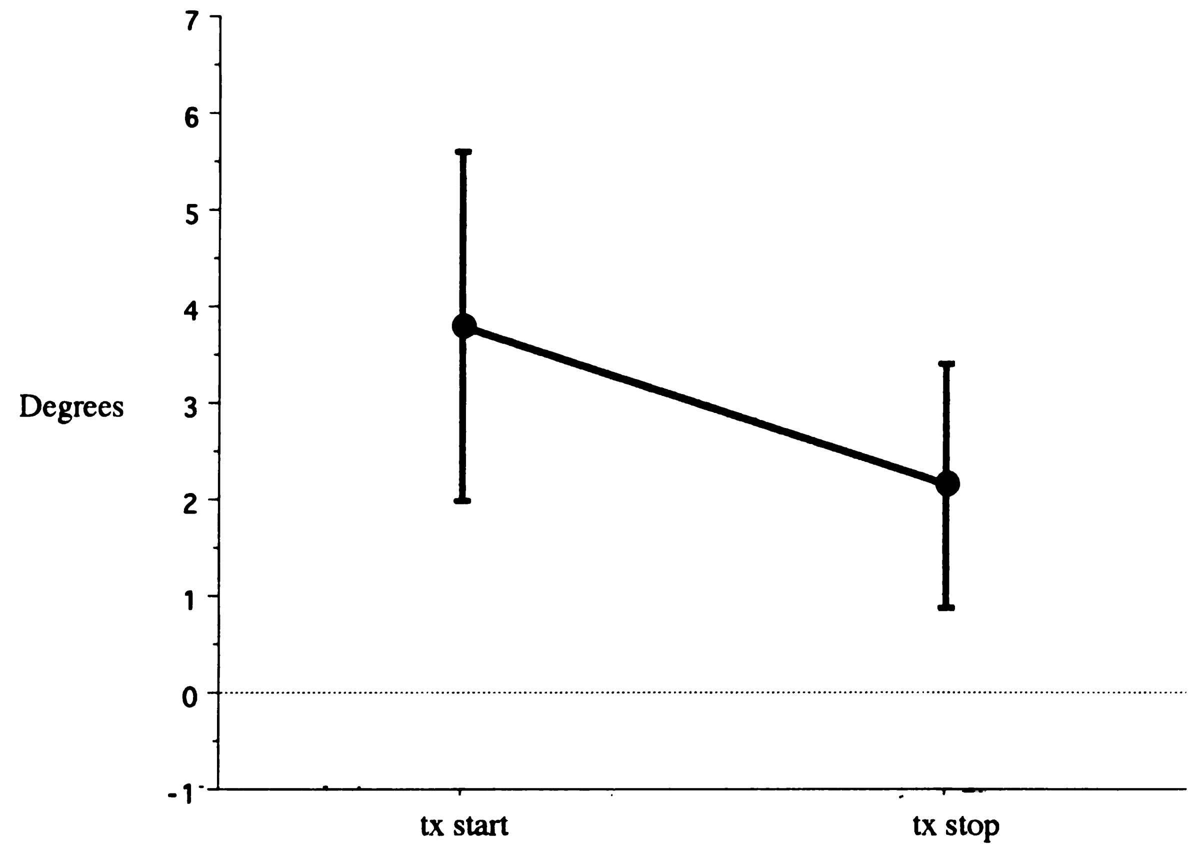


Figure 44. Boys (n=28) Change in Overbite

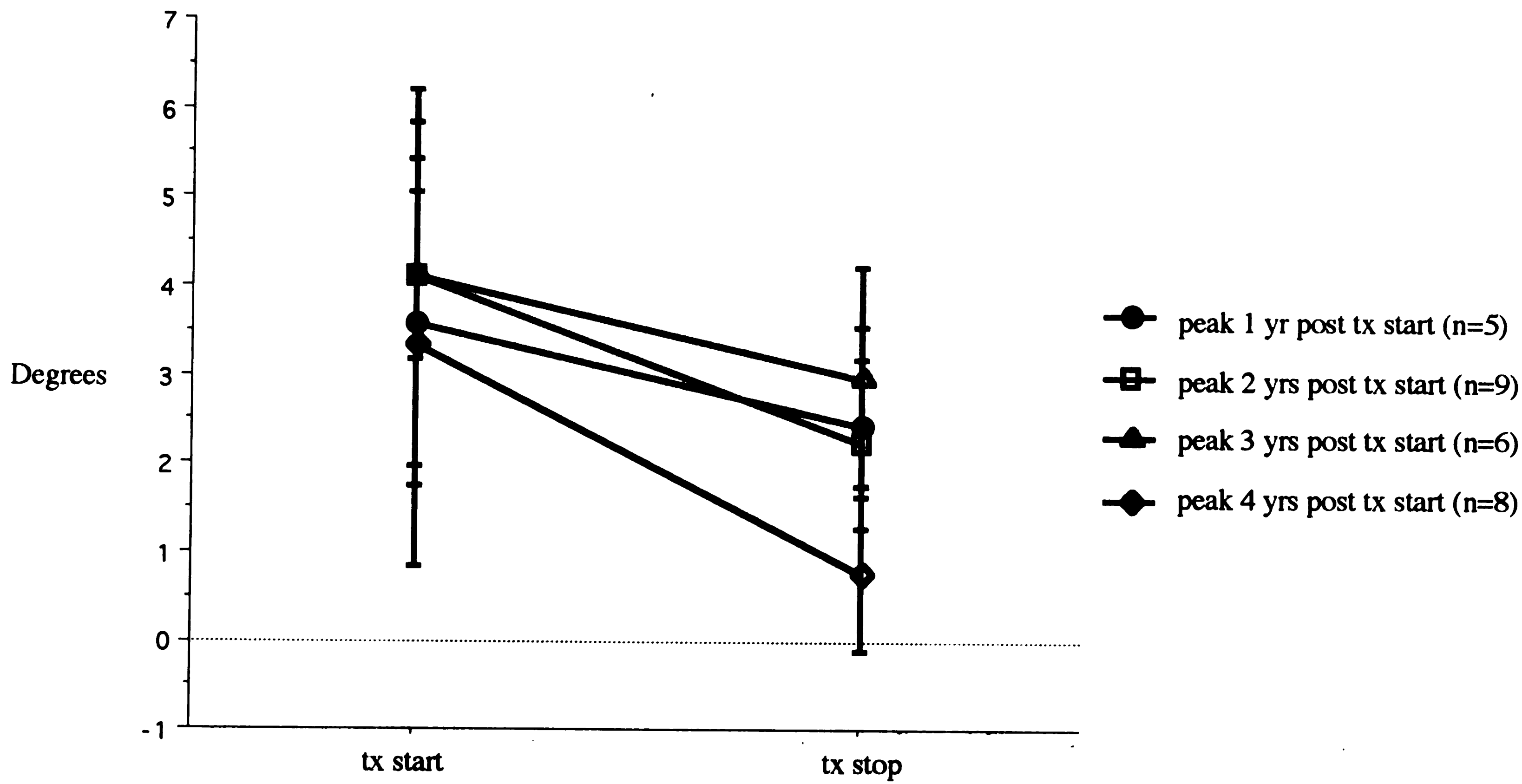


Figure 45. Subgrouped Boys (n=28) Change in Overbite

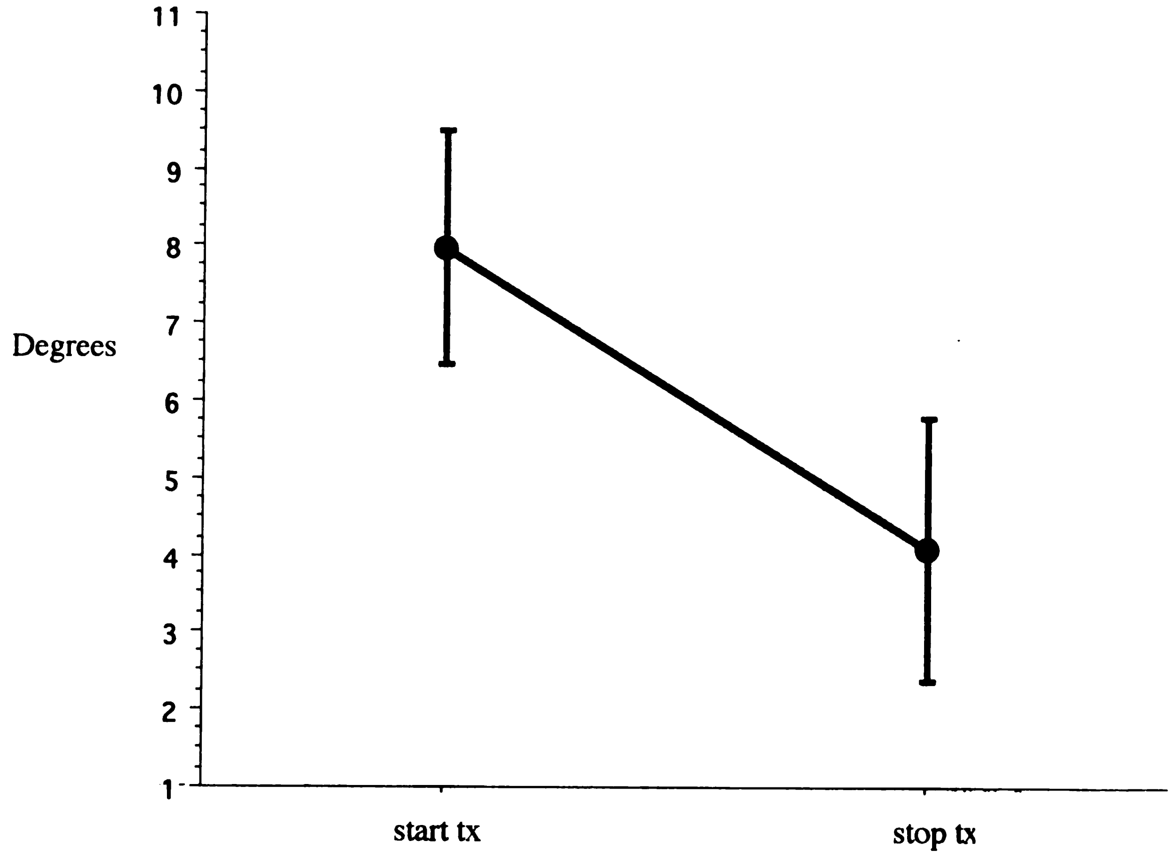


Figure 46. Boys (n=28) Change in Overjet

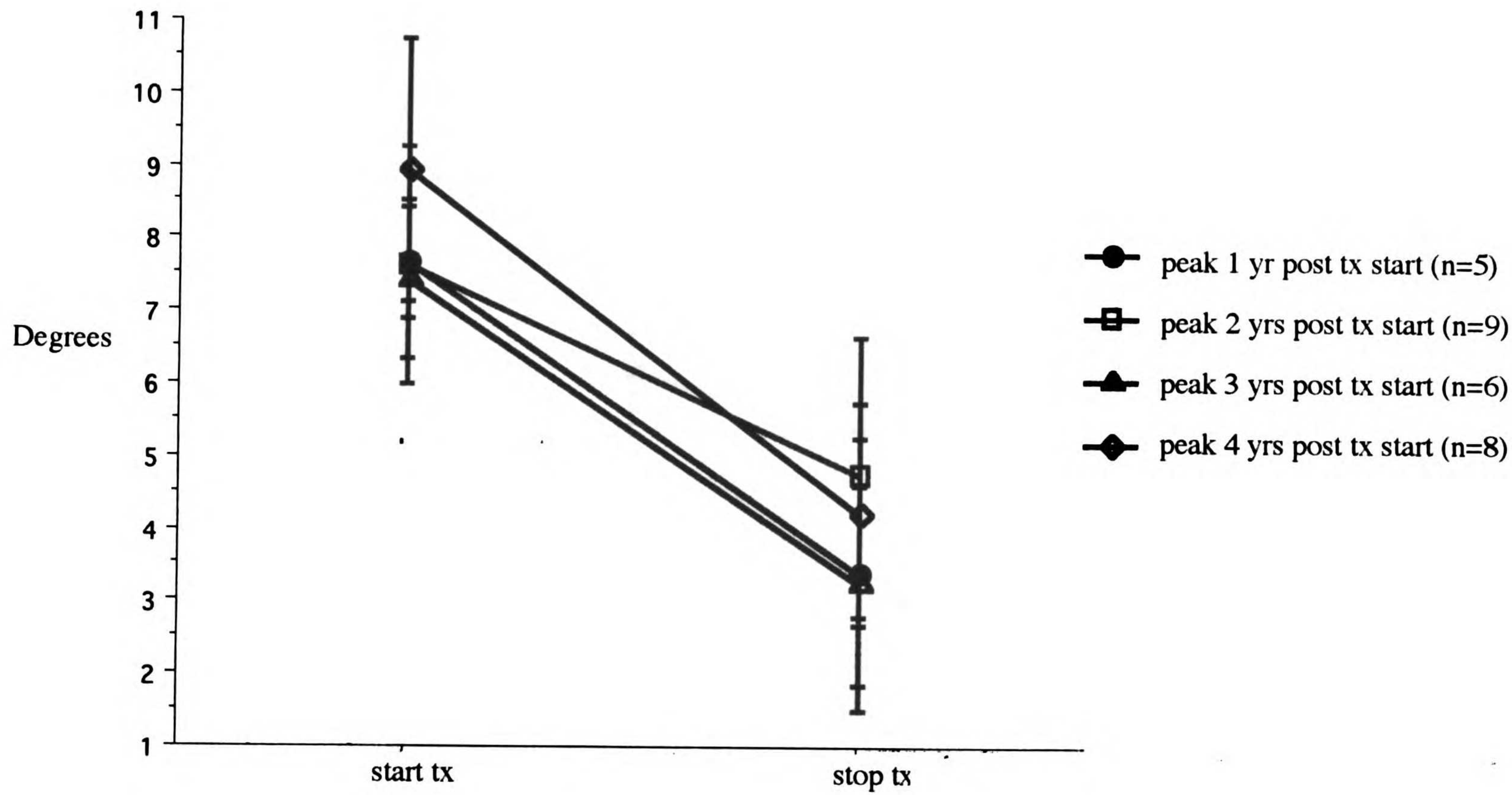


Figure 47. Subgrouped Boys (n=28) Change in Overjet

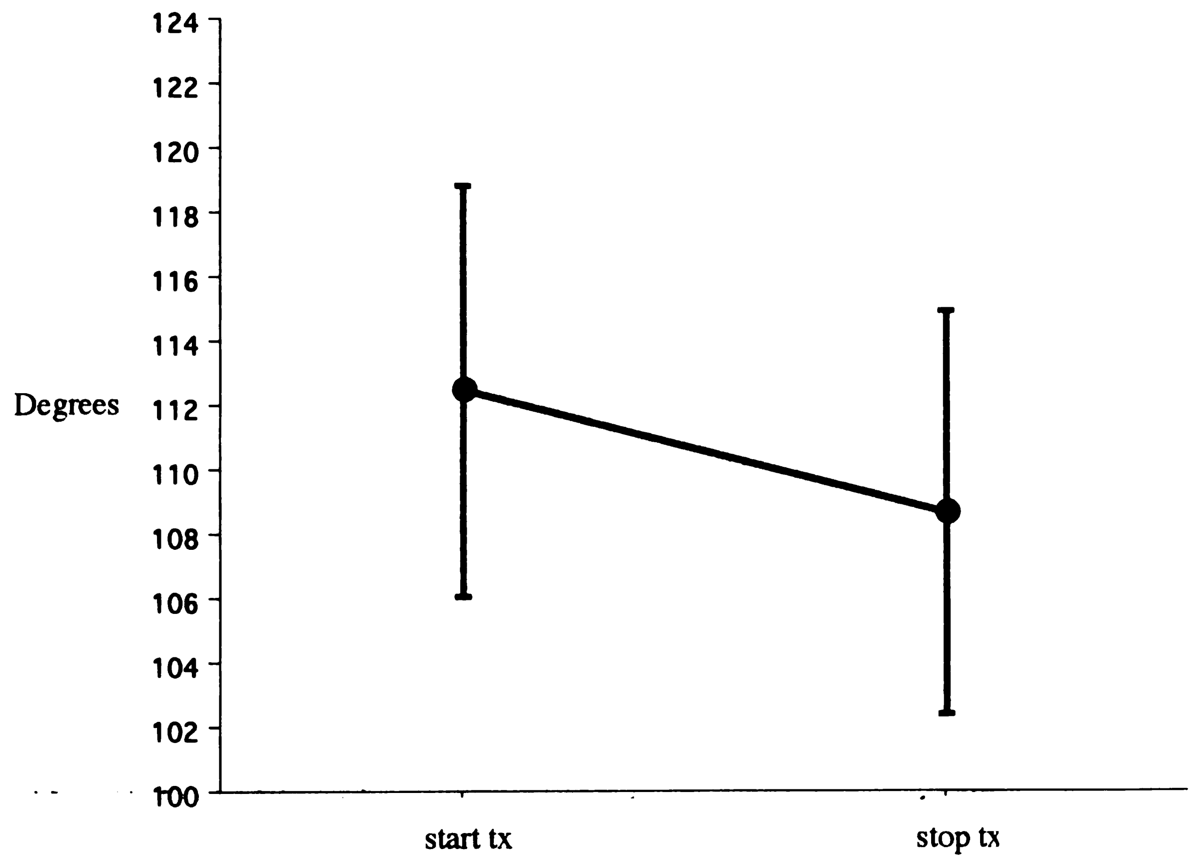


Figure 48. Boys (n=28) Change in Maxillary Incisor Inclination

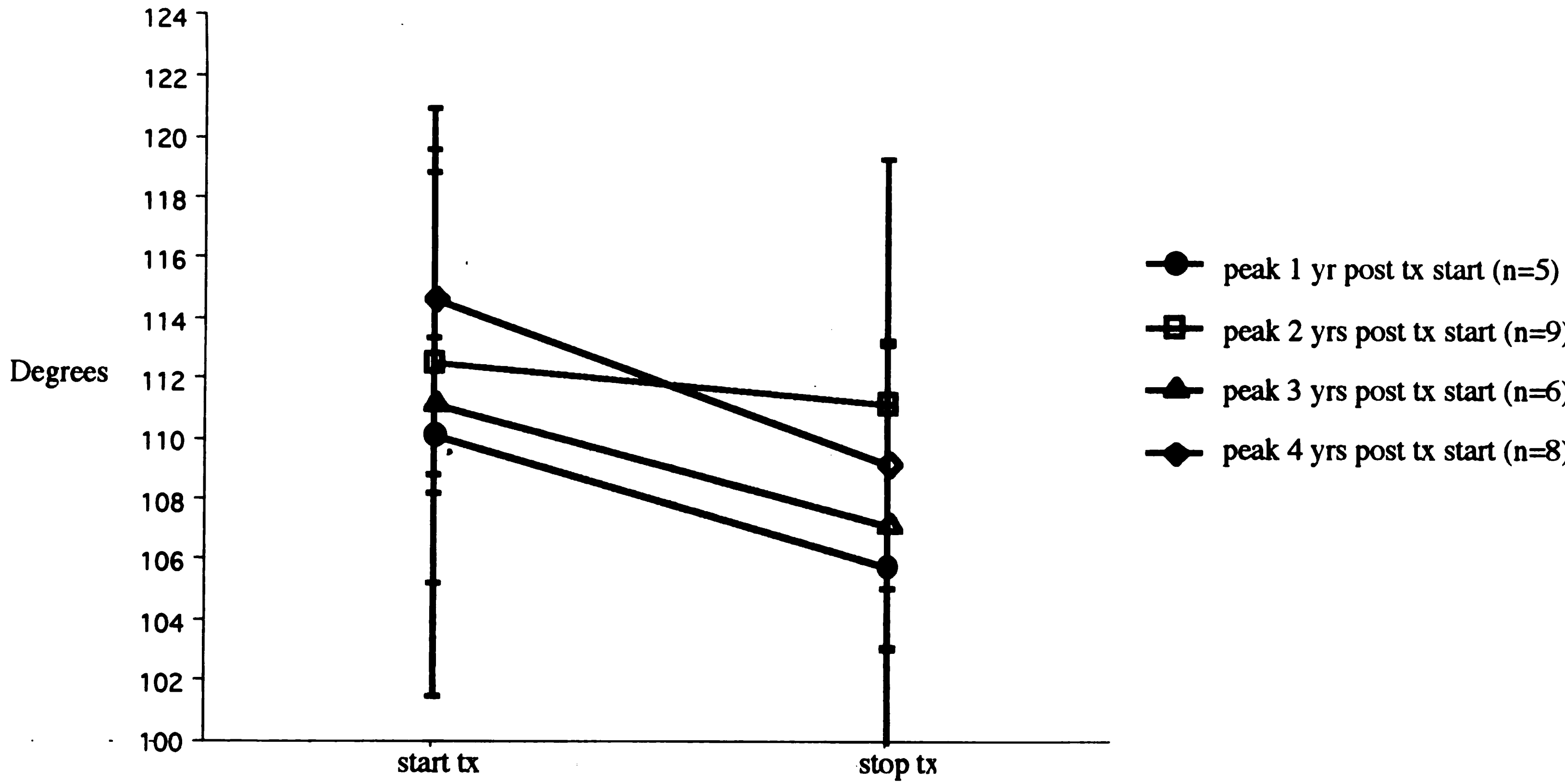


Figure 49. Subgrouped Boys (n=28) Change in Maxillary Incisor Inclination

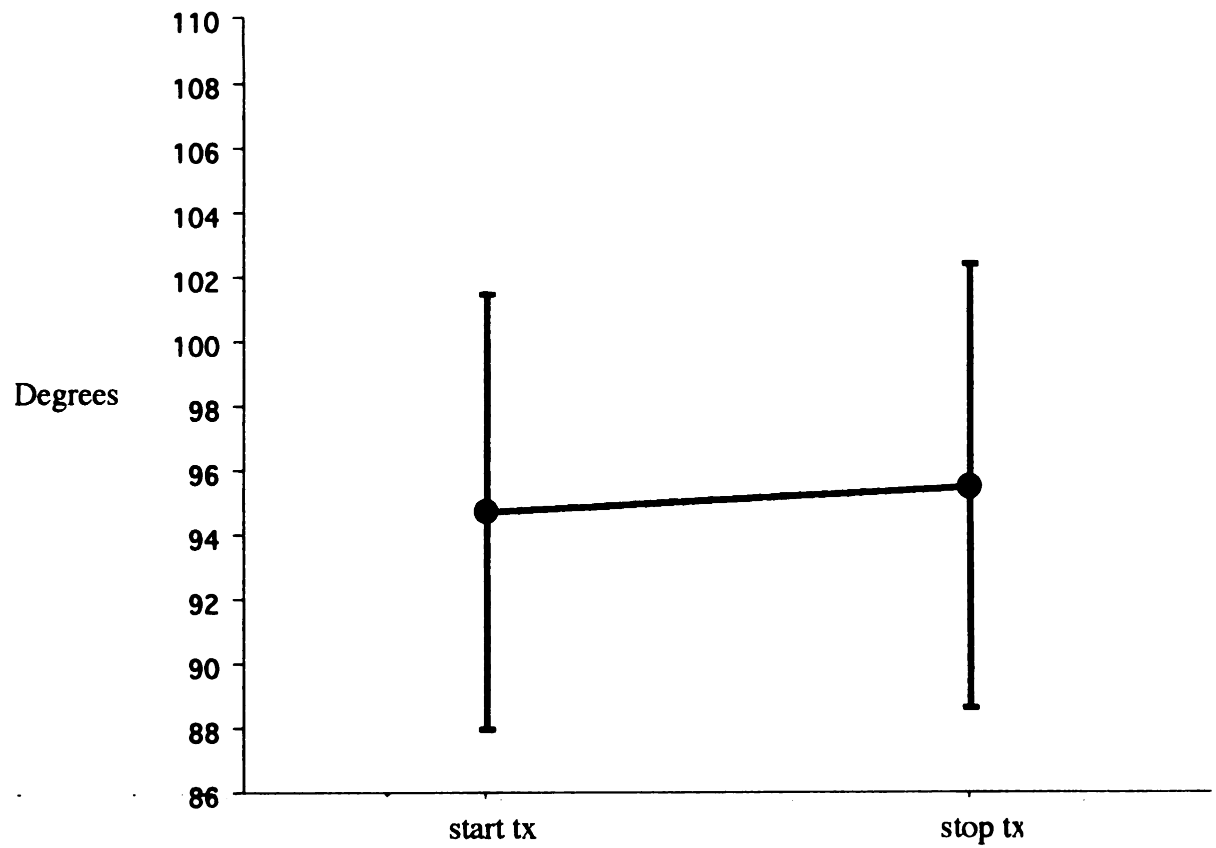


Figure 50. Boys (n=28) Change in Mandibular Incisor Inclination

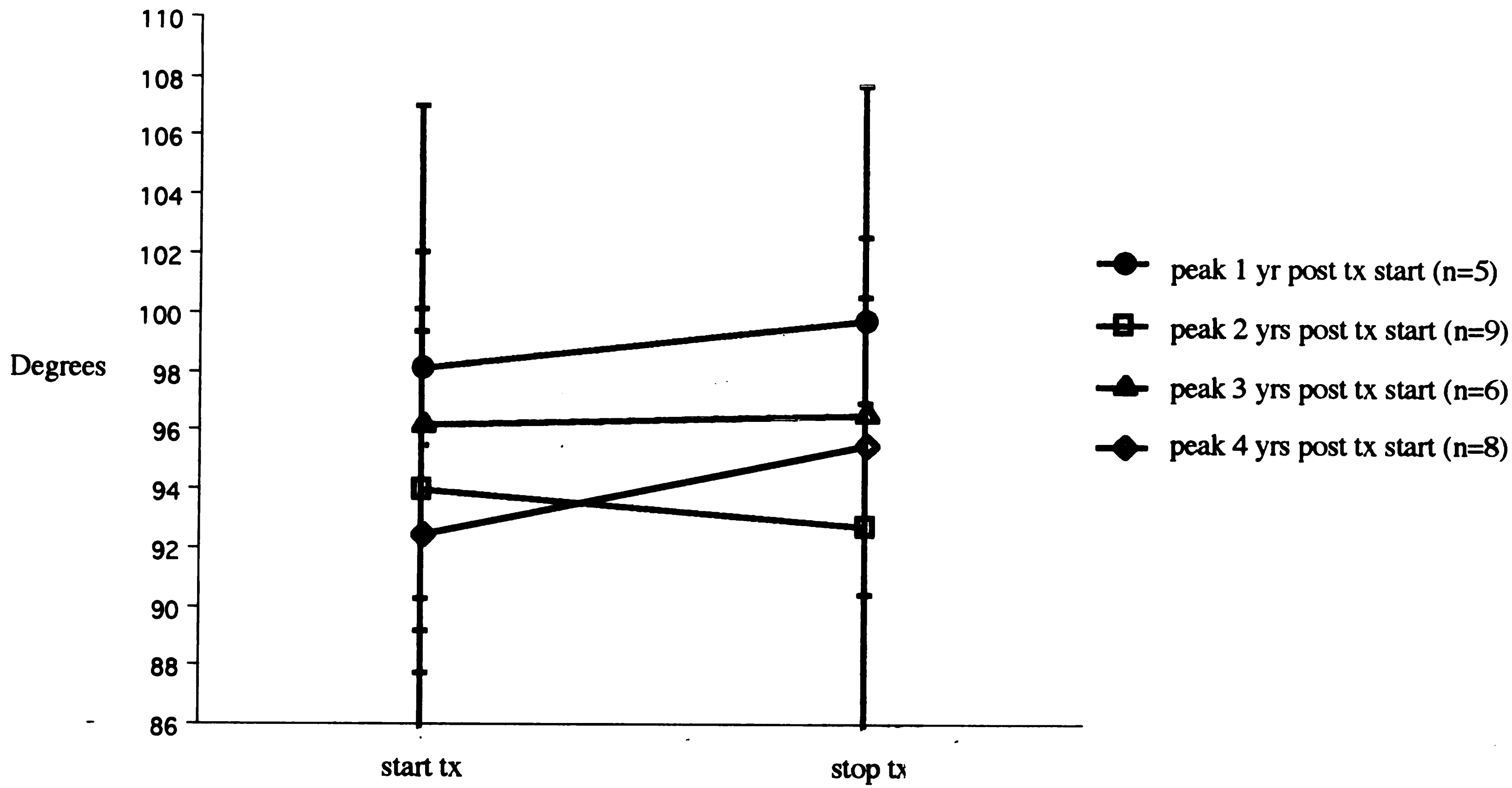


Figure 51. Subgrouped Boys (n=28) Change in Mandibular Incisor Inclination

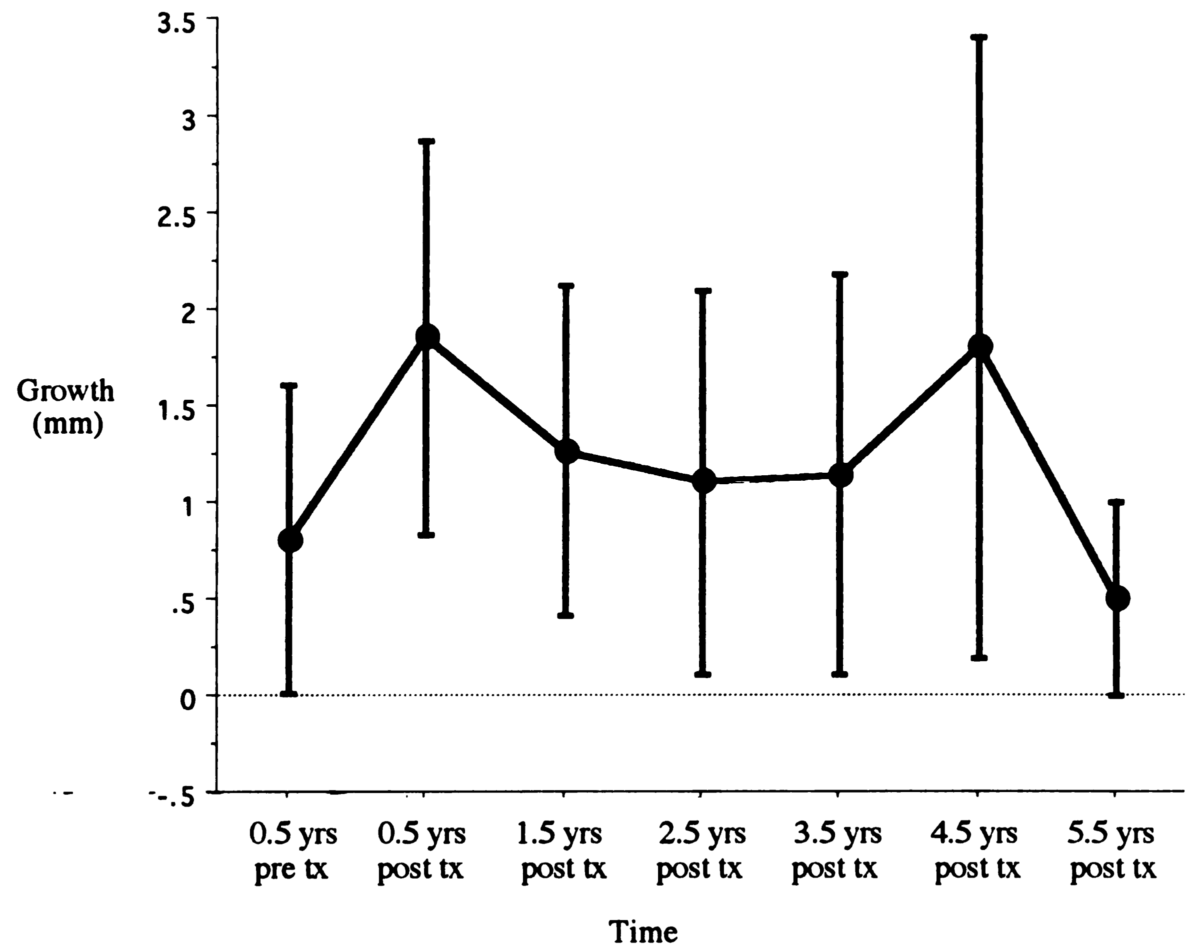


Figure 52. Boys (n=28) Eruption Velocity Curve for Mandibular Molars Relative to the Time of Treatment Start

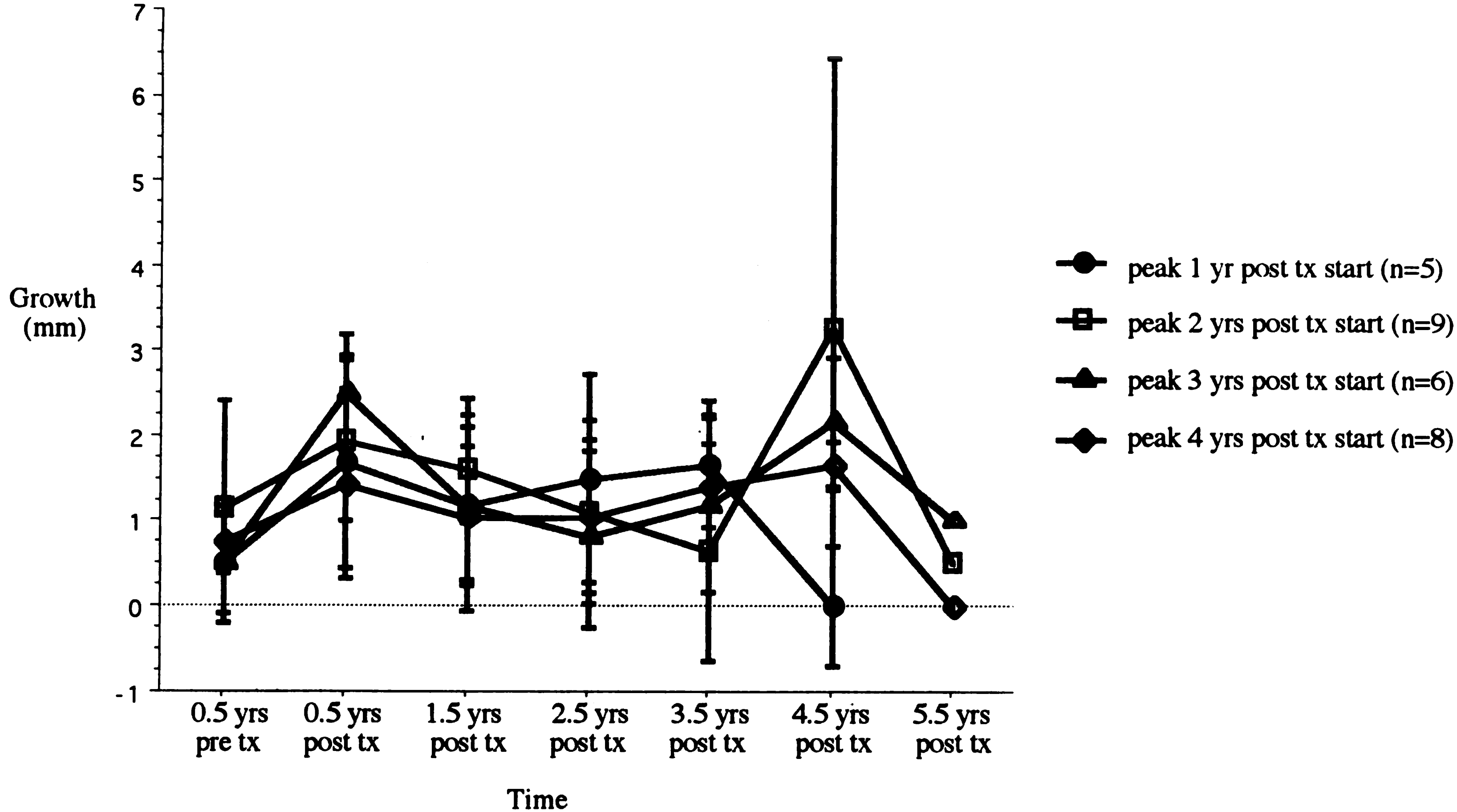


Figure 53. Subgrouped Boys (n=28) Eruption Velocity Curve for Mandibular Molars Relative to the Time of Treatment Start

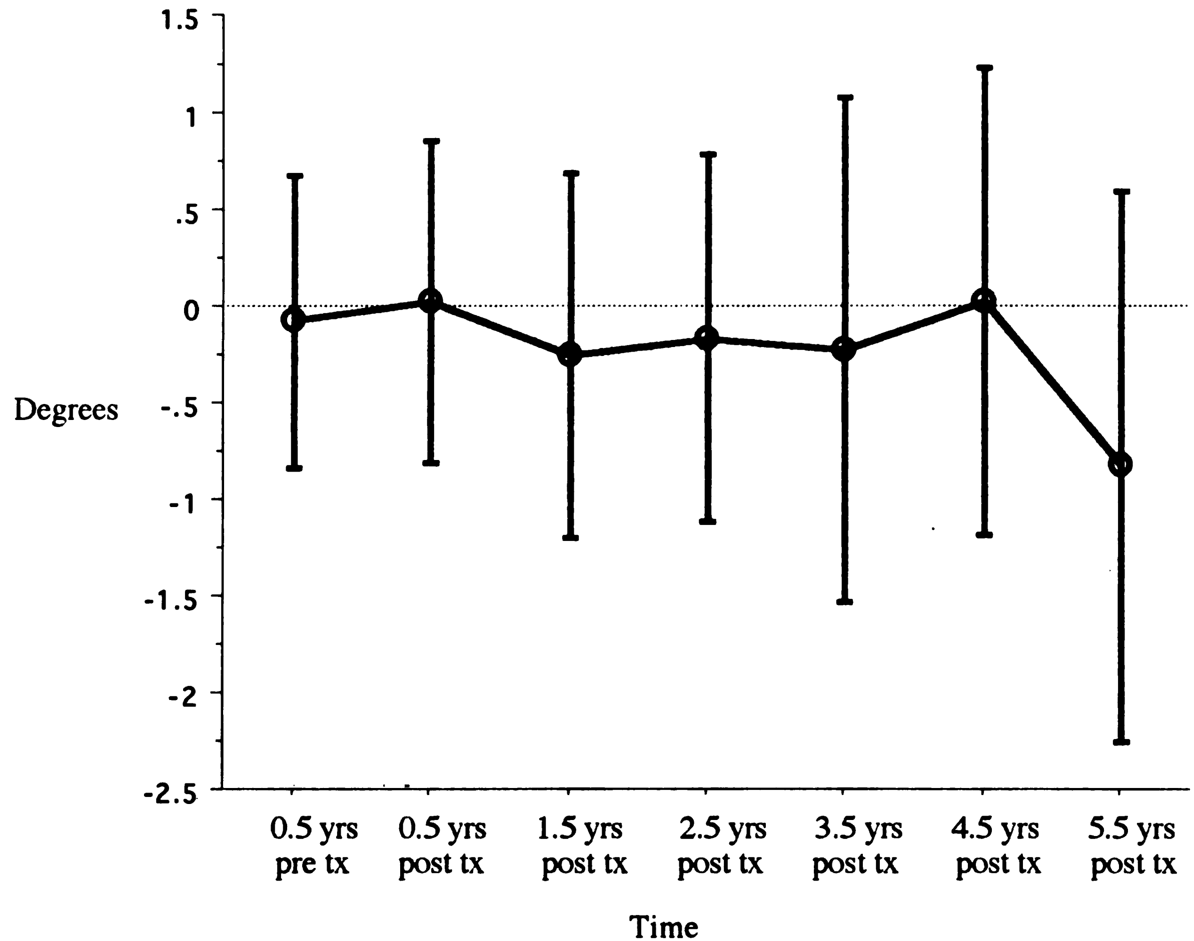


Figure 54. Boys (n=28) SNA Velocity Curve Relative to the Time of Treatment Start

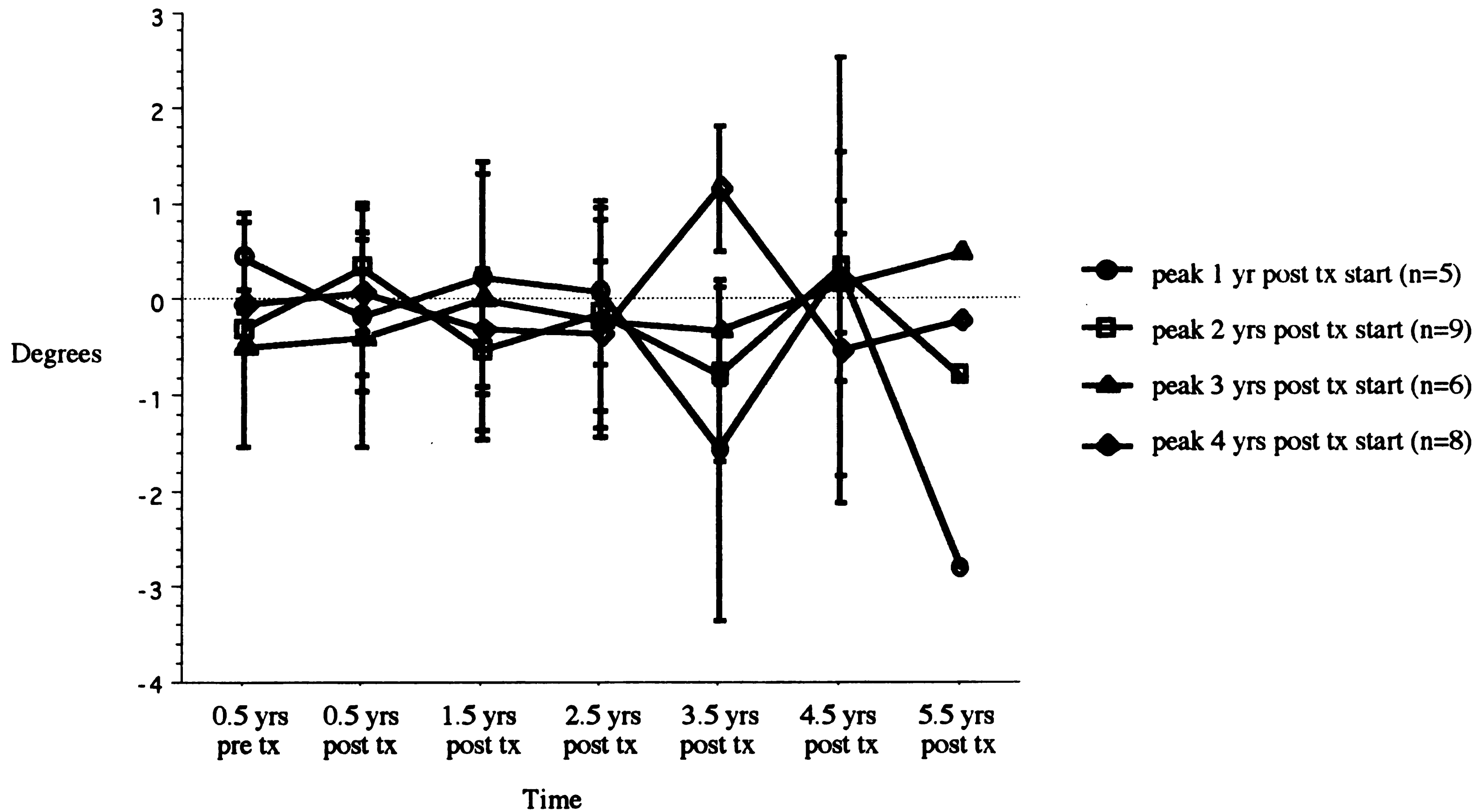


Figure 55. Subgrouped Boys (n=28) SNA Velocity Curve Relative to the Time of Treatment Start

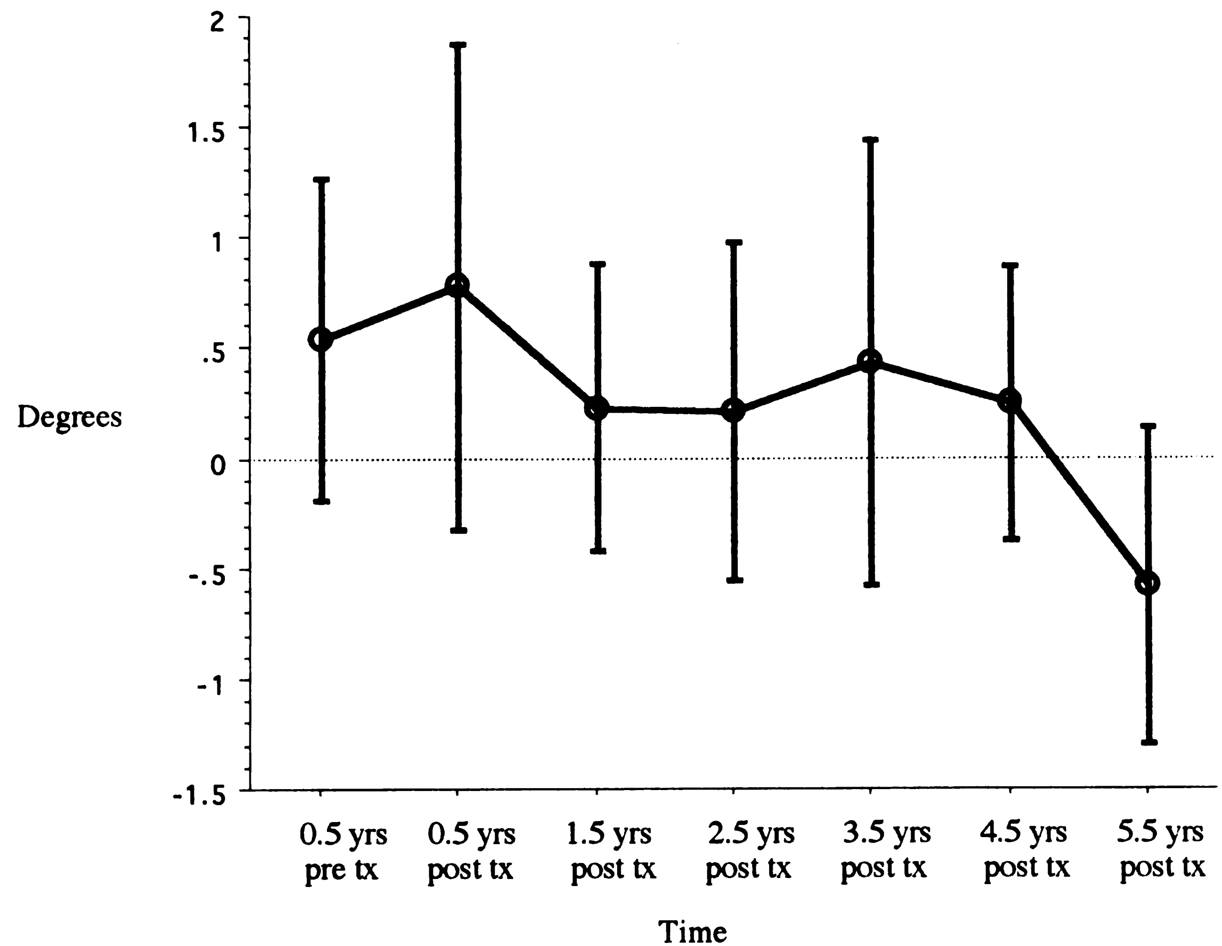


Figure 56. Boys (n=28) SNPg Velocity Curve Relative to the Time of Treatment Start

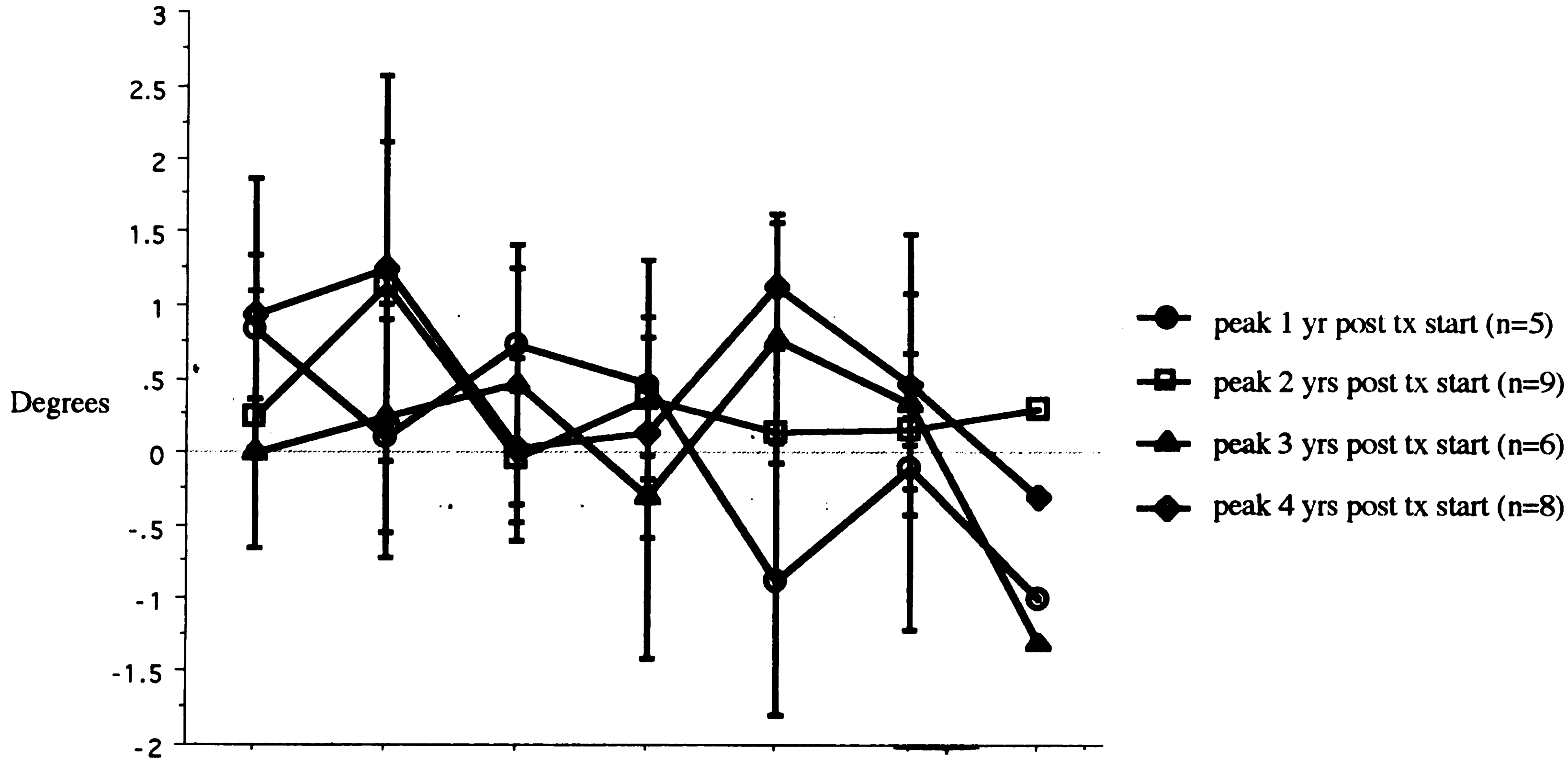


Figure 57. Subgrouped Boys (n=28) SNPg Velocity Curve Relative to the Time of Treatment Start

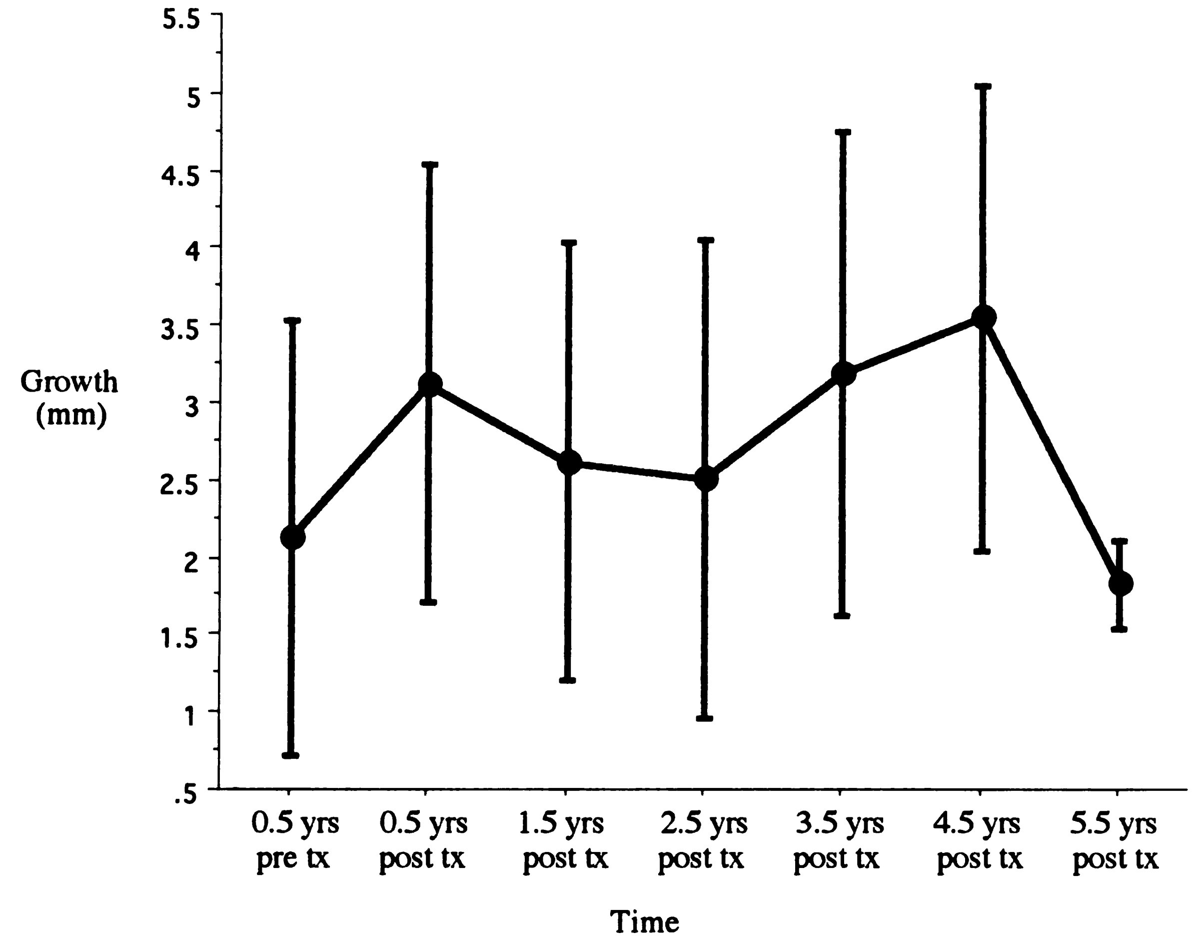


Figure 58. Boys (n=28) ArPg Velocity Curve Relative to the Time of Treatment Start

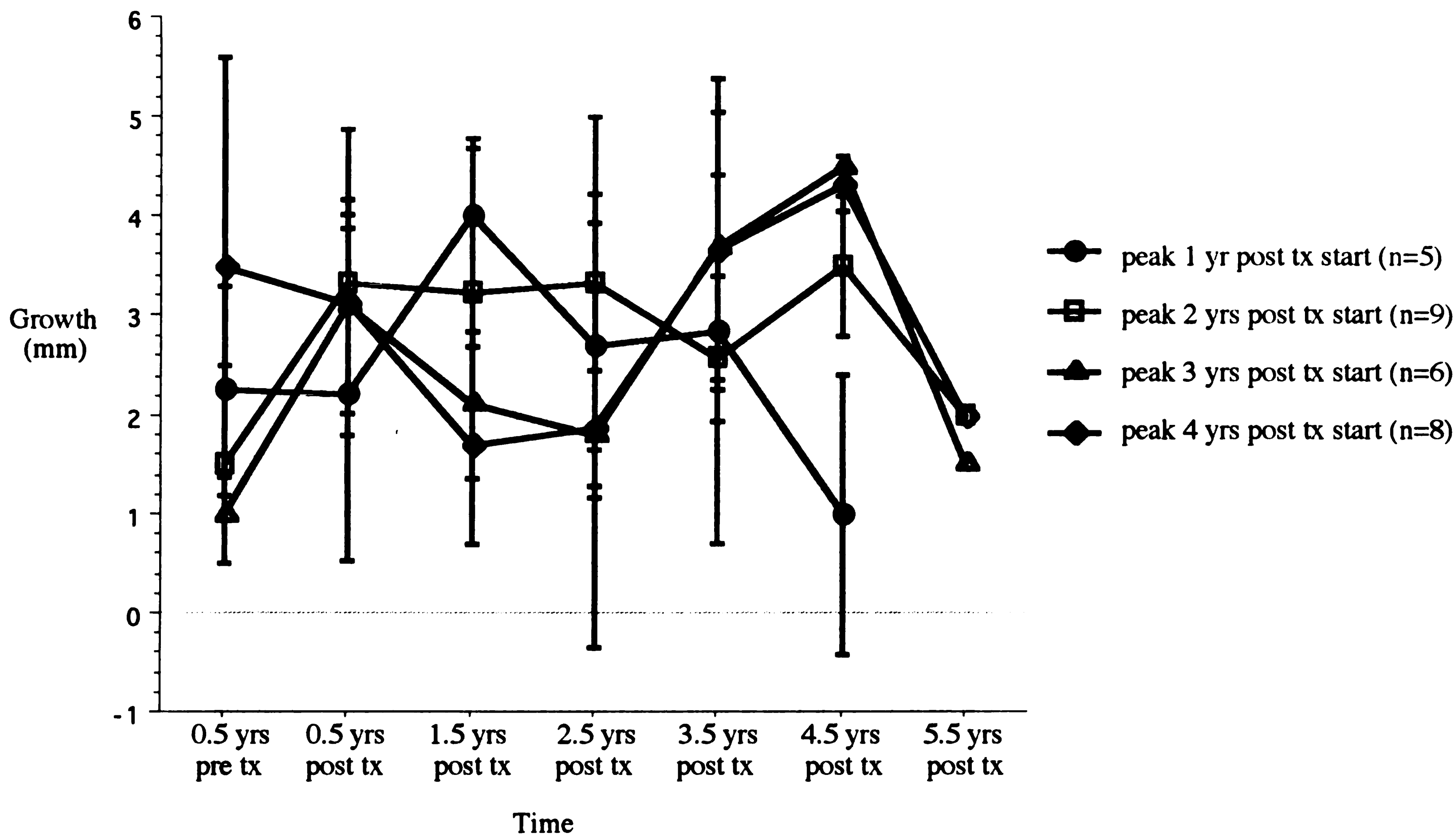


Figure 59. Subgrouped Boys (n=28) ArPg Velocity Curve Relative to the Time of Treatment Start

Figure 60. Individual Changes in Maxillary Prognathism (SNA) in Girls (n=31)

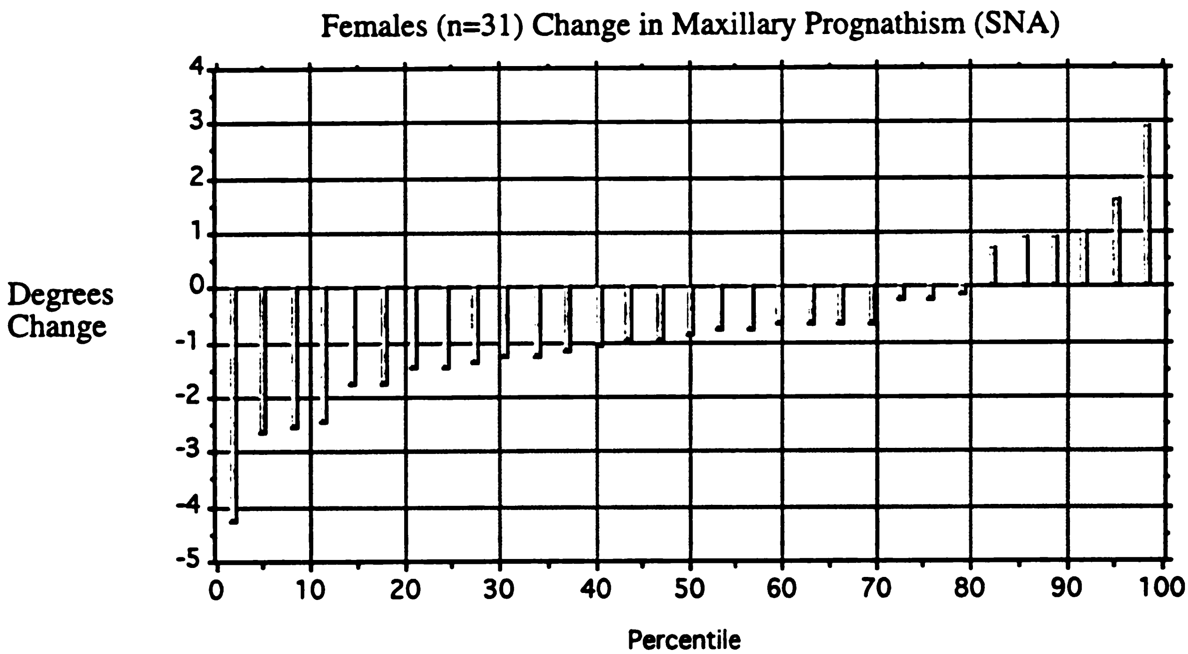


Figure 61. Individual Changes in Mandibular Prognathism (SNPg) in Girls (n=31)

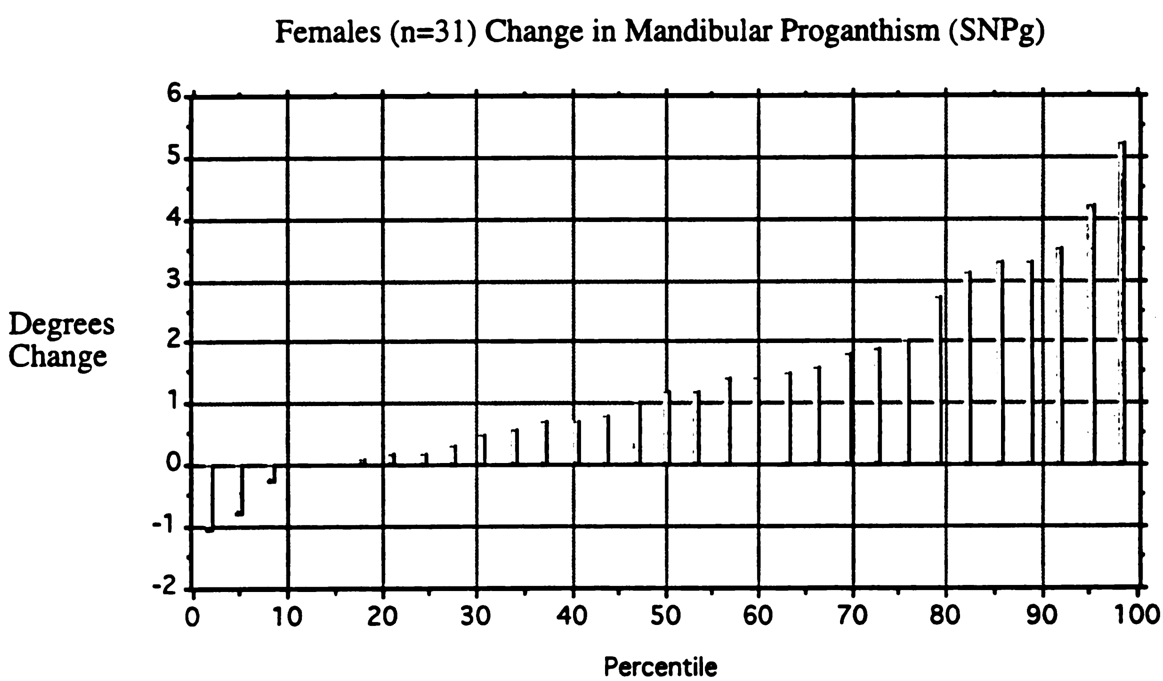


Figure 62. Individual Changes in Mandibular Inclination (NSL/ML) in Girls (n=31)

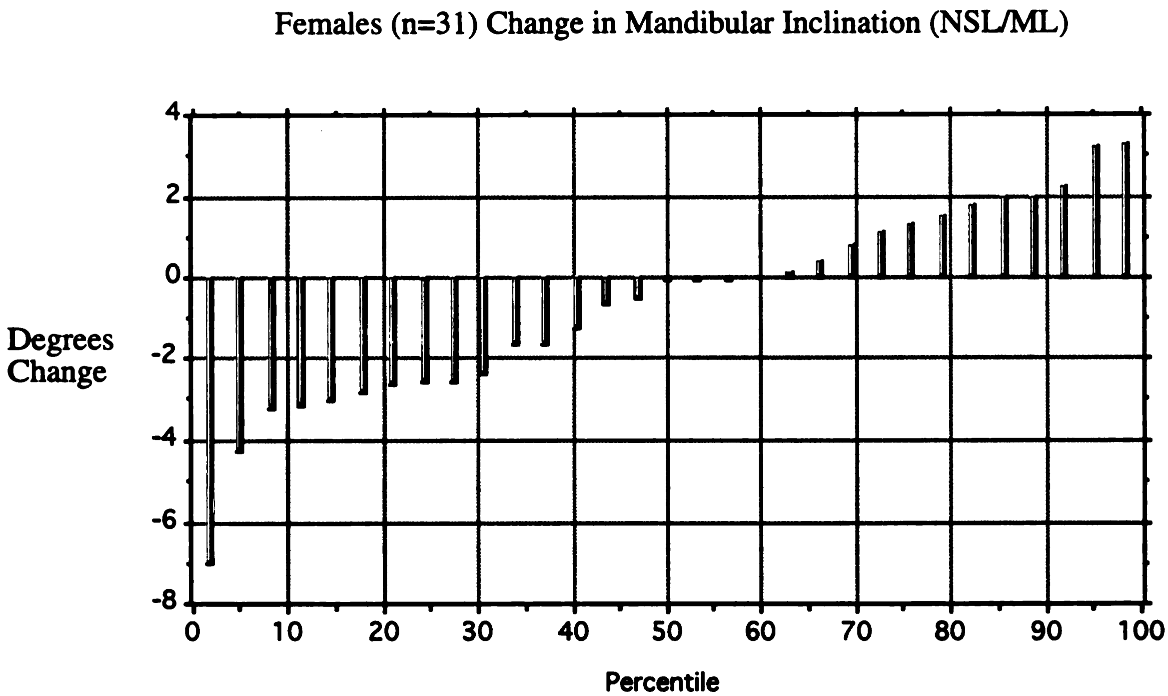


Figure 63. Individual Changes in Maxillary Inclination (NSL/NL) in Girls (n=31)

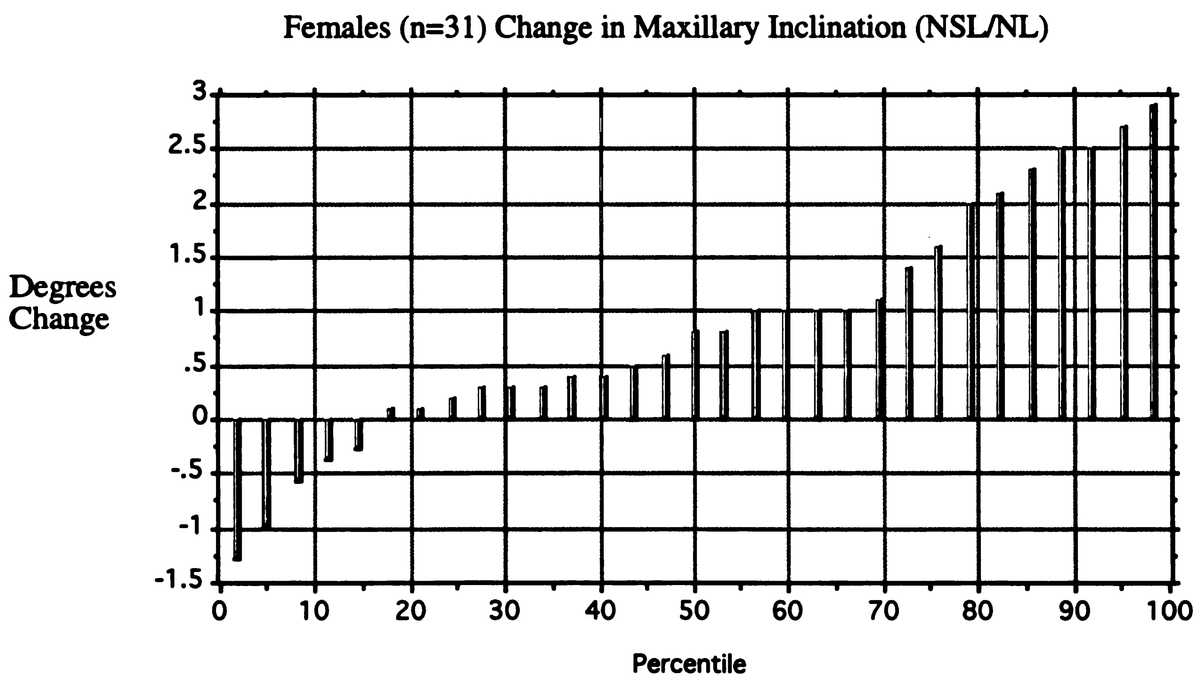


Figure 64. Individual Changes in Maxillary Prognathism (SNA) in Boys (n=28)

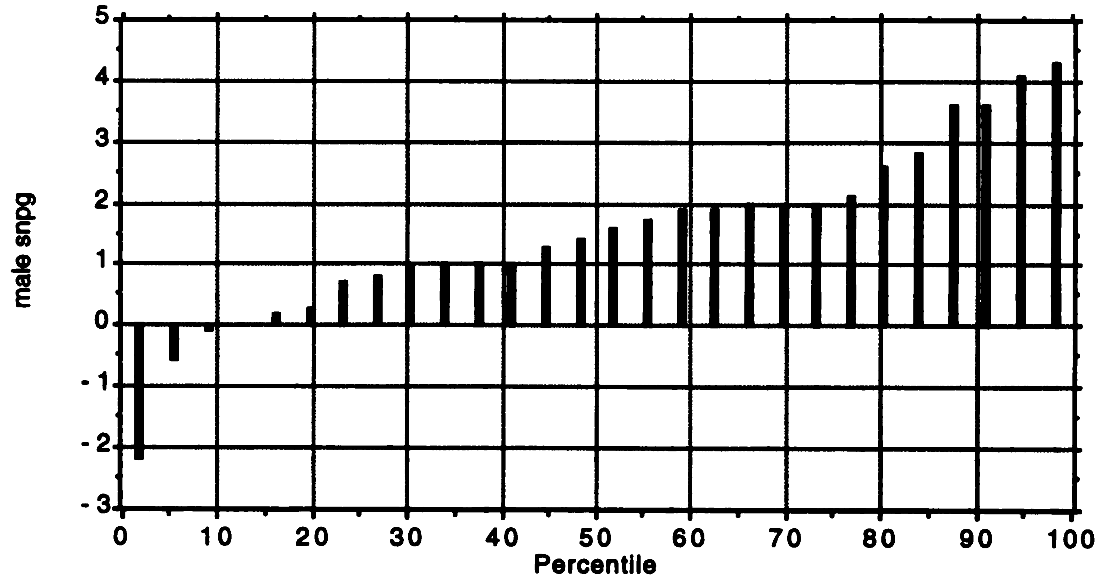


Figure 65. Individual Changes in Mandibular Prognathism (SNPg) in Boys (n=28)

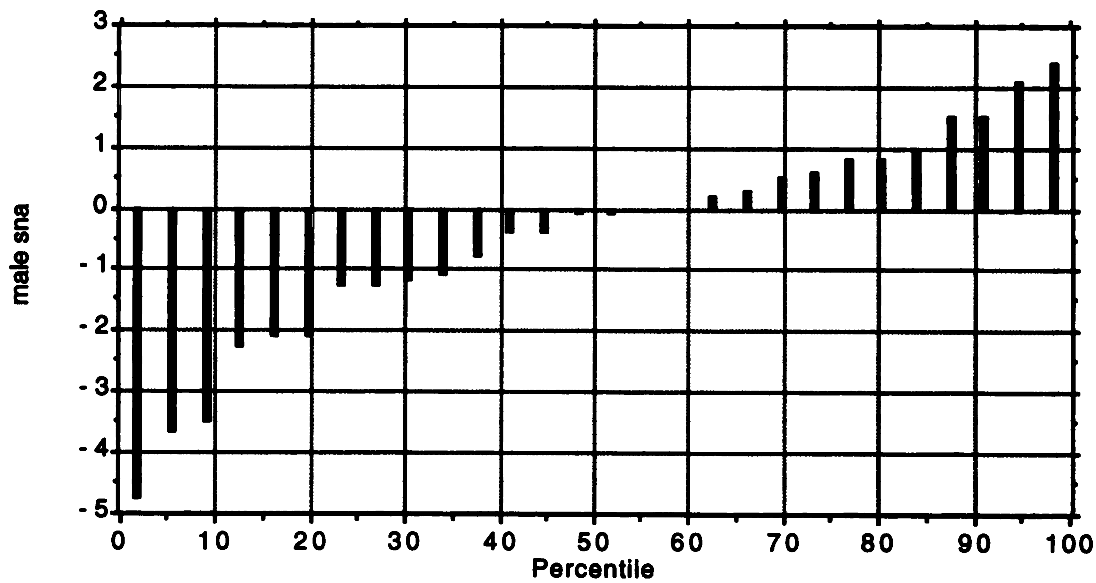


Figure 66. Individual Changes in Mandibular Inclination (NSL/ML) in Boys (n=28)

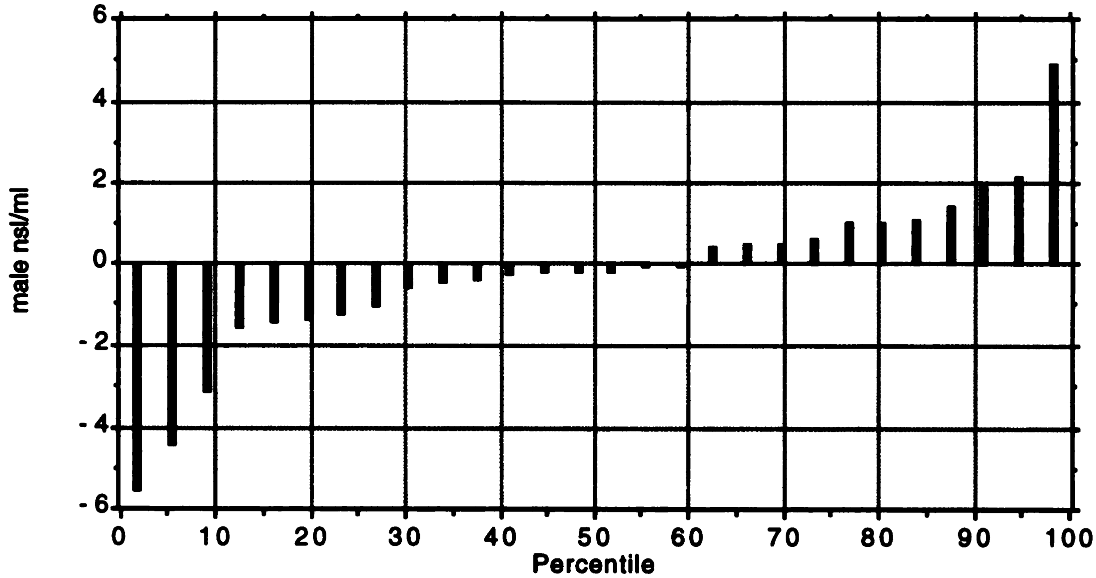


Figure 67. Individual Changes in Maxillary Inclination (NSL/NL) in Boys (n=28)

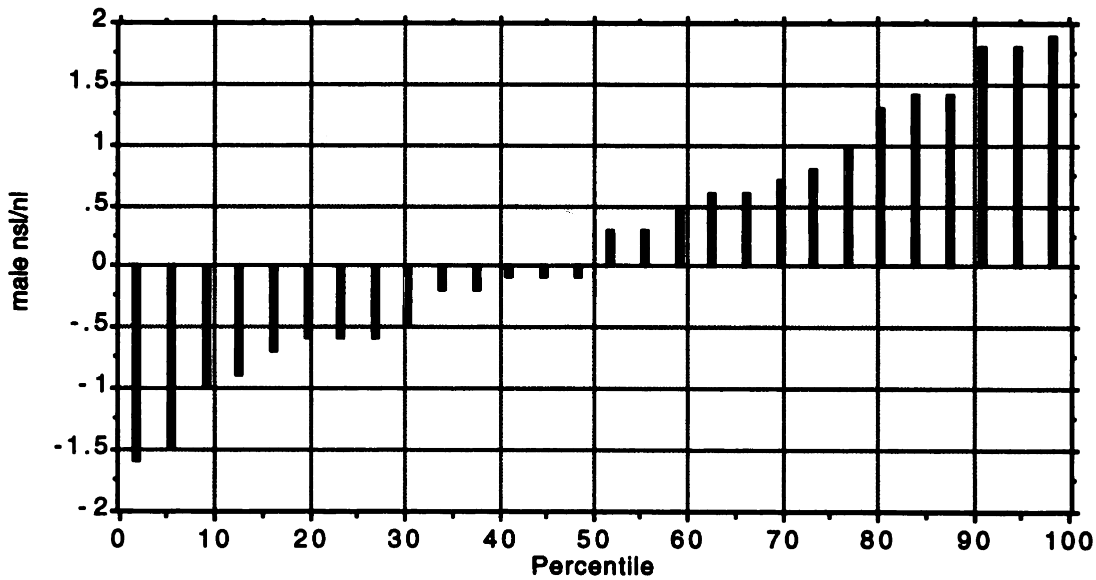
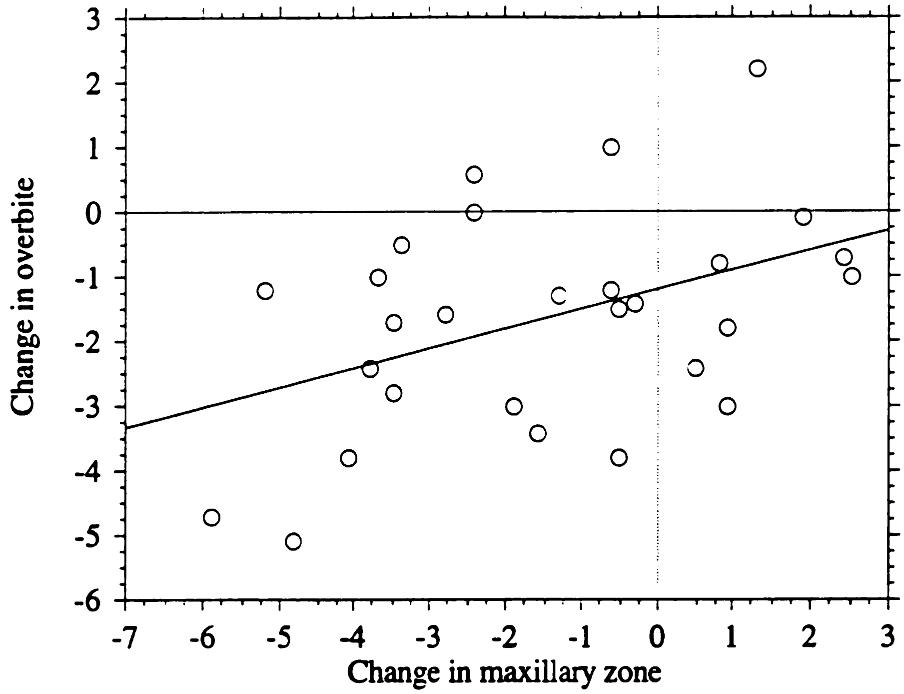
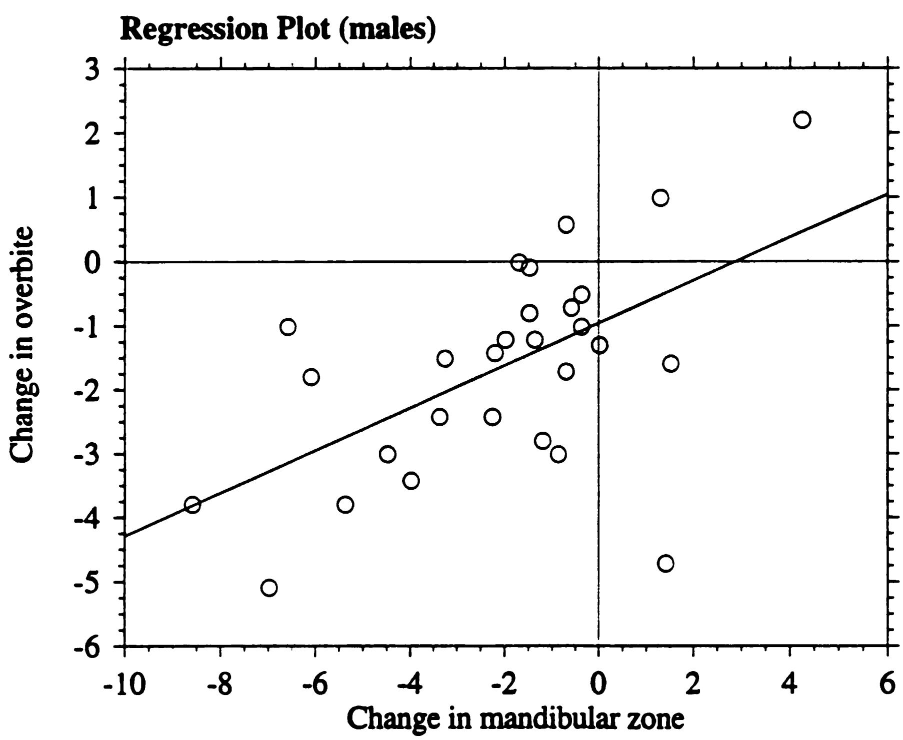


Figure 68. Change in Overbite Compared to Change in Maxillary Zone for Boys (n=28)



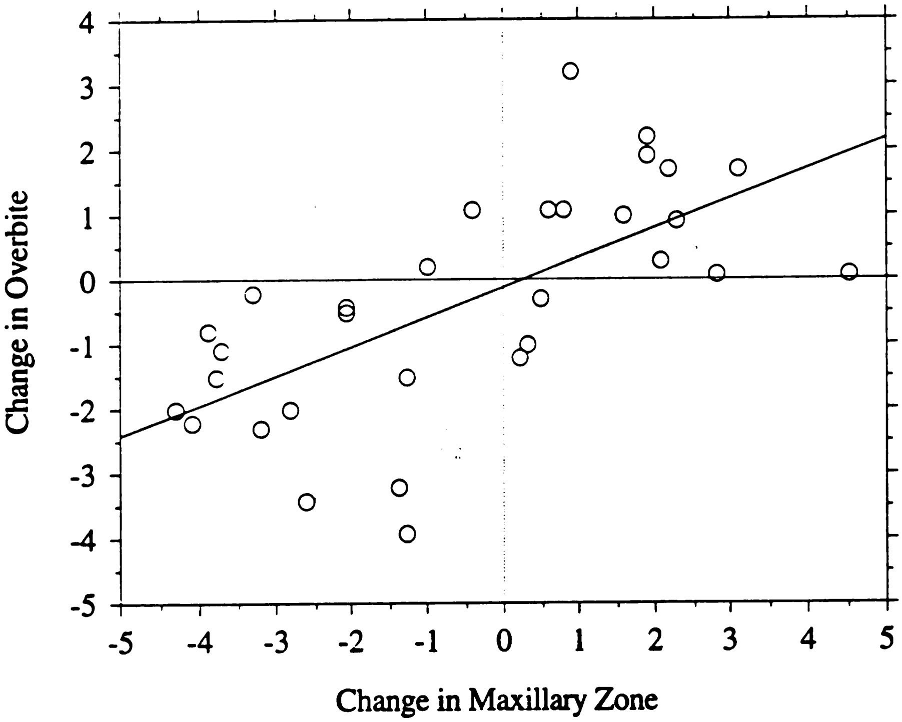
Y = -1.201 + .307 * X; R^2 = .189

Figure 69. Change in Overbite Compared to Change in Mandibular Zone for Boys (n=28)



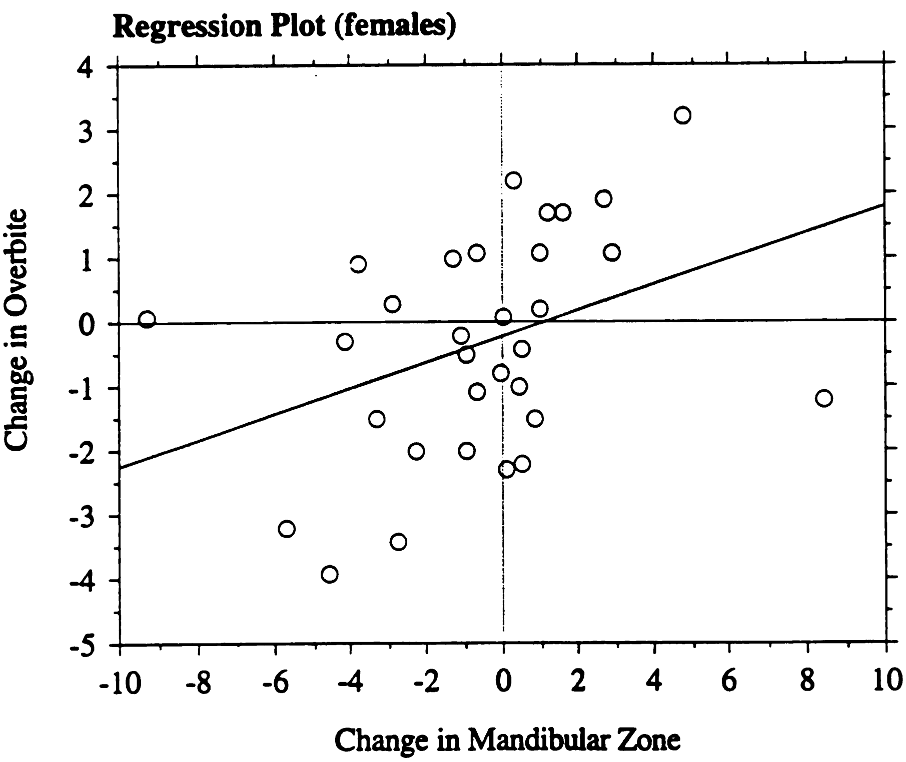
Y = -.968 + .333 * X; R^2 = .324

Figure 70. Change in Overbite Compared to Change in Maxillary Zone for Girls (n=31)



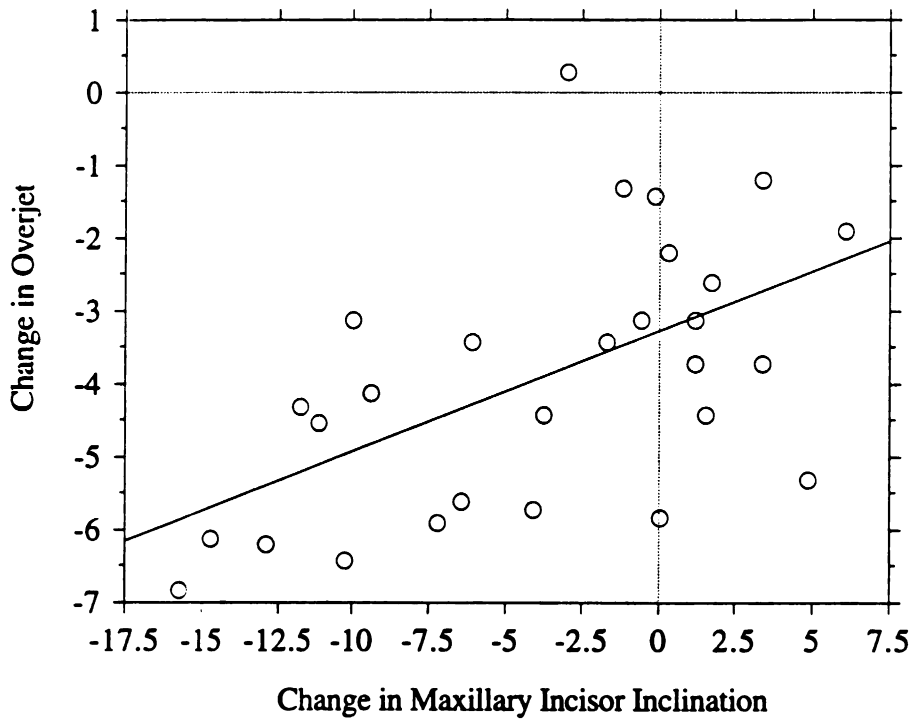
Y = -.12 + .461 * X; R^2 = .436

Figure 71. Change in Overbite Compared to Change in Mandibular Zone for Girls (n=31)



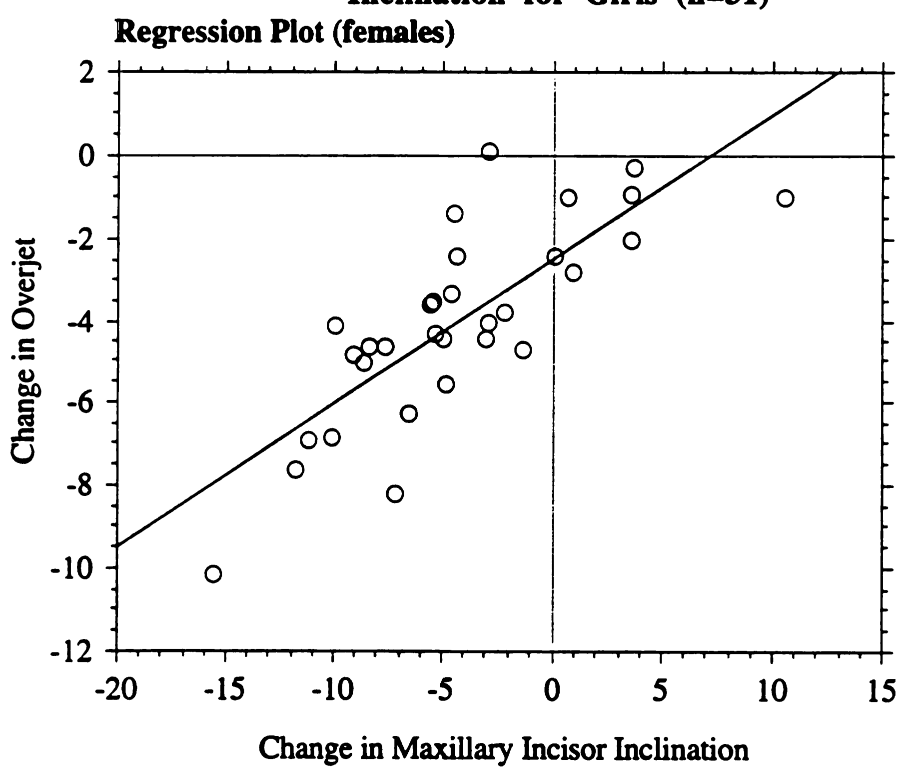
Y = -.231 + .201 * X; R^2 = .14

Figure 72. Change in Overjet Compared to Change in Maxillary Incisor Inclination for Boys (n=28)



Y = -3.278 + .163 * X; R^2 = .309

Figure 73. Change in Overjet Compared to Change in Maxillary Incisor Inclination for Girls (n=31)



Y = -2.483 + .348 * X; R^2 = .628

Table 21. RUS Bone Maturity Scores (Girls)

RUS (Radius, Ulna, Short) Bone Maturity Scores

GIRLS

RATINGS	A	B	C	D	E	F	G	H	I
BONES									
Radius	0	23	30	44	56	78	114	160	218
Ulna	0	30	33	37	45	74	118	173	
Metacarpal I	0	8	12	18	24	31	43	53	67
III	0	5	8	12	16	23	37	47	53
V	0	6	9	12	17	23	35	48	52
Proximal Phalanges I	0	9	11	14	20	31	44	56	67
III	0	5	7	12	19	27	37	44	54
V	0	6	7	12	18	26	35	42	51
Middle Phalanges III	0	6	8	12	18	27	36	45	52
V	0	7	8	12	18	28	35	43	49
Distal Phalanges I	0	7	9	15	22	33	48	51	68
III	0	7	8	11	15	22	33	37	49
V	0	7	8	11	15	22	32	36	47

Table 22. RUS Bone Maturity Scores (Boys)

RUS (Radius, Ulna, Short) Bone Maturity Scores

BOYS

RATINGS	A	B	C	D	E	F	G	H	I
BONES									
Radius	0	16	21	30	39	59	87	138	213
Ulna	0	27	30	32	40	58	107	181	
Metacarpal I	0	6	9	14	21	26	36	49	67
III	0	4	5	9	12	19	31	43	52
V	0	4	6	9	14	18	29	43	52
Proximal Phalanges I	0	7	8	11	17	26	38	52	67
III	0	4	4	9	15	23	31	40	53
V	0	4	5	9	15	21	30	39	51
Middle Phalanges III	0	4	6	9	15	22	32	43	52
V	0	6	7	9	15	23	32	42	49
Distal Phalanges I	0	5	6	11	17	26	38	46	66
III	0	4	6	8	13	18	28	34	49
V	0	5	6	9	13	18	27	34	48

***After Tanner and Whitehouse (1983)**

Figure 74. Standards for RUS Skeletal Maturity Scores: Boys

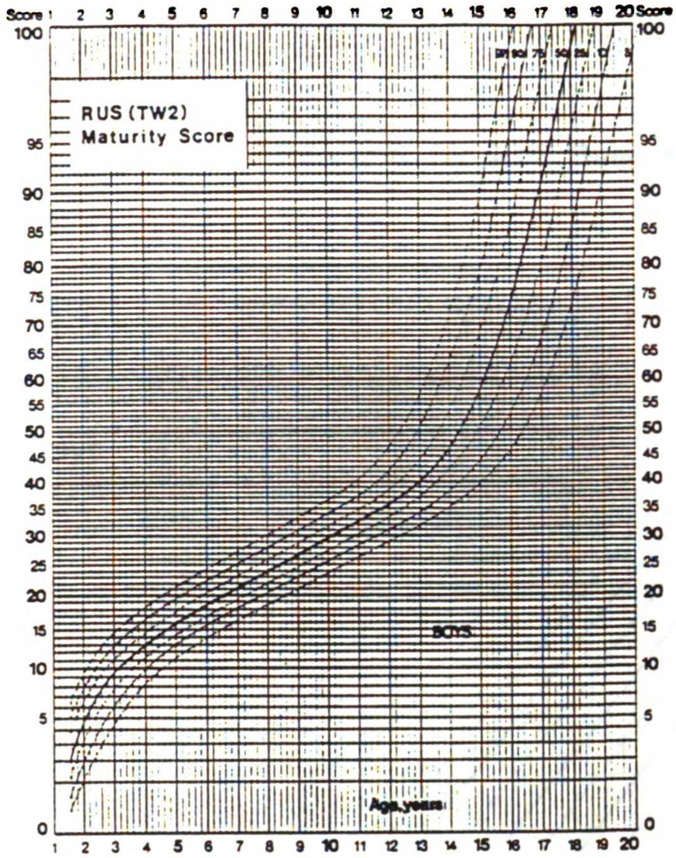


Fig. 2. Standards for RUS skeletal maturity score: boys.

Figure 75. Standards for RUS Skeletal Maturity Scores: Girls

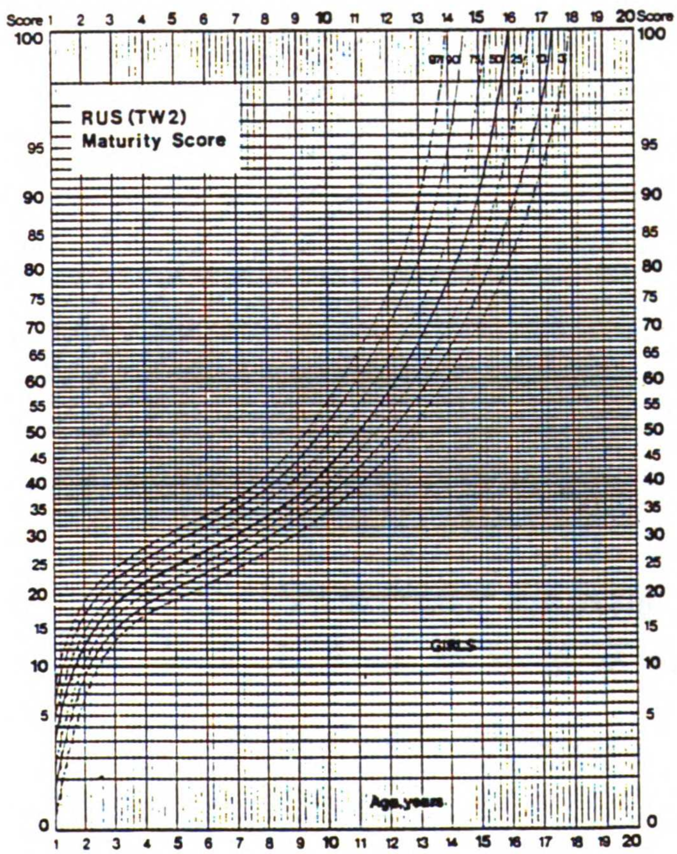


Fig. 3. Standards for RUS skeletal maturity score: girls.

Figure 76. Standards for RUS Bone Age: Boys

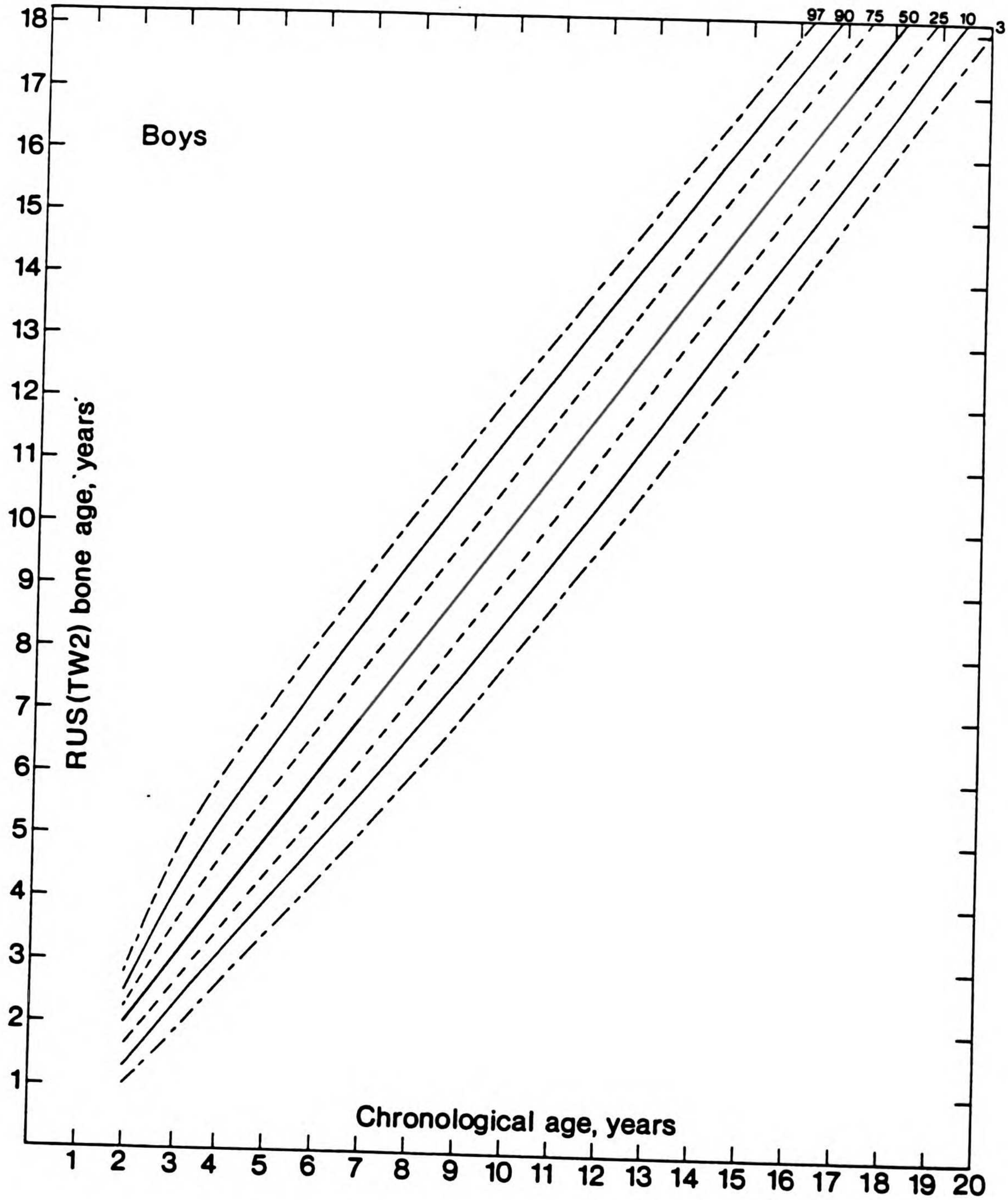


Fig. A10. Standards for RUS bone age: boys.

***After Tanner and Whitehouse 1983**

Figure 77. Standards for RUS Bone Age: Girls

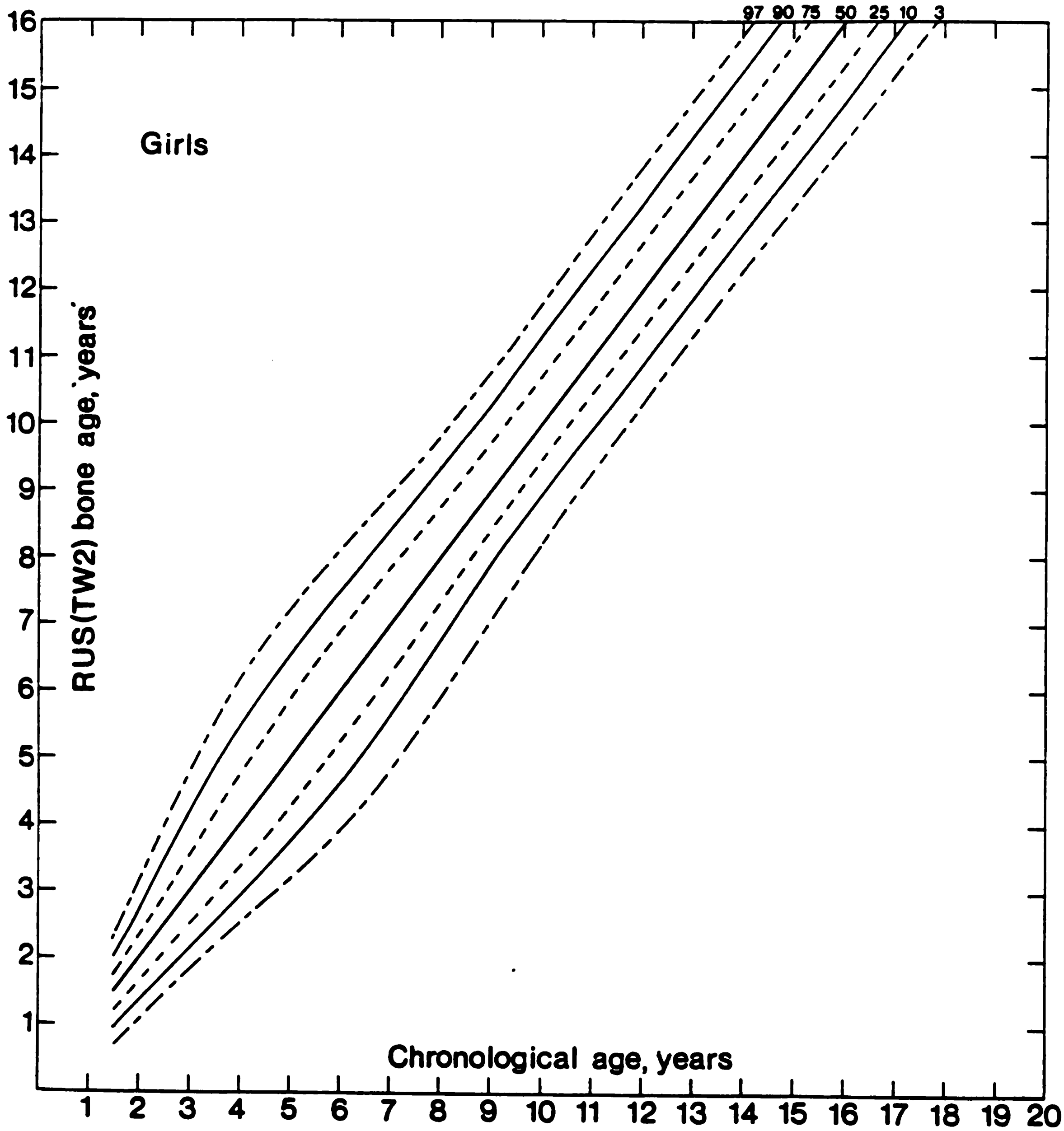


Fig. A11. Standards for RUS bone age: girls.

*After Tanner and Whitehouse 1983