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Mandibular growth and growth prediction in unilateral cleft lip and palate individuals

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Mandibular Growth and Growth Prediction
in Unilateral Cleft Lip and Palate Individuals
by

Scott Wayne Kaloust

THESIS

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I. Abstract

Mandibular Growth and Growth Prediction in Unilateral Cleft Lip and Palate Individuals.

Scott Wayne Kaloust, D.D.S.

Objective: The purpose of the present study was to evaluate mandibular growth and mandibular rotation. Second, to perform mandibular growth prediction in unilateral cleft lip and palate individuals. Third, determine the effects of altered maxillary growth on the overall growth of the mandible.

Design: This retrospective longitudinal study sample consisted of lateral cephalometric radiographs of 55 unilateral cleft lip and palate (UCLP) subjects at two time points (T1 and T2) at least one year apart, who had undergone a standard surgical cleft repair protocol and no orthodontic or orthopedic treatment. Comparisons were made to a sex and age matched control group of normal subjects with skeletal class I occlusion.

Results and Conclusions: Although absolute mandibular length showed no difference between the two groups, the sagittal position of the mandible was decreased in the UCLP group at both time points. The mandibular plane angle of the UCLP group was significantly greater than the control group. There was no difference in the total mandibular rotation between the two groups, with both demonstrating about 1 degree per year of forward mandibular growth rotation. Maxillary vertical growth affected both groups equally, with a greater backward maxillary rotation over the observation period, resulting in a decreased sagittal and increased vertical mandibular position. Finally, the (TIOPS™) computer program for growth prediction accurately predicted mandibular sagittal and vertical position for both the UCLP and Control group.

II. Introduction

A. Mandibular Growth

Development of the mandible begins as a condensation of mesenchyme just lateral to Meckel's cartilage and continues entirely as an intramembranous bone formation. The condylar cartilage develops initially as an independent secondary cartilage, which is separated by a wide gap from the body of the mandible. Early in life, it fuses with the developing mandibular ramus.

The mandible of the newborn is proportionally smaller vertically than the adult mandible and the gonial angle is obtuse. The condyle is rudimentary and horizontally located approximately at the level of the future occlusal plane. At birth, and for a few months postnataly, the mandible maintains an intrauterine growth center, the symphyseal suture. The lateral expansion in this suture permits the primary anterior teeth to align themselves in the arch. With the closure of this suture, all growth of the mandible is limited to posterior growth sites.

Both endochondral and periosteal cellular activity are important contributing factors to the growth of the mandible. Cartilage covers the surface of the condyle, and although this cartilage is not like the cartilage at an epiphyseal plate, hyperplasia, hypertrophy, and endochondral replacement do occur. All other areas of the mandible are formed and grow by direct surface apposition and modeling.

As a growth site, the anterior portion of the chin is almost inactive. It is translated downward and forward, as the actual growth occurs at the condyle and along the posterior surface of the ramus.

The body of the mandible grows in length by periosteal apposition of bone on its posterior surface, while the ramus increases in height by endochondral replacement at the condyle and appositional growth at the coronoid process, accompanied by surface modeling. Growth of the mandible continues at a relatively steady rate, on average, before puberty, however, the individual patient shows variations from year to year. On average, the ramus height increases 1-2 mm per year, and body length increases 2-3 mm per year [1].

One of the earliest theories of mandibular growth was proposed by John Hunter in 1771 [2]. He compared a series of dried mandibles and concluded that, in order to gain space for the development and eruption of the permanent molar teeth, the mandible must grow by posterior apposition of the ramus and anterior resorption [2]. By tying wires around the mandibles of pigs, Humphry (1866) showed that the wires became imbedded in the posterior margin and free in the anterior border of the ramus [2]. Brash (1924) fed pigs the "madder" plant root that contains the red stain alizarin and labels appositional bone growth [2]. The conclusions were similar: apposition occurred posteriorly and superiorly on the ramus, with resorption anteriorly, of the growing pig mandible.

A major contribution to the understanding of mandibular growth was the implant studies of Arne Bjork [3, 4] and Bjork and Skieller [4, 5]. Bjork et al. found, using metallic radiographic markers, placed at specific sites in the jaw bones, that the outer surfaces undergo modeling over time in growing individuals. This modeling in most subjects included resorption of the lower posterior border of the mandible and apposition under the lower anterior border. In other subjects apposition was found posteriorly only. As a result of these modeling changes it is apparent that a change in the mandibular plane inclination does not only reflect positional changes of the mandible but also any associated modeling. For this reason the mandibular plane angle can not be reliably used without adjustments to determine changes in facial height over time, but only to describe the morphology of the face at a given point in time.

Longitudinal mandibular growth changes were described by Bjork [6, 7] to be associated with not only linear changes, but also rotational displacement of the mandible. Bjork [7] demonstrated a large variation in condylar growth direction of the mandibular condyles. His implant studies showed that in subjects with upward forward condylar growth, the mandible rotates in a forward direction, or towards the anterior cranial base (Fig. 1). Subjects with posteriorly directed condylar growth, in contrast, show backward rotation, or rotation away from the anterior cranial base. The range in his sample of twenty-five boys was as much as 42 degrees between the most anterior and the most posterior growing condyle, demonstration a large individual variation in the normal population.

The rotational growth change, as measured with the use of the metallic implants, was referred to by Bjork as *Total Rotation.* The modeling that takes place over time was called *Intramatrix Rotation* and the resulting change in inclination of the lower border of the mandible was referred to as *Matrix Rotation.* Bjork et al. found that whereas total rotation, or the actual rotation that occurred, in a sample of normal subjects on average amounted to as much as 15 degrees, 75% of this rotation was masked by surface modeling (*Intramatrix rotation)* [4]. Only 25% of the total rotation was expressed as a change in inclination at the mandibular plane.

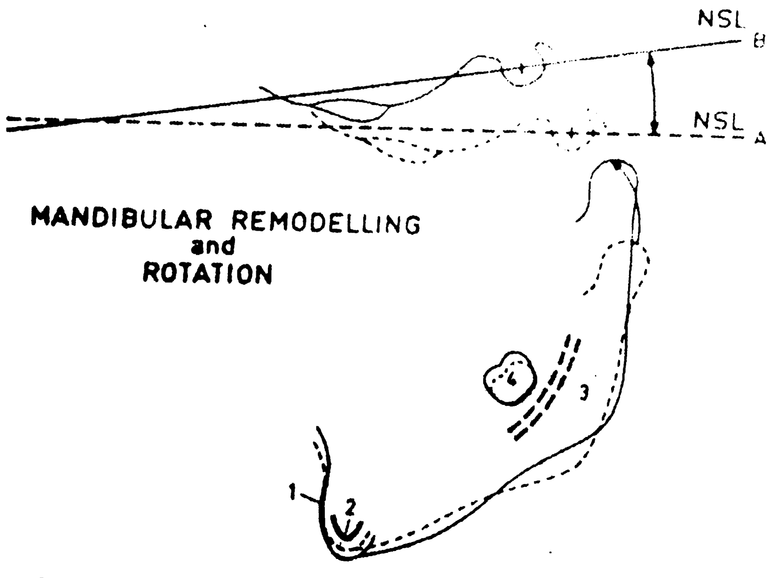

Figure 1. Typical Mandibular Growth Rotation and Remodeling.

B. Mandibular Growth Prediction

Raymond Curtner, in an article titled "Predetermination of the Adult Face," compared five sets of siblings to their parents using lateral cephalograms [8]. His conclusions were that lateral cephalograms have "unquestionable value in the determination of resemblance of children to their parents," and that it appears to be possible to predetermine the adult face in most children by superimposing radiographs of children and their parents [8]. He concluded that predetermination of the adult face appears to be the "missing link" in orthodontic diagnosis and treatment planning [8].

In 1970, Melvin Moss developed his logarithmic growth theory of the mandible [9]. From a study using small lead shots fixed to the foramen ovale, mandibular foramen, and mental foramen of dried skulls; lateral cephalograms were taken to determine the path of the inferior alveolar nerve. A single logarithmic spiral was developed, which was meant to describe the path of mandibular growth for all individuals [9].

Ricketts' arcial growth of the mandible developed from a trial and error procedure using longitudinal cephalometric records [1]. Ricketts' theory is that the normal human mandible grows by superior-anterior (vertical) apposition at the ramus on a curve or arch which is a segment formed from a circle. The radius of this circle is determined by using the distance from mental protuberance (Pm) to a point at the forking of the stress lines at the terminus of the oblique ridge on the medial side of the ramus (point Eva) [1]. The growth velocity was determined from serial cephs of 40 patients. An average mandibular growth of 2.5 mm was determined to be the annual amount of mandibular growth [1]. This mean annual growth velocity was then combined with the path or arc of mandibular growth to predict the future mandibular growth of a given individual.

C. Craniofacial growth of UCLP individuals

It has long been known that there is a deficiency in the downward and forward growth of the midface in cleft lip and palate individuals [10] [11] [12] [13] [14] [15]. The mandible has been shown to grow normally in rate and dimension in most cleft types. One major exception is isolated cleft palate patients, where the mandible is smaller in length and tends to be retrognathic [10] [16] [17] [13] [18] [15]. Ross found smaller and more obtuse gonial angles in many of the centers in his UCLP review [19]. Omar Gabriel da Silva Filho observed that the mandibles of the cleft group were shorter in ramus and body length and displayed a downward and backward growth rotation associated with a more obtuse gonial angle [20]. Bishara et al., observed a larger mandibular length in cleft lip and palate individuals compared with subjects exhibiting cleft lip only [21].

Ross stated three reasons for abnormal facial morphology [19]:

1. Intrinsic developmental deficiencies.
2. Functional distortions affecting the position and growth of both normal and abnormal parts.
3. Iatrogenic factors introduced by treatment.

The only significant intrinsic abnormality is in the maxillary complex (maxilla, palatine bone, nasal septum, teeth, soft palate, and lip) with the possibility of a slight mandibular deficiency [22]. Functional components of abnormal facial morphology stem mainly from muscle activity, which cause distortion of both normal and abnormal parts [22]. Iatrogenic factors are the major source of midface deficiency.

Several studies have evaluated the craniofacial morphology of untreated cleft lip and palate individuals [17] [21] [23] [24] [25] [26] [27] [28] [29]. The majority of these studies have demonstrated normal growth of both maxilla and mandible. In contrast, some authors have reported a certain degree of maxillary and mandibular retrusion, which suggests an intrinsic growth deficiency may be the cause [21] [29]. Several studies have also shown increased mandibular plane angles and increased anterior facial height [25] [21] [29]. Capelozza et al. [28] found that although the mandibular plane angle was increased in his sample of twenty-six unoperated unilateral cleft lip and palate subjects, the vector of craniofacial growth in the sample did not show any difference from that of the control group. The difference in mandibular plane angle, without similar alterations in the facial axis, is probably linked to changes in the gonial angle, which has been shown to be larger in cleft subjects [28].

D. Protocol for Management of Children with Cleft Lip and Palate at the Center for Craniofacial Anomalies, University of California, San Francisco

When studying facial growth and morphology in cleft individuals, it is important to define several aspects of the project. First, the study sample needs to be well defined, which will be described in the materials and methods section. Second, it is also important to define the treatment protocol of the study sample. Previous studies have clearly shown differences between treatment protocols at different craniofacial centers [30] [31] [32] [33] [19] [34]. For this reason, the standard treatment protocol for individuals with unilateral cleft lip and palate at the University of California, San Francisco is outlined below:

-Immediately after birth: Counseling, feeding instructions, diagnosis by a geneticist, and a pediatric consultation.

-Within first weeks of life: Team evaluation, including hearing evaluation.

-At 10 to 12 weeks: surgical repair of the cleft lip.

-Before age 1 year: A second team evaluation followed by surgical repair of cleft palate and placement of pressure equalization tubes.

-Three months after palate repair: Team evaluation, including speech/language assessment.

-Between 2 and 5 years of age: Team evaluations; medical and behavioral intervention as needed (speech therapy, treatment for middle ear disease, fistula repair, soft palate lengthening, etc.).

-At 5 to 6 years of age: Lip and nose revision if necessary.

-At 7 years of age or as maxillary permanent central incisors erupt: Begin orthopedic/orthodontic treatment (Phase I).

-Between 9 and 11 years: Alveolar cleft bone grafting.

-At age 12 or later: Begin full orthodontic treatment (Phase II).

-At the end of orthodontic treatment: Place implants to replace missing teeth.

-When growth is nearly completed: Surgical advancement of the maxilla if indicated.

-When orthodontic and prosthetic treatment is completed: Final lip and nose revision.

E. Purpose and Hypotheses

The primary purpose of the present study was to evaluate mandibular growth, including mandibular growth rotation. The second purpose was to test a model for growth prediction in unilateral cleft lip and palate individuals. Also of interest was to determine the effects of altered maxillary growth on the overall growth of the mandible. This was accomplished with the use of serial lateral cephalometric radiographs of unilateral cleft lip and palate individuals (UCLP) who had undergone a standard surgical cleft lip and palate repair, but who had not undergone any orthodontic or orthopedic treatment. This study is unique in that it evaluates longitudinal records and uses the Bjork superimposition technique for evaluating mandibular growth, as well as tests a growth prediction model on UCLP individuals.

Although many studies have evaluated the craniofacial morphology of cleft individuals, several aspects have not been studied. Also, most studies have been crosssectional in nature, not longitudinal. It is the purpose of this study to evaluate longitudinal records of unilateral cleft lip and palate individuals to test the following null hypotheses:

1) There is no difference in the selected parameters of craniofacial morphology or rate of growth between UCLP and control individuals.

2) There is no difference in the total mandibular rotation between UCLP and control individuals.

3) There is no difference between the effects of vertical maxillary growth on mandibular growth between UCLP and control individuals.

4) There is no difference between UCLP and control individuals for prediction of mandibular growth using a computer prediction model.

III. Materials and Methods

A. Subjects

The materials used for this study were obtained from the University of California, San Francisco, Center for Craniofacial Anomalies (CCFA). The centers computer database was searched using the keywords unilateral cleft lip and palate (UCLP). All nonsyndromic unilateral cleft lip and palate individuals were included as the beginning sampling frame. 279 individuals were found to fit this criteria.

The patient records of the 279 UCLP individuals were reviewed to obtain records of individuals who met the following inclusion criteria:

1. Two lateral cephalometric radiographs at least one year apart.
2. No history of orthodontic treatment.
3. A standard UCSF cleft repair protocol was followed.

Fifty-five patients fulfilled these criteria (23 females and 32 males). The major reasons for not meeting the inclusion criteria were that some form of orthodontic treatment had taken place or there were inadequate radiographs.

The control group was obtained from the University of Toronto, Burlington Growth Center. Fifty-five control subjects were matched for age and gender to the UCLP subjects. All control subjects demonstrated a normal sagittal jaw relationship (Class I).

B. Cephalometric Analysis

The UCLP group's lateral cephalometric headfilms were all taken on the same cephalostat by the same technician. The two serial headfilms for each subject were traced in succession at one sitting by one investigator on standard acetate tracing paper using a fine lead pencil (0.5 mm HB). All double contours were bisected to minimize landmark location error [35].

The following techniques were utilized to limit tracing and superimpositional errors. First, each acetate tracing was critically evaluated 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 ethmoid bones) as shown by Melsen [36] (figure 2). The nasion sella line (NSL) of the first headfilm was carried forward to the second headfilm. When an aberrant landmark location or a suspected rotational error in a given tracing was found, that acetate tracing was placed back on the headfilm to check for errors in landmark identification. In case of an error in landmark identification, the corrected position was marked.

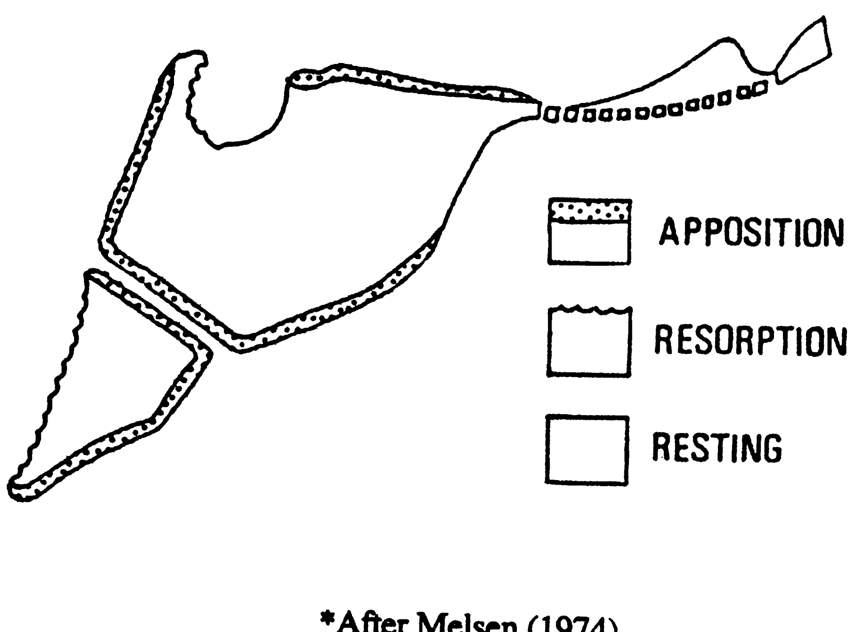

Figure 1. Stable structures of the cranial base

The second step was to critically evaluate the computerized superimpositions (TIOPS™). The software overlays the headfilms on the digitized reference points sella anterior and nasion. The nasion point located on the first film is carried forward to the second film after superimposition on the stable structures of the cranial base. The two headfilms are then superimposed and it is observed that a logical sequence of growth changes is present [4]. The problem associated with the conventional technique of superimposing headfilms is that any vertical displacement of nasion will result in significant errors in the antero-posterior positioning of landmarks in the midface and the mandible. Baumrind, Moore, Nelson, and Knott have all shown that nasion has a high degree of variability in the vertical dimension with growth [37-39] [40]. Baumrind [37] reported the standard deviation in the location of nasion in the vertical plane is +/- 1.33 mm. Baumrind [41] 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 problem contributes to a 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. Using the above-mentioned method of superimposition eliminated much of this problem.

To further reduce these possible sources of error, both tracings for a given patient were digitized and the superimposition evaluated on the computer monitor screen. Once again, the superimposition was evaluated for aberrant landmark location or a suspected rotational error in a given tracing. In 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 cephalometric landmarks were digitized using a Numonics™ digitizer and the x and y coordinates were entered into a computer program, TIOPS™. A total of fifty-seven hard and soft tissue landmarks were digitized from each tracing into the TIOPS™ program (figure 3). Reference lines were located relative to these points and were then used to calculate the angular measurements used in this study (figure 4). The magnification of the headfilms was 9.8%. No correction of the magnification was needed due to the fact that the information sought was incremental changes of linear measurements and angular measurements.

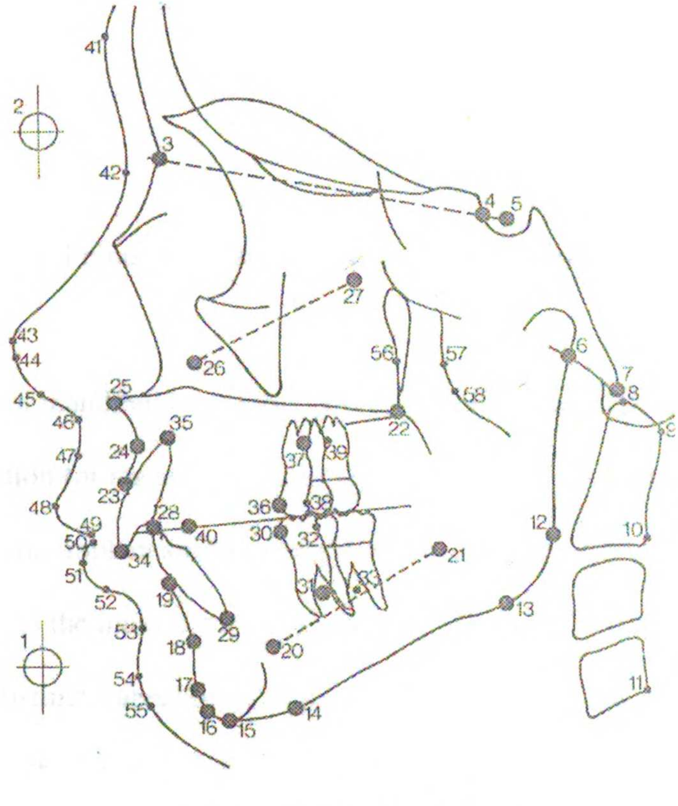

Figure 3. Digitized Points

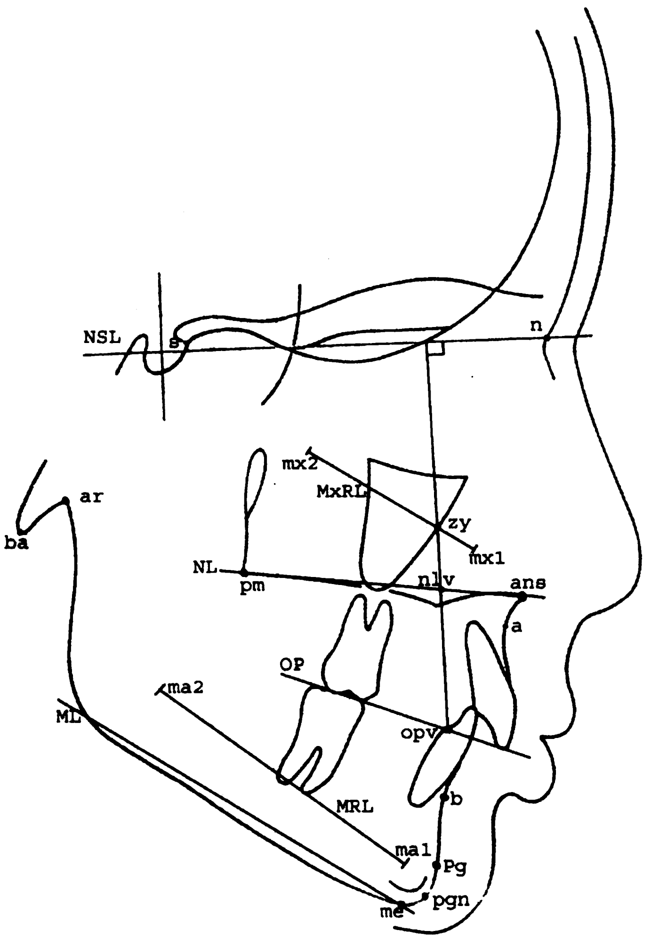

Figure 4. Points and Planes used for Cephalometric Measurements

The technique of mandibular superimposition (figure 5) used the Bjork method of landmark identification for mandibular superimposition [4]. This technique, developed by Bjork 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.

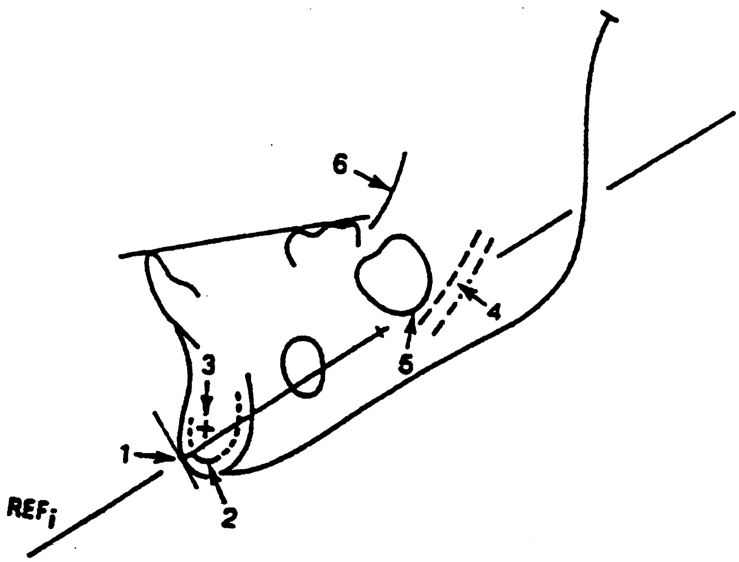

Figure 5. Anatomic Structures used for the Mandibular Superimposition

Table 1. Reference Points on the Lateral Cephalometric Headfilm

<u>Cranial Base Landmarks</u>

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 the sella turcica.
Sa	*sella-anterior.* A point at the intersection of the anterior wall of sella turcica and the anterior clinoid process.

<u>Maxillary Landmarks</u>

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.
a	*a-point.* The most posterior point on the anterior contour of the upper alveolar arch.

nlv *Nasal Line Vertical.* The intersection of the nasal floor(NL) and NSLp.

opv *Occlusal Plane Vertical.* The intersection of OP and NSLp.

mx1 *Maxillary reference point 1.*

mx2 *Maxillary reference point 2.*

zy *Zygomatic point.* Intersection of the maxillary reference line and the anterior border of the zygomatic process.

Mandibular Landmarks

me *Menton.* The most inferior point on the mandibular symphysis.

pg *Pogonion.* The most anterior point on the mandibular symphysis.

b *b-point.* The most posterior point on the anterior contour of the lower alveolar arch.

ma1 *Mandibular reference point 1.*

ma2 *Mandibular reference point 2.*

Table 2. Reference Lines on the Lateral Headfilm

NSL	*Nasion Sella Line.* The line through point *n* and point *s* on the first headfilm.
NL	*Nasal Line.* The line through *ans* and *pm.*
OP	*Occlusal Plane.* A functional occlusal plane through the most posterior tooth in occlusion and the most anterior tooth in occlusion.
ML	*Mandibular Line.* The tangent to the lower border of the mandible through *gn.*
NSLp	*Nasion Sella Line perpendicular.* A line perpendicular to NSL through the point *zy.*
MRL	*Mandibular reference line.* The line joining *ma1* and *ma2.*
MxRl	*Maxillary reference line.* The line joining *mx1* and *mx2.*

Table 3. Angular Measurements on the Lateral Headfilm

NSL/NL	*Maxillary inclination*
NSL/ML	*Mandibular inclination*
NL/ML	*Vertical jaw relationship*
SNA	*Maxillary prognathism*
SNPg	*Mandibular prognathism*
ANPg	*Sagittal jaw relationship*
NSBa	*Cranial base angle*

Table 4. Points used for Linear Measurements on the Lateral Headfilm

(Measurements are relative to NSLp)

zy *Zygomatic point.* Intersection of the maxillary reference line and the anterior border of the zygomatic process.

nlv *Nasal Line vertical.* The intersection of the nasal floor(NL) and NSLp.

opv *Occlusal plane vertical.* The intersection of OP and NSLp.

Table 5. Other Measurements

max-rot	*Maxillary Rotation.* Angular change of NSL between the first and second lateral headfilms when the maxilla is superimposed on MxRL.
mand-rot	*Mandibular Rotation.* Angular change of NSL between the first and second lateral headfilms when the mandible is superimposed on MRL.
ar-pg	*Mandibular length.* The linear distance between points *ar* and *pgn*.

Several measurements were made directly on the acetate tracings. The Nasion-Sella line was traced on the first headfilm. The second headfilm was superimposed on the stable structures of the cranial base and the NSL reference line was transferred to the second headfilm. The measurements were made to the nearest 0.5 mm. The vertical measurements made directly on the acetate tracings were all made relative to NSL (figure 6) Mandibular length was measured from articulare to prognathion.

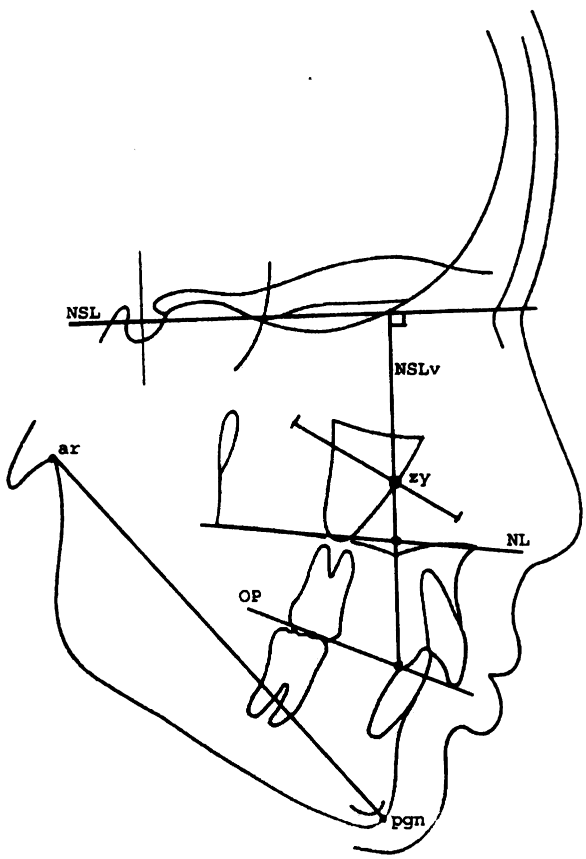

Figure 6. Points used for Linear Measurements

C. Mandibular Growth Prediction

From the T1 lateral ceph, a computerized growth prediction was performed by inputting the date from the T2 lateral ceph. This procedure was carried out for both the cleft group and the control group. The predicted values were then compared to the actual measured values by means of an unpaired t-test. The TIOPS™ computer programs data bank was used for this growth prediction analysis.

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 inputting the data into the computer. Superimposing the headfilms also has inherent 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 [41]. He demonstrated 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 its 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 [41] 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 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 helped obtain the most accurate superimposition possible as well as checking for accuracy in landmark identification.

The method errors for this study were determined by means of duplicate tracings, digitizing, and measurements of 5 randomly selected headfilms. The selected headfilms were traced, digitized, and measured on three separate occasions by the same investigator. The statistical analysis was performed using the StatView® statistical program (Abacus Concepts, INC. Berkeley, Ca). The intraclass correlation was calculated by the formula:

rho $_{I}$= MS(subj) – MSE / MS(subj) + 3 * MSE.

Where MS(subj) is the mean square from subjects and MSE is the mean square error. The results of the intraclass correlation test for eleven angular and linear measurements are shown in Table 6.

Table 6: Intraclass Correlation Results

Measurement	Intraclass Correlation
ar-pg	0.98
SNA	0.94
ANPg	0.95
NSL-NL, mm	0.94
NSL-OP, mm	0.89
NSL-Zy, mm	0.89
NL/ML	0.82
NSBa	0.88
NSL/NL	0.79
NSL/ML	0.96

E. Statistical Analysis

The statistical analysis of the data was performed using the Statview® (Abacus Concepts, Berkeley, CA) statistical program. A paired t test was performed on the T1 cephalometric values of girls and boys to determine possible differences between the two groups. A paired t test was also used on the T2 values to determine any significant differences between the groups. A paired t test was used to determine any significant differences between the UCLP group and the control group at T1, annualized change between T1 and T2, and T2.

Utilizing linear regression analysis and Pearson product-moment correlations, the following associations were evaluated: 1) the association between maxillary growth rotation and sagittal jaw relationship; 2) the association between maxillary vertical growth and mandibular growth rotation; and 3) the association between maxillary vertical growth and the sagittal jaw relationship. A Bonferroni-Holm test was utilized to adjust the significance level to compensate for the multiple correlations being made.

IV. Results

A. Age and Gender Distribution of UCLP and Control Groups.

The age distribution for both the UCLP and control groups can be seen in table 7 below. The mean age of the T1 lateral ceph was 5.8 and 6.0 years for the UCLP and control groups, respectively. The mean age of the T2 lateral ceph was 8.0 and 8.2 years for the UCLP and control groups, respectively. The observed growth period (T2-T1) was 2.25 and 2.20 years for the UCLP and control groups, respectively.

Table 7: Mean Values for Ages of UCLP and Control Groups

UCLP Group

	Years	min	max
T1 lateral ceph	5.8	3.1	11.1
T2 lateral ceph	8	5	13.1
T2-T1	2.25	1	6.6

Control Group

	Years	min	max
T1 lateral ceph	6	4	11
T2 lateral ceph	8.2	5	14
T2-T1	2.2	1.3	7

Gender differences were evaluated by comparing the T1 lateral cephalometric radiographs for both UCLP and control groups. Of the twelve measurements evaluated, only one from each group was found to be significantly different ($p<.05$). In the cleft group, the cranial base angle (NSBa) was found to be more acute in males than females. In the control group, the vertical jaw relationship was found to be greater in males than females. Table 8 shows the mean measures for males and females in the UCLP and control groups. Because only minimal differences were found between males and females, the two groups were combined for the remainder of the study.

Table 8: Comparison of Males and Females for UCLP and Control Groups at T1

	UCLP Group				Control Group			
Measure	male	female	mean diff.	signif.	male	female	mean diff.	signif.
mand. Rot	-2.8	-1.8	0.55	ns	-2.5	-2.4	0.065	ns
max. rot	0.25	0.39	0.14	ns	-0.5	-0.3	0.2	ns
ar-pg, mm	93.1	92.3	0.77	ns	93.5	2.7	0.7	ns
SNA	80.5	79.7	0.77	ns	81.2	81.2	0	ns
SNPg	74	73.9	0.14	ns	76.1	76.7	0.52	ns
ANPg	6.3	5.8	0.51	ns	5.1	4.5	0.56	ns
NSL/NL	9.3	10.5	1.1	ns	6.9	7.8	0.88	ns
NSL/ML	39.9	42.6	2.7	ns	36.8	35.2	1.6	ns
NL/ML	30.5	32.1	1.58	ns	30.3	27.4	2.9	*
NSBa	130.8	133.8	2.9	*	129.7	130.5	0.79	ns
NSL-NL, mm	39	38.3	0.74	ns	40.1	40.5	0.41	ns
NSL-OP, mm	66.5	64.9	1.58	ns	64.1	64.7	0.48	ns

*p<.05

B. Timepoint 1 (T1) Facial Morphology

The T1 averaged tracings for UCLP and control groups are seen in Figures 7, 8, 9 and 10. The measured values are seen in Table 9. Although the absolute length of the mandible (ar-pg, mm) was similar in both groups, the sagittal position relative to the cranial base was decreased in the UCLP group. This retrognathic mandibular position is associated with an increased mandibular plane angle in the UCLP group. The mean difference between the UCLP and control group for the mandibular plane angle (NSL/ML) was 4.9 degrees, which is highly significant and accounts for several of the other measurements being significantly different as well. The sagittal jaw relationship was found to be greater in the UCLP group than the control group. Likewise, the vertical jaw relationship in the UCLP group was significantly greater than the control group.

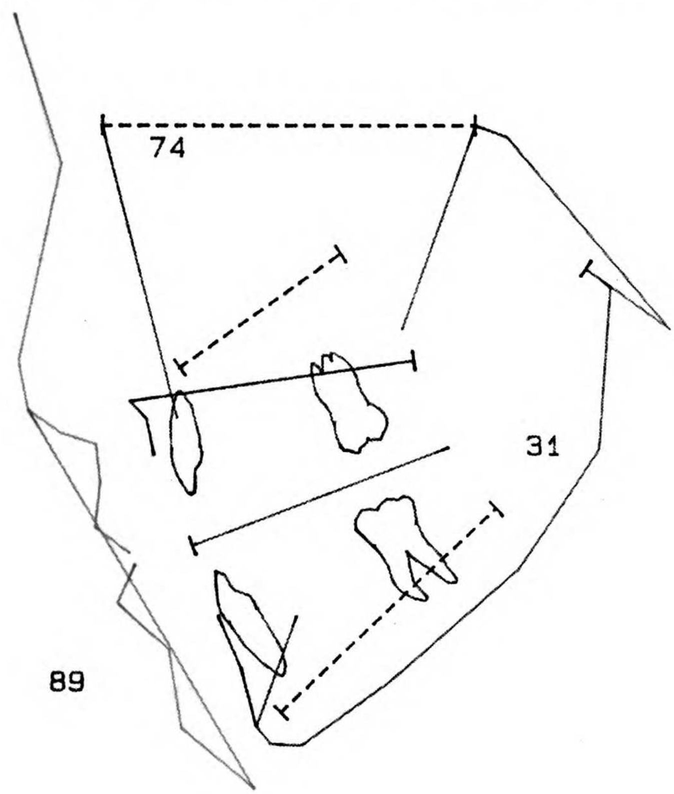

Figure 7. UCLP Group Mean Tracing at T1

Maxillary vertical position was also found to be significantly different between the two groups. A decreased vertical maxillary development of the palatal plane (NSL-

NL, mm) in the UCLP group was found. The dentoalveolar complex seemed to compensate, with the overall vertical maxillary development (NSL-OP, mm) slightly greater in the UCLP group than the control group (p<.05). The maxillary inclination was greater in the UCLP group than the control group. There was no difference in maxillary sagittal position between the two groups.

The cranial base angle was found to be greater in the UCLP group than the control group.

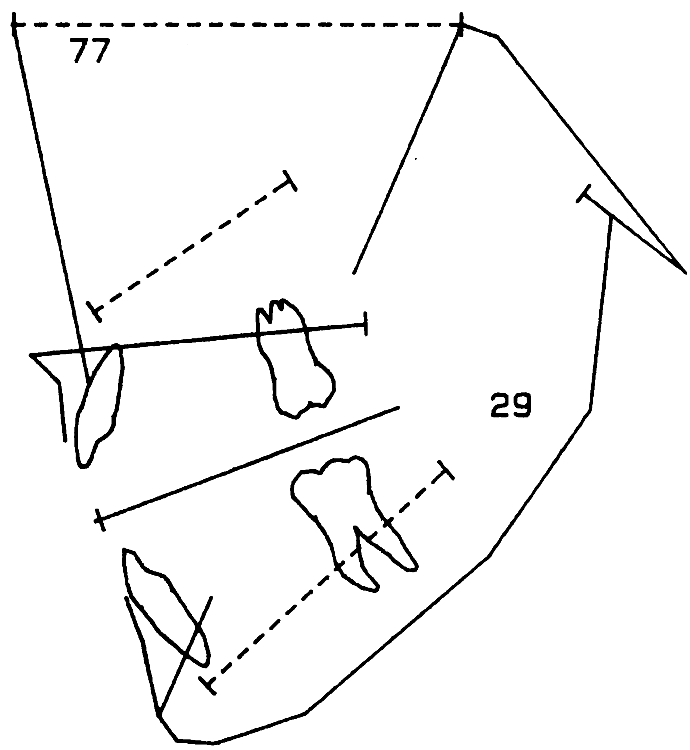

Figure 8. Control Group Mean Tracing at T1

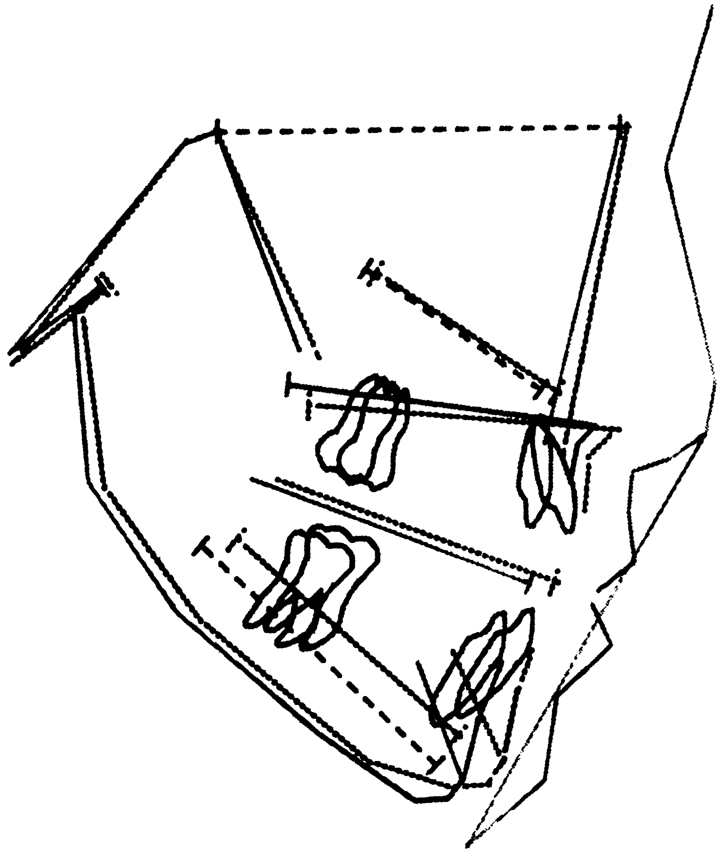

Figure 9. General Superimposition of Mean Tracings at T1. UCLP Group = solid line. Control Group = dashed line.

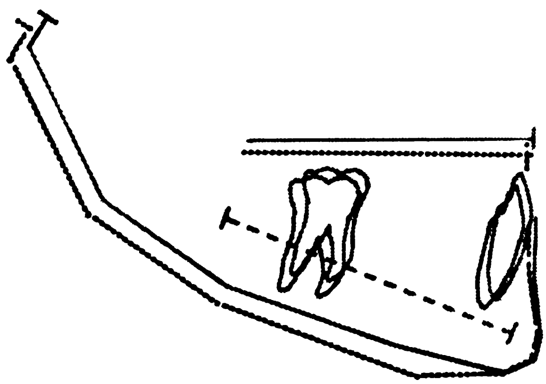

Figure 10. Mandibular Superimposition of Mean Tracings at T1. UCLP Group = solid line, Control Group = dashed line

Table 9: T1 Facial Morphology of UCLP and Control Groups

	UCLP Group		Control Group			
	Mean	**S.D.**	**Mean**	**S.D.**	**Mean Diff.**	**Signif.**
SNA	80.2	4.4	81.2	3.4	1	n.s.
SNPg	74	3.4	76.4	2.9	2.4	***
ANPg	6.1	4.4	4.8	2	1.2	*
NSL/NL	9.8	3.4	7.3	2.3	2.5	***
NSL/ML	41.1	6.1	36.1	4.7	4.9	***
NL/ML	31.2	5.7	29.1	4.9	2.1	*
NSL-NL, mm	38.7	3.4	40.3	3.5	1.5	**
NSL-OP, mm	65.9	4.2	64.4	4.2	1.5	*
ar-pg, mm	92.7	5.5	93.2	5.8	0.391	n.s.
NSBa	132.1	4.5	130	4.2	2	**

***p<.05 **p<.01 ***p<.001**

C. Timepoint 2 (T2) Facial Morphology

The T2 averaged tracings and measured values are seen in Figures 11, 12, 13, 14 and Table 10. The absolute mandibular length was similar for the two groups, but the sagittal position of the UCLP mandible is significantly more retrognathic than the control group. The significantly increased mandibular plane angle (NSL/ML) in the UCLP group is again associated with this retrognathic mandibular position. At T2, the sagittal jaw relationship of the UCLP group decreased to the point where no significant difference existed between the UCLP and control groups.

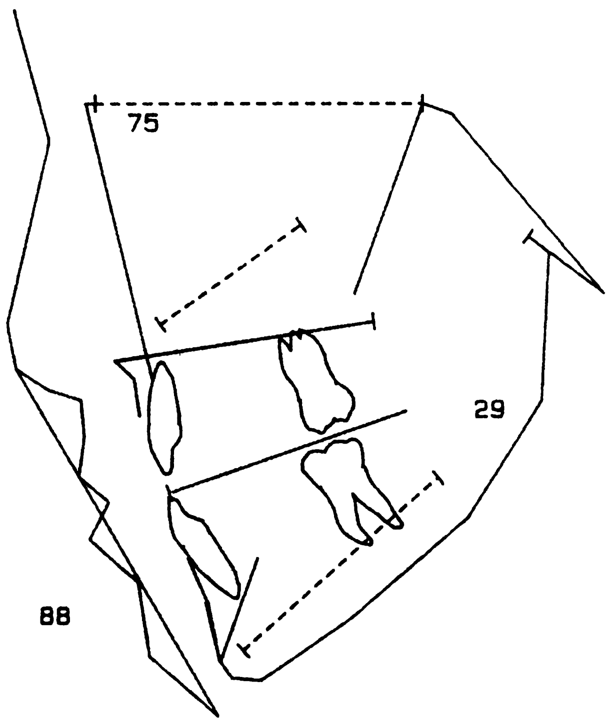

Figure 11. UCLP Group Mean Tracing at T2

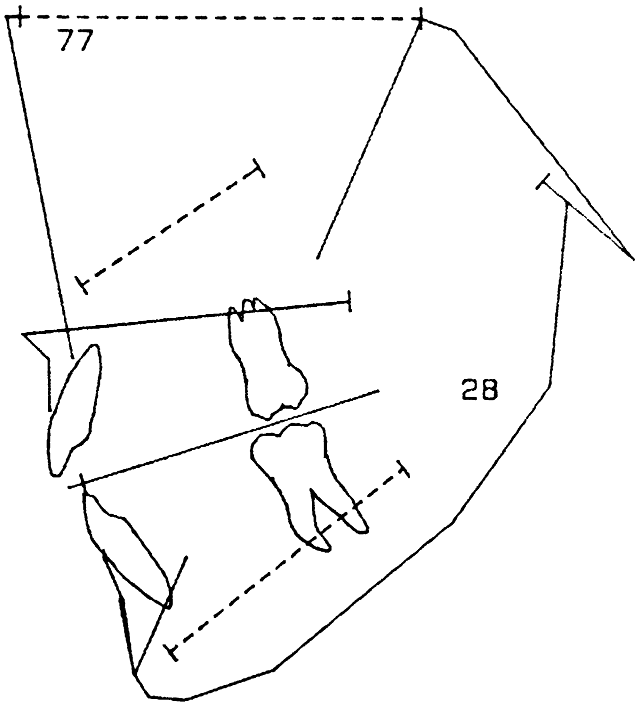

Figure 12. Control Group Mean Tracing at T2

The maxillary measurements at T2 were similar to T1: Decreased vertical development of the UCLP palatal plane; overcompensation of the dentoalveolar complex of the UCLP group to the point of overall greater vertical maxillary development (NSL-OP, mm) than the control group; greater maxillary inclination in the UCLP group than the control group. The maxillary sagittal position, which demonstrated no significant difference at T1, now demonstrates a significantly smaller value in the UCLP group than the control group.

The cranial base angle (NSBa) was significantly greater ($p<.05$) in the UCLP group than the control group.

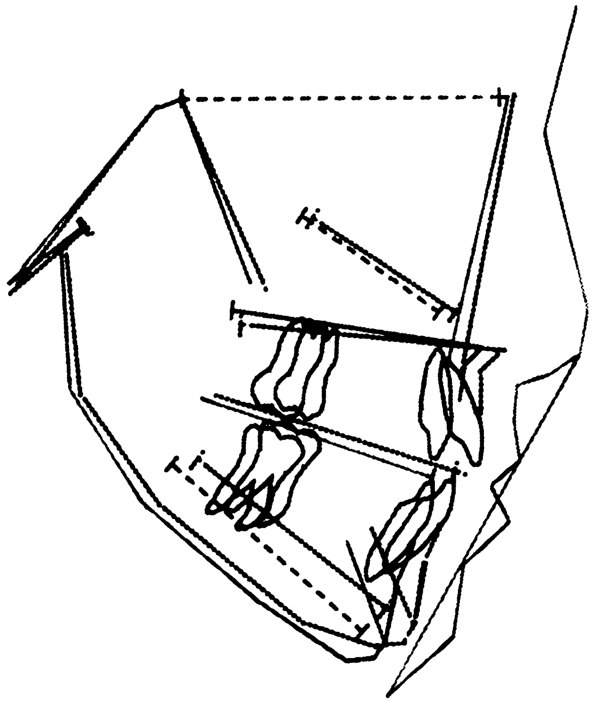

Figure 13. General Superimposition at T2. Solid line = UCLP Group, Dashed line = Control Group.

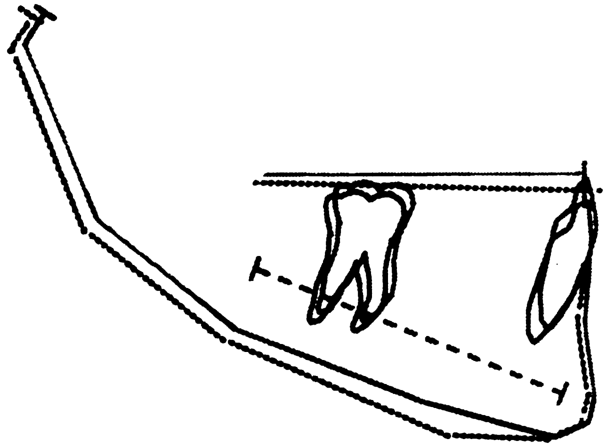

Figure 14. Mandibular Superimposition at T2. Solid line = UCLP Group, Dashed line = Control Group.

Table 10: T2 Facial Morphology of UCLP and Control Groups

	UCLP Group		Control Group			
	Mean	**S.D.**	**Mean**	**S.D.**	**Mean Diff.**	**Sign.**
SNA	78.8	4.5	81.2	3.2	2.4	**
SNPg	75	3.5	77.1	2.6	2.1	***
ANPg	3.8	4.7	4.1	1.9	0.26	n.s.
NSL/NL	10.4	3.2	7.4	2.6	3	***
NSL/ML	39.9	6.1	35.5	4.3	4.5	***
NL/ML	29.6	6	28	4.6	1.6	n.s.
NSL-NL, mm	41.9	3.4	43.4	3.9	1.5	**
NSL-OP, mm	69.7	5	67.2	4.7	2.4	**
ar-pg, mm	98.4	6.4	98.8	6.8	0.44	n.s.
NSBa	131.7	4.6	129.8	3.9	1.9	*

*p<.05 **p<.01 ***p<.001

D. Annualized Growth Changes from T1 to T2 for UCLP and Control Groups

The average changes from T1 to T2 for both UCLP and control groups are seen in Figure 15, 16, 17 and 18. The annualized computed differences between T1 and T2 are seen in Table 11. The vertical linear maxillary measurements demonstrated no significant differences from T1 to T2 between the two groups. Vertical maxillary sutural growth (NSL-zy, mm) averaged about 1mm per year. Vertical development of the palatal plane (NSL-NL, mm) averaged 1.5 mm per year. The vertical development of the maxillary occlusal plane (NSL-OP, mm) also averaged about 1.5 mm per year. The sagittal development of the maxilla (SNA) did show a significant difference, with the control group demonstrating no change and the UCLP group demonstrating –0.6 degrees per year.

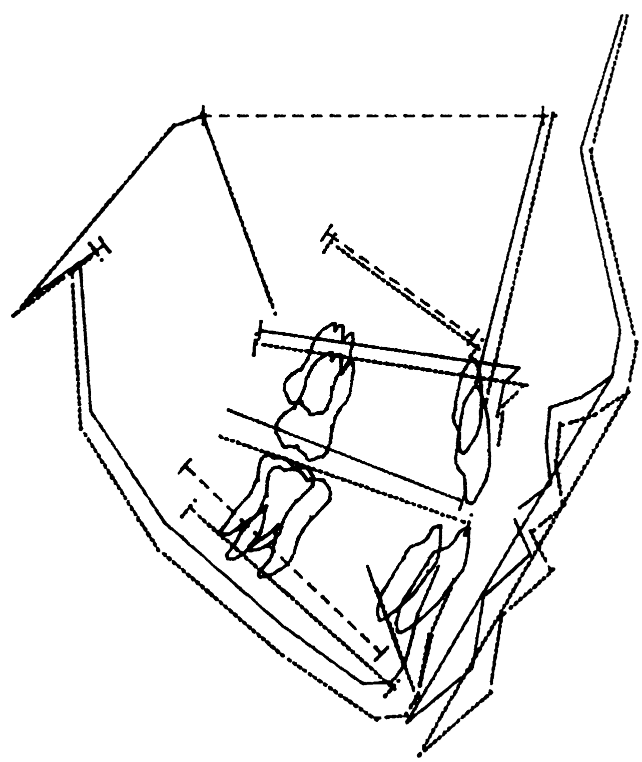

Figure 15. General Superimposition of Mean Changes from T1 to T2 for the UCLP Group

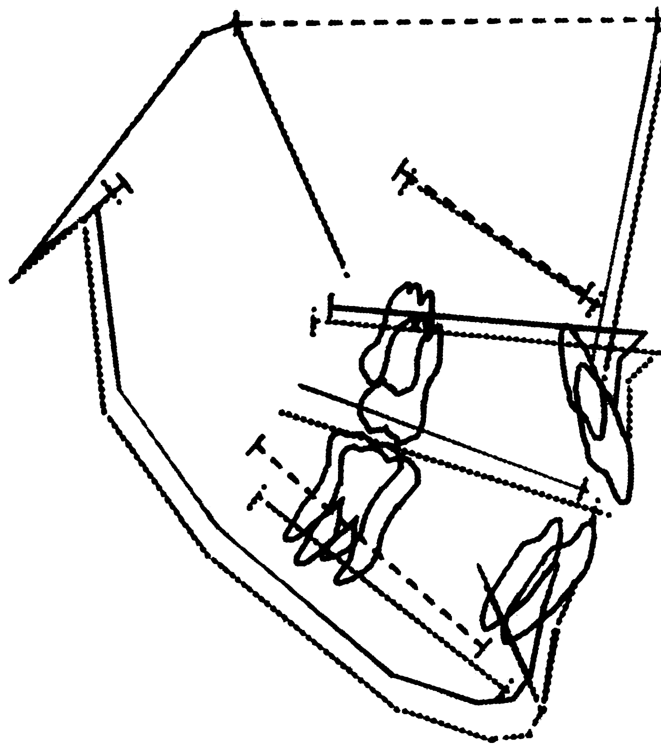

Figure 16. General Superimposition of Mean Changes from T1 to T2 for the Control Group

There were significant differences between the UCLP and control groups for the maxillary rotation and inclination. In the UCLP group, the maxilla demonstrated a backward or clockwise rotation, whereas the control group demonstrated a forward or counterclockwise rotation. The end result is a significant difference in the inclination of the palatal plane relative to the cranial base between the two groups. In the UCLP group, the inclination of the palatal plane (NSL/NL) increased 1.5 mm per year, whereas in the control group, the inclination of the palatal plane did not change.

Annualized changes in mandibular morphology demonstrated no significant differences between the UCLP and control group. Overall, mandibular growth (ar-pg, mm) was found to average 2.5 mm per year for both groups. Mandibular rotation occurred in a forward direction in the amount of approximately 1mm per year. The mandibular sagittal position increased about 0.5 mm per year. The mandibular vertical position decreased about –0.3 mm per year.

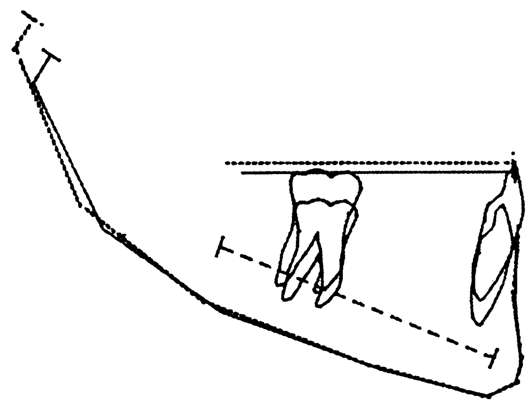

Figure 17. Mandibular Superimposition of Mean Changes from T1 to T2 for the UCLP Group.

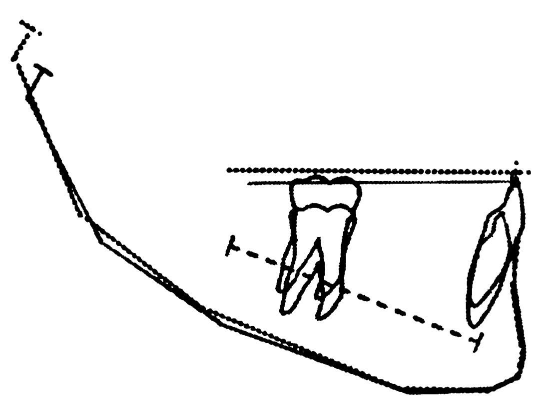

Figure 18. Mandibular Superimposition of Mean Changes from T1 to T2 for the Control Group.

The sagittal jaw relationship, ANPg, decreased approximately 1 degree per year for the UCLP group and 0 degrees for the control group ($p<.01$).

In summary, although many differences in morphology exist between the UCLP and control groups at T1 and T2, there are actually few differences in the rate of growth between the two groups. The differences are related primarily to maxillary growth, with a restriction in posterior maxillary vertical growth. This restriction of the vertical growth of the posterior maxilla relative to the vertical growth of the anterior maxilla leads to a posterior maxillary growth rotation, an increase in the palatal plane inclination, and, along with the decreased maxillary sagittal position, a decrease in the sagittal jaw relationship.

Table 11: Annualized Changes from T1 to T2 for UCLP and Control Groups.

Measurement (Annualized)	UCLP Group Mean	S.D.	Control Group Mean	S.D.	Mean Diff.	Signif.
Mand. Rotation	-0.8	1.7	-1.2	1.2	0.35	n.s.
ar-pg, mm	2.4	1.1	2.5	1	0.126	n.s.
SNPg	0.4	1	0.3	1.2	0.086	n.s.
NSL/ML	-0.4	1.4	-0.2	1.5	0.203	n.s.
Maxillary rotation	0.4	1.4	-0.2	1.1	0.592	*
NSL-NL, mm	1.5	1.2	1.5	0.8	0.045	n.s.
NSL-OP, mm	1.7	1.2	1.3	1.2	0.428	n.s.
NSL-zy, mm	0.8	0.6	1	0.6	0.147	n.s.
NSL/NL	1.5	1.2	0	1	1.536	***
NL/ML	-0.8	1.8	-0.5	1.4	0.361	n.s.
SNA	-0.6	1.6	-.05	1.4	0.59	*
ANPg	-0.8	1.8	0	0	0.729	**
NSBa	-0.2	1.3	-0.3	1.2	0.058	n.s.

*p<.05 **p<.01 ***p<.001

E. Correlation between Vertical Maxillary Growth and Mandibular Growth

Table 12 displays the results of the correlations between vertical maxillary growth and mandibular growth. The vertical maxillary measurements included maxillary sutural growth (NSL-Zy, mm), vertical change of the palatal plane (NSL-NL, mm), vertical change of the maxillary occlusal plane (NSL-OP, mm), and the total maxillary rotation from T1 to T2.

These maxillary measurements were correlated to three measures of mandibular position. The mandibular measurements were the mandibular sagittal position (SNPg), the mandibular inclination (NSL/ML), and the total mandibular rotation from T1 to T2.

For both the control group and the UCLP group the total maxillary rotation was significantly correlated to all three mandibular measurements ($p<.01$). This means that the greater the posterior rotation of the maxilla: the more retrognathic the mandible; the steeper the mandibular plane; and the greater the posterior rotation of the mandible.

Besides total maxillary rotation, total mandibular rotation was most affected by vertical maxillary growth (NSL-Zy, mm) for the UCLP group and change in vertical position of the maxillary occlusal plane (NSL-OP, mm) for the control group.

For the mandibular vertical position, or mandibular plane angle (NSL/ML), the only significant findings in the UCLP group were the linear measurements, NSL-Zy and NSL-OP.

The measurement of mandibular sagittal position (SNPg) revealed that the less maxillary vertical sutural growth, the greater the mandibular sagittal position in the UCLP group. For the control group, an opposite correlation existed for the vertical measurement of the palatal plane. The greater the vertical change in the palatal plane, the greater the mandibular sagittal position.

Table 12: Correlation between Maxillary Vertical Growth and Mandibular Position

	UCLP Group				Control Group			
Measure	Correlation	P Value	Bon-Holm P Value	Bon-Holm adj. Signif.	Correlation	P Value	Bon-Holm P Value	Bon-Holm adj. Signif.
Mand. Rot. vs NSL-NL, mm	-0.1	0.47	0.47	ns	-0.12	0.38	0.38	ns
Mand. Rot. vs NSL-OP, mm	0.12	0.36	0.59	ns	0.24	0.09	0.24	ns
Mand. Rot. vs NSL-Zy, mm	0.26	0.06	0.17	ns	-0.14	0.32	0.54	ns
Mand. Rot. vs Max. rot.	0.4	0.003	0.01	**	0.5	0.0001	0.0004	***
NSL/ML vs NSL-NL, mm	0.03	0.82	0.82	ns	-0.34	0.02	0.05	*
NSL/ML vs NSL-OP, mm	0.25	0.06	0.12	ns	0.03	0.8	0.8	ns
NSL/ML vs NSL-Zy, mm	0.36	0.006	0.02	*	0.06	0.66	0.89	ns
NSL/ML vs Max. rot.	0.3	0.03	0.08	ns	0.37	0.006	0.02	*
SNPg vs NSL-NL, mm	-0.1	0.52	0.52	ns	0.4	0.002	0.009	**
SNPg vs NSL-OP, mm	-0.2	0.21	0.37	ns	-0.1	0.55	0.55	ns
SNPg vs NSL-Zy, mm	-0.3	0.04	0.11	ns	0.12	0.41	0.65	ns
SNPg vs Max. rotation	0.4	0.006	0.02	*	-0.33	0.01	0.04	*

*p<.05 **p<.01 ***p<.001

F. Comparison of Computerized Growth Predictions to Actual Measurements for the UCLP and Control Groups

The computer (TIOPS™) growth prediction values were compared to the actual T2 values with the results found in Table 13 and 14. For both groups the mandibular growth predictions were accurate to about 0.25 degrees for both sagittal and vertical measurements. The vertical jaw relationship (NL/ML) prediction was within 0.5 degrees as was the cranial base angle.

The only significant differences were found for the maxillary sagittal position (SNA) and thus the sagittal jaw relationship (ANPg). For both the UCLP and control group, the actual values for SNA and ANPg were less than the predicted values.

Table 14: Comparison of Actual T2 values to Computer Prediction values for the Control Group.

Measure	Actual T2 value	Computer Predicted Value	Mean Difference	Significance
SNA	78.9	81.3	2.4	***
SNPg	77.1	76.9	0.21	n.s.
ANPg	4.1	4.5	0.4	*
NSL/NL	7.4	7.3	0.04	n.s.
NSL/ML	35.4	35	0.33	n.s.
NL/ML	27.9	27.7	0.25	n.s.
NSBa	129.8	130.2	0.39	n.s.

*p<.05 **p<.01 ***p<.001

Table 14: Comparison of Actual T2 values to Computer Prediction values for the Control Group.

Measure	Actual T2 value	Computer Predicted Value	Mean Difference	Significance
SNA	78.9	81.3	2.4	***
SNPg	77.1	76.9	0.21	n.s.
ANPg	4.1	4.5	0.4	*
NSL/NL	7.4	7.3	0.04	n.s.
NSL/ML	35.4	35	0.33	n.s.
NL/ML	27.9	27.7	0.25	n.s.
NSBa	129.8	130.2	0.39	n.s.

*p<.05 **p<.01 ***p<.001

V. Discussion

The concept of growth rotation was first demonstrated by Bjork in his implant study of facial growth in 1955 [42]. The fact that the lower border of the mandible on average changes during the growth period, and becomes less inclined with time, was pointed out first by Lande in 1952 [43]. However, it was not until the introduction of metallic implants by Bjork, that it was possible to demonstrate that a much greater underlying mandibular rotation occurs, which is masked by periosteal remodeling at the lower border. Bone growth in areas that articulate with other bones is termed articular growth. Bone growth in areas that do not articulate with other bones is termed remodeling growth. The corpus, or central core of a bone is the part that is not affected by articular or remodeling growth. To determine the displacement of the bone corpus, points are needed which remain stable in the bone corpus, defined by internal structures or by implants. Articular growth results in bone displacement whereas remodeling growth occurs without bone displacement. In a single bone, the overall change in shape and size due to both articular and remodeling growth may be determined by superimposing successive cephalometric radiographs on stable internal structures.

It is well known that individuals with repaired clefts of the lip and palate demonstrate abnormal maxillary growth [44]. The precise etiology of the deficient growth it not fully understood, although is seems likely that a large proportion of this results from scarring produced by the primary surgical repair [29]. Scar formation is unavoidable if the cleft defect is to be repaired, although it appears that different types of surgical procedures can have different outcomes in terms of craniofacial growth [33]. There are a variety of techniques used in the treatment of patients with clefts. For example, some clinicians advocate the use of presurgical orthopedics as an adjunct to surgery. Despite the fact that no long-term benefits of this technique have been shown, it is in wide use, with pinned orthopedic plates suggested as an effective way of helping the surgical repair [45] [46] [47]. Recent intercenter study results have shown that the centers with the more conservative treatment protocols, no use of presurgical orthopedics, and large annual case loads produce more favorable results in terms of craniofacial growth [34].

In the present study, the aim was to evaluate mandibular growth, mandibular growth rotation, and mandibular growth prediction in unilateral cleft lip and palate individuals. Also of interest was to determine the effects of altered maxillary growth on the overall growth of the mandible. The study used serial lateral cephalometric radiographs of UCLP individuals who had undergone a standard surgical cleft lip and palate repair, but no orthodontic or orthopedic treatment. This study was unique in that it evaluated longitudinal records and used the Bjork superimposition technique for evaluating mandibular growth. This study was the first to test a growth prediction model on UCLP individuals.

Comparing the craniofacial morphology of the UCLP individuals to that of the control group at T1 revealed that there were statistically significant differences for all measurements except mandibular length and maxillary sagittal position. Mandibular length seems to be unaffected by clefting or its surgical repair. This would indicate that there is no intrinsic mandibular growth disturbance in absolute mandibular length. Although not significant, the maxillary sagittal position of the UCLP group was less than that of the control group, which would be in agreement with previous studies [10] [11]

[12] [13] [14] [15].

The sagittal jaw relationship was significantly greater in the UCLP group than the control group. The control group was chosen based on a near normal (class I) sagittal jaw relationship, but it would be expected that the UCLP group might have a decreased or negative sagittal jaw relationship. This increased sagittal jaw relationship was primarily due to a retrognathic mandible. The retrognathic mandibular position can be attributed to a steep mandibular plane. The increased mandibular plane angle also accounts for the increased vertical jaw relationship seen in the UCLP group. It has been postulated that frequent respiratory infections and nasal septal deviations are possible causes of mouth breathing and habitual open mouth position. These factors, together with a narrow maxillary arch and a low palatal vault cause these individuals to assume a low tongue posture. As a result the mandible drops down and back, resulting in an increased mandibular plane angle [48] [49].

Comparing the craniofacial morphology at T2, between the UCLP group and the controls, show very similar values with two notable exceptions. First, the vertical jaw relationship (NL/ML) in the UCLP group was similar to the control at T2, where it was increased at T1. This finding is the result of a steepening or backward rotation of the palatal plane. The measure NSL/NL did not increase from T1 to T2 for the control group, whereas for the UCLP group, it increased from 9.8 degrees to 10.4 degrees. Second, the sagittal jaw relationship, which was significantly greater in the UCLP group than the control group at T1, shows no difference at T2 between the two groups. Because the mean ages at T1 and T2 were 6 years and 8 years, respectively, it may be speculated that the inhibition of maxillary growth is just beginning[50]. It seems that while the control group maxilla is not changing relative to the cranial base, the UCLP maxilla is demonstrating a trend of decreased growth. This seems to be most true for the posterior vertical maxilla, thus explaining the backward rotation of the palatal plane.

The annualized changes of the mandibular measurements showed no difference between the two groups. The change in mandibular length was about 2.5 mm per year (+/-1 mm) for both control and UCLP subjects, which is similar to other growth studies [42] [1]. Mandibular total rotation was approximately –1 (+/-1.5) degree per year, which is in agreement with Bjork's findings[7]. The change in mandibular sagittal position also was similar for both groups.

Changes in maxillary development varied considerably. The linear measurements of the vertical position of the maxillary suture (NSL-zy, mm), the palatal plane (NSL-NL, mm), and the occlusal plane (NSL-OP, mm) showed similar annual changes with the suture being displaced about 1 mm per year and the palatal plane and occlusal plane about 1.5 mm per year. There were significant differences, however, again in the changes in the palatal plane relative to the cranial base. While the control group measurement NSL/NL showed no change, the UCLP demonstrated an increase of 1.5 mm per year. This suggests that there is differential growth between the anterior and posterior portions of the maxilla, in the vertical plane, with the end result being a steepening of the palatal plane. The other measurement demonstrating a significant difference between the UCLP and control groups is the maxillary sagittal position (SNA), which was shown to decrease by 0.6 degrees per year in the UCLP group, while remaining unchanged in the control group. This too may be attributed to a restriction of growth in the posterior maxilla. The change in the sagittal jaw relationship (ANPg) is –

0.08 degrees per year in the UCLP group, while remaining unchanged in the control group.

The association between maxillary vertical development and the vertical and sagittal development of the mandible suggests that, overall, the rotational changes of the maxilla effect the position and growth of the mandible. This was true for both control and UCLP groups for all mandibular measurements except for the mandibular plane angle. This finding indicates that the altered respiration and low tongue posture may have a greater influence on mandibular vertical position than does the maxillary rotation [48]. The only other positive correlation found was that of the vertical displacement of the palatal plane (NSL-NL, mm) and the sagittal position of the mandible (SNPg). This suggests that, in individuals with a large growth potential, that the sagittal growth of the mandible keeps up with or exceeds the vertical displacement of the palatal plane.

The computer growth prediction model (TIOPS™) proved to be highly accurate for predicting mandibular growth for both the control and UCLP groups. The predictions were within 0.5 degrees for both the vertical and sagittal mandibular measurements. The significant differences that did occur were due to the decreased growth of the maxilla in the UCLP group. The actual measurement for the maxillary sagittal position was 1.7 degrees less than the predicted value. This influenced the sagittal jaw relationship, ANPg, where the actual measure was 2 degrees less than the predicted value.

VI. Conclusions

Hypothesis 1. There were significant differences found in the craniofacial morphology of UCLP subjects compared to control subjects:

a. Increased sagittal jaw relationship at T1 due to a retrognathic mandible.

b. Increased vertical jaw relationship at T1 due to a steep mandibular plane angle.

c. No difference in the absolute mandibular length.

d. The annualized rate of growth demonstrated significant differences between the UCLP and control groups due to an inhibition of maxillary sagittal and posterior vertical growth.

Therefore, the null hypothesis must be rejected.

Hypothesis 2. There were no significant differences in the total mandibular rotation between UCLP and control subjects.

a. Both groups demonstrated approximately 1 degree per year of forward mandibular growth rotation. Therefore the null hypothesis cannot be rejected

Hypothesis 3. There were weak correlations between the effects of maxillary vertical growth on mandibular sagittal and vertical growth. There were no strong differences between the UCLP subjects and the control subjects.

a. The greater the backwards rotation of the maxilla, the greater the retrognathic and vertical position of the mandible. The null hypothesis cannot be rejected, but the evidence is not strong.

Hypothesis 4. There were no differences between UCLP and control subjects for prediction of mandibular growth using a computer prediction mode.

a. The accuracy of the prediction for the sagittal and vertical position of the mandible was about 0.25 degrees for both groups. Therefore, the null hypothesis cannot be rejected.

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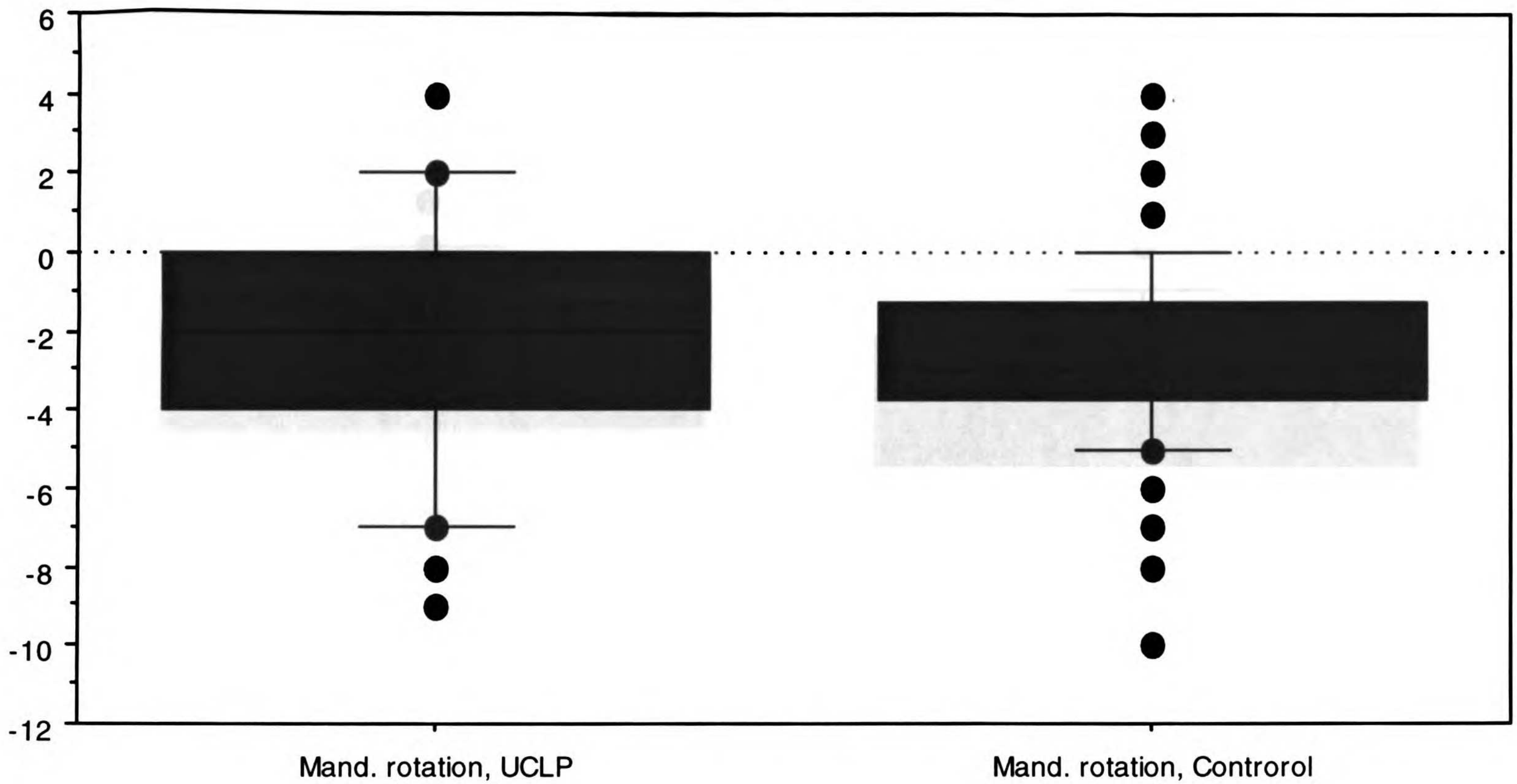


Fig. 19: Mandibular Growth Rotation between T1 and T2 for UCLP and Control Groups.

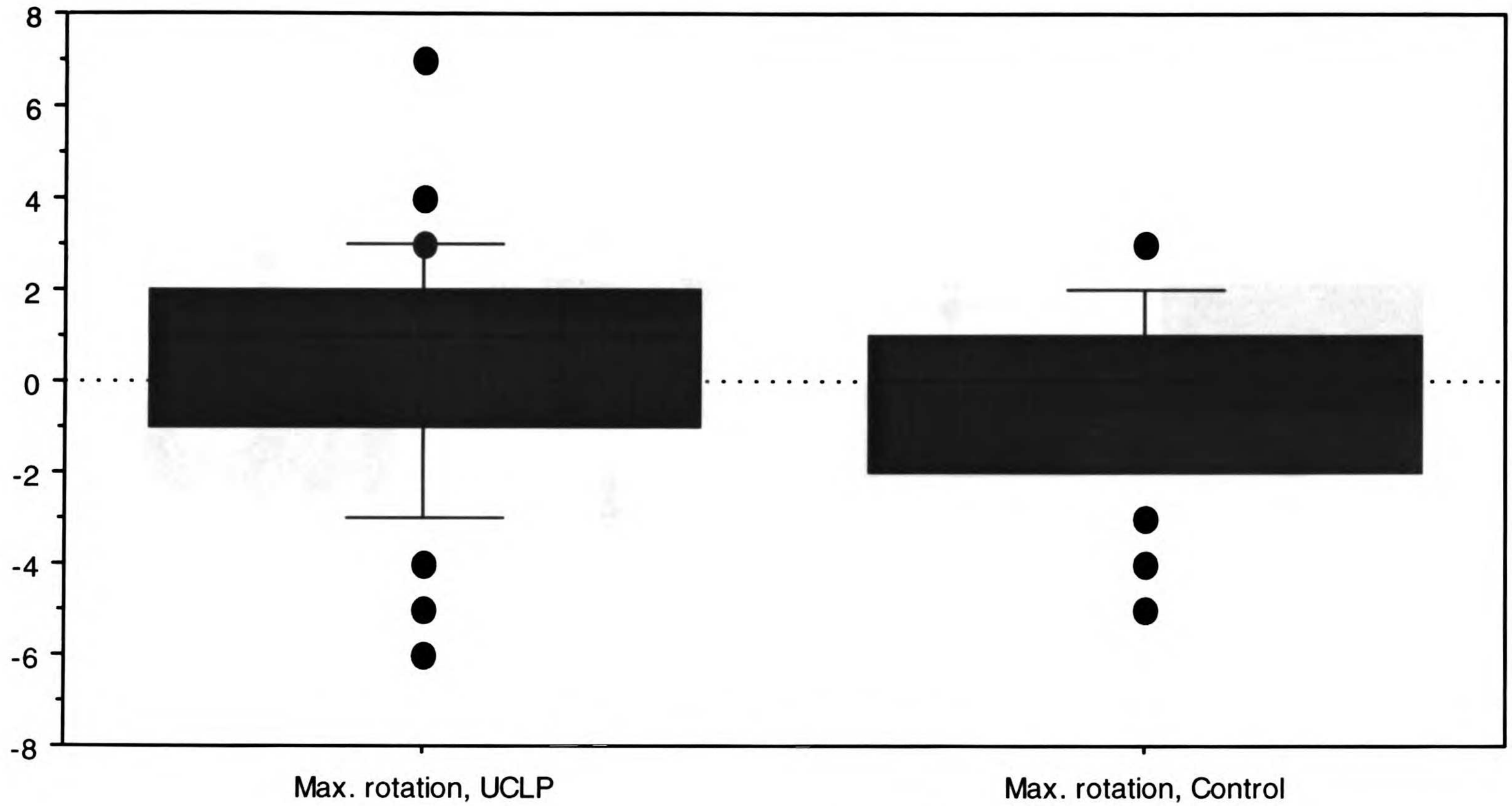


Fig. 20 : Maxillary Growth Rotation between T1 and T2 for UCLP and Control Groups.

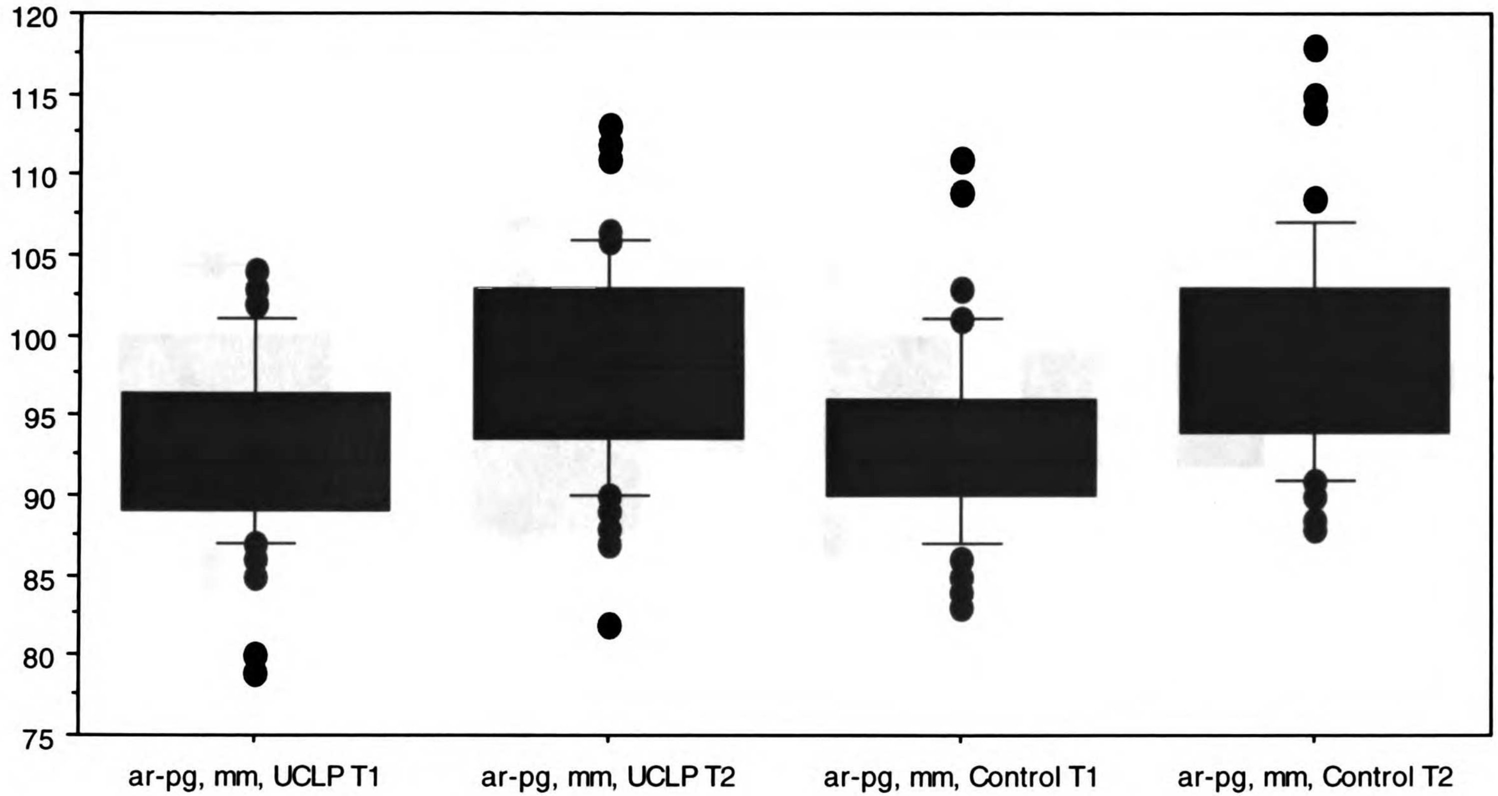


Fig. 21 : Distance articulare (ar) to pogonion (pg) in mm, for UCLP and Control groups.

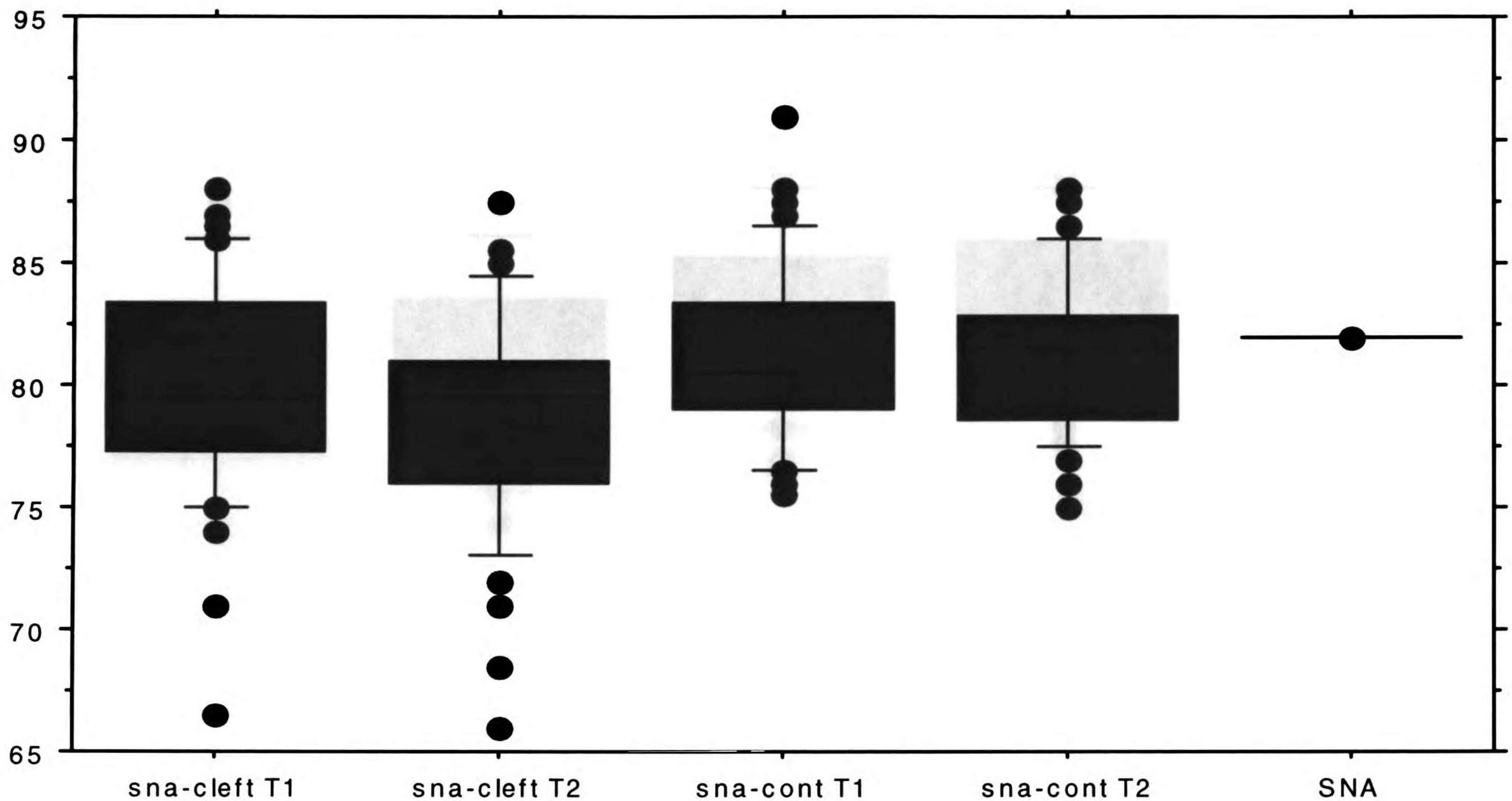


Fig. 22 : Angle SNA for UCLP and Control group. Bjork mean included.

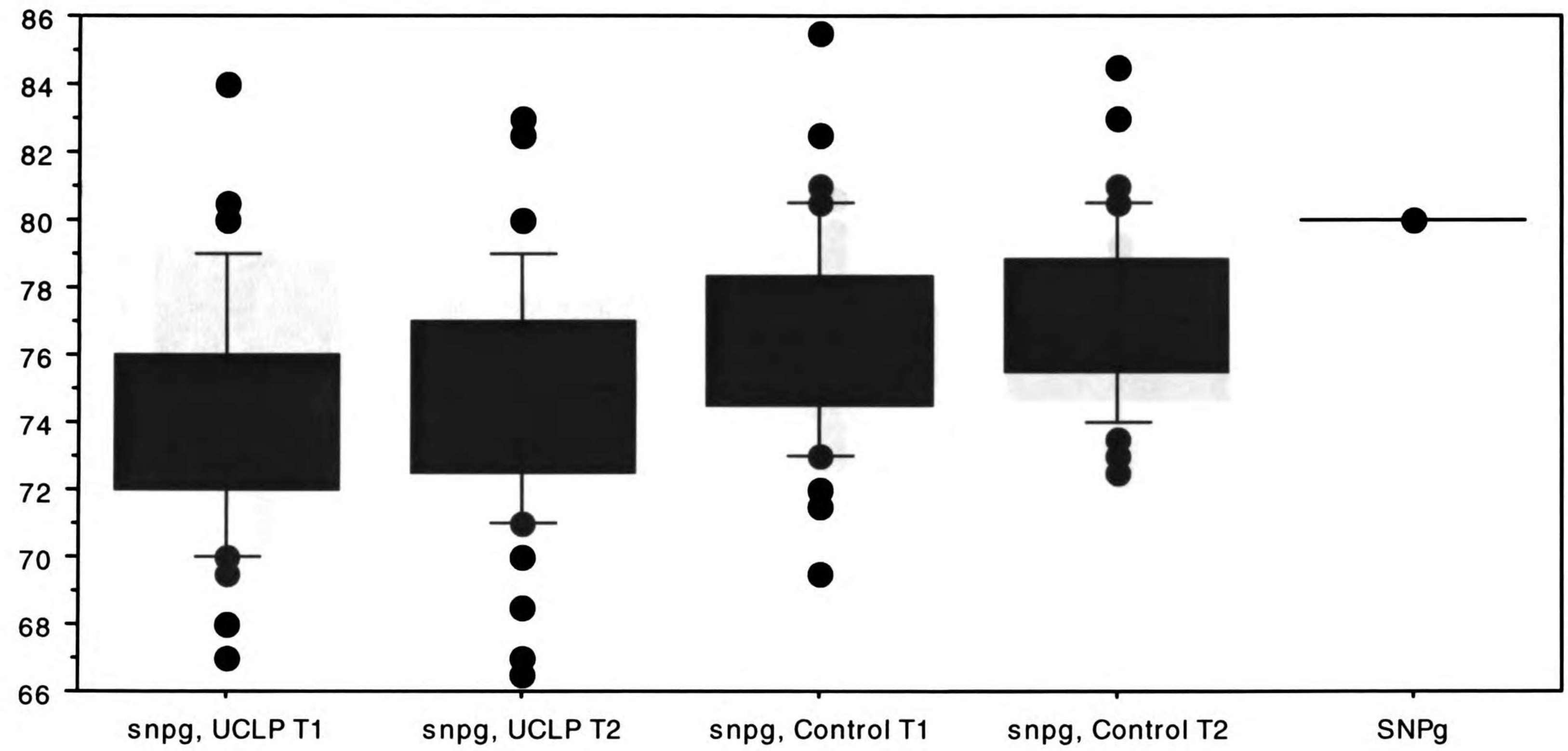


Fig. 23 : Angle SNPg for UCLP and Control Groups. Bjork mean included.

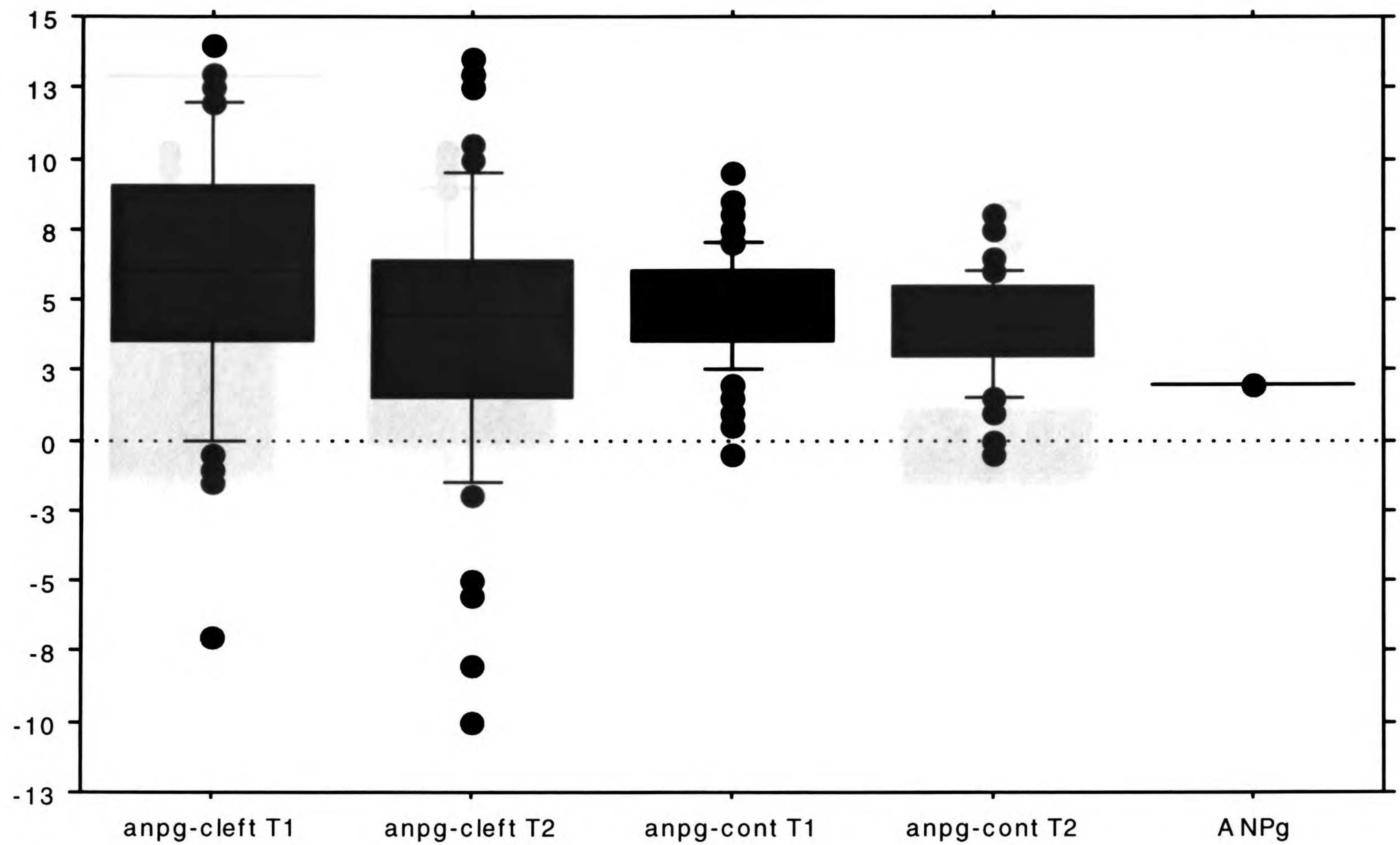


Fig. 24 : Angle ANPg for UCLP and Control Groups. Bjork mean included.

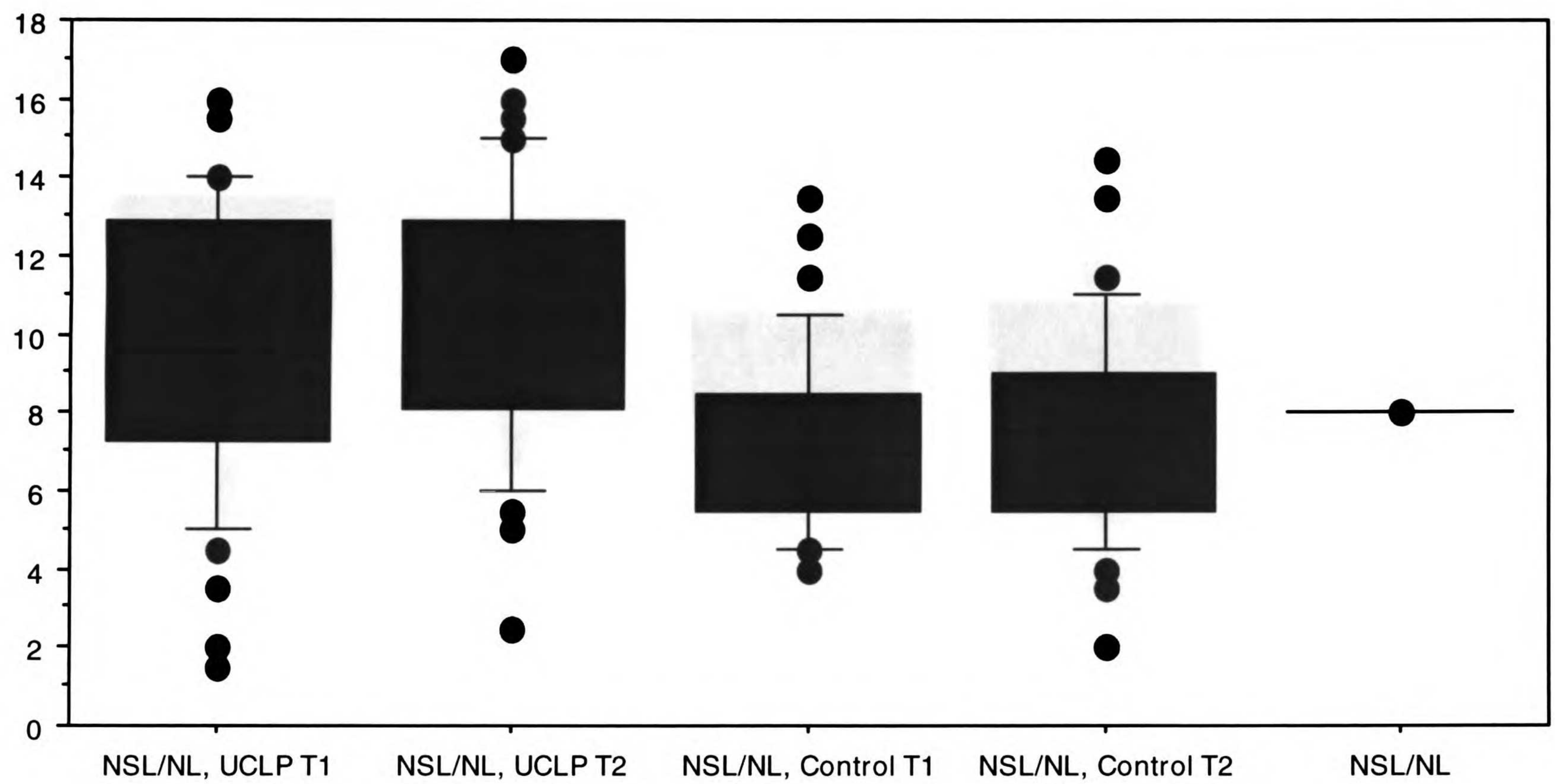


Fig. 25 : Angle NSL/NL for UCLP and Control Groups. Bjork mean included.

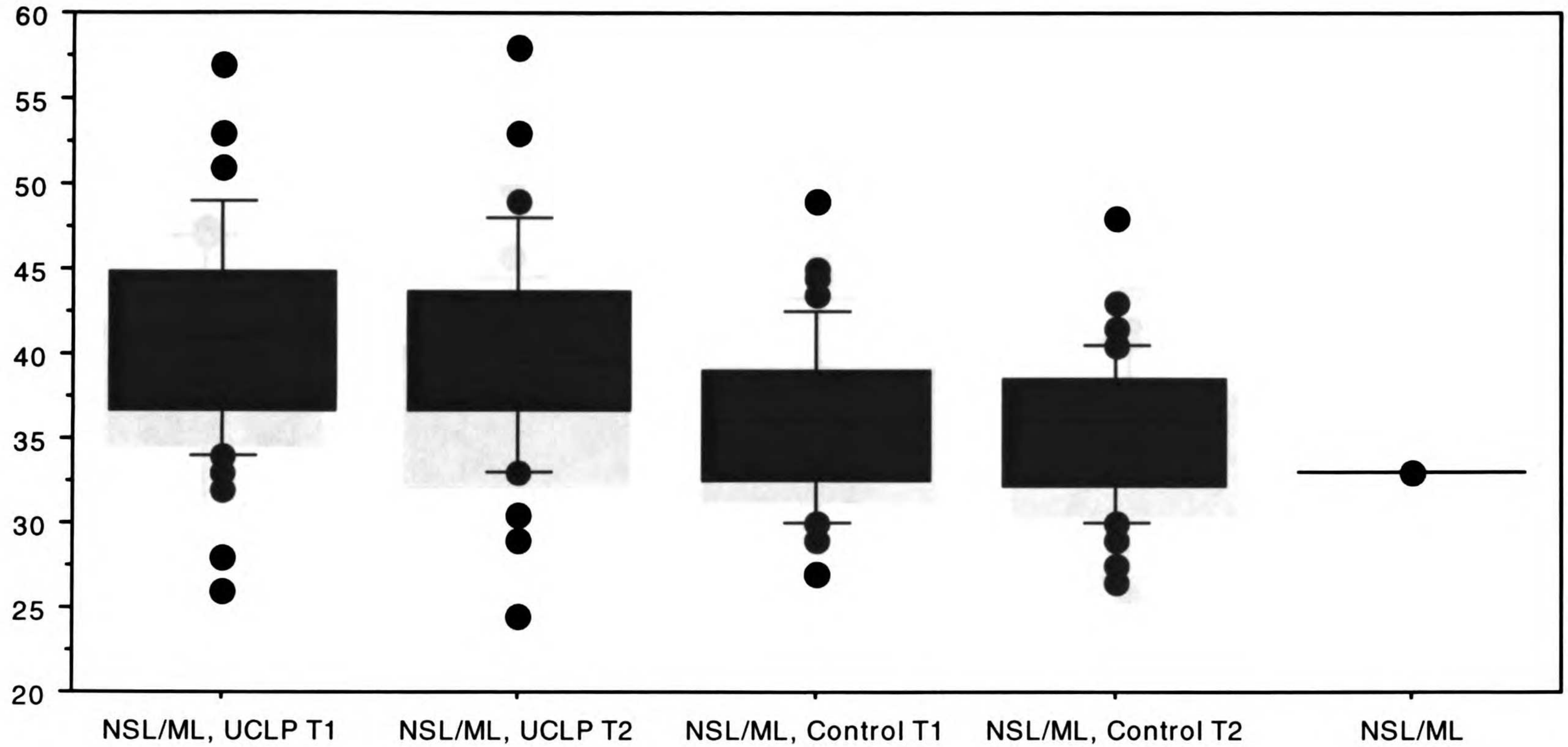


Fig. 26 : Angle NSL/ML for UCLP and Control Groups. Bjork mean included.

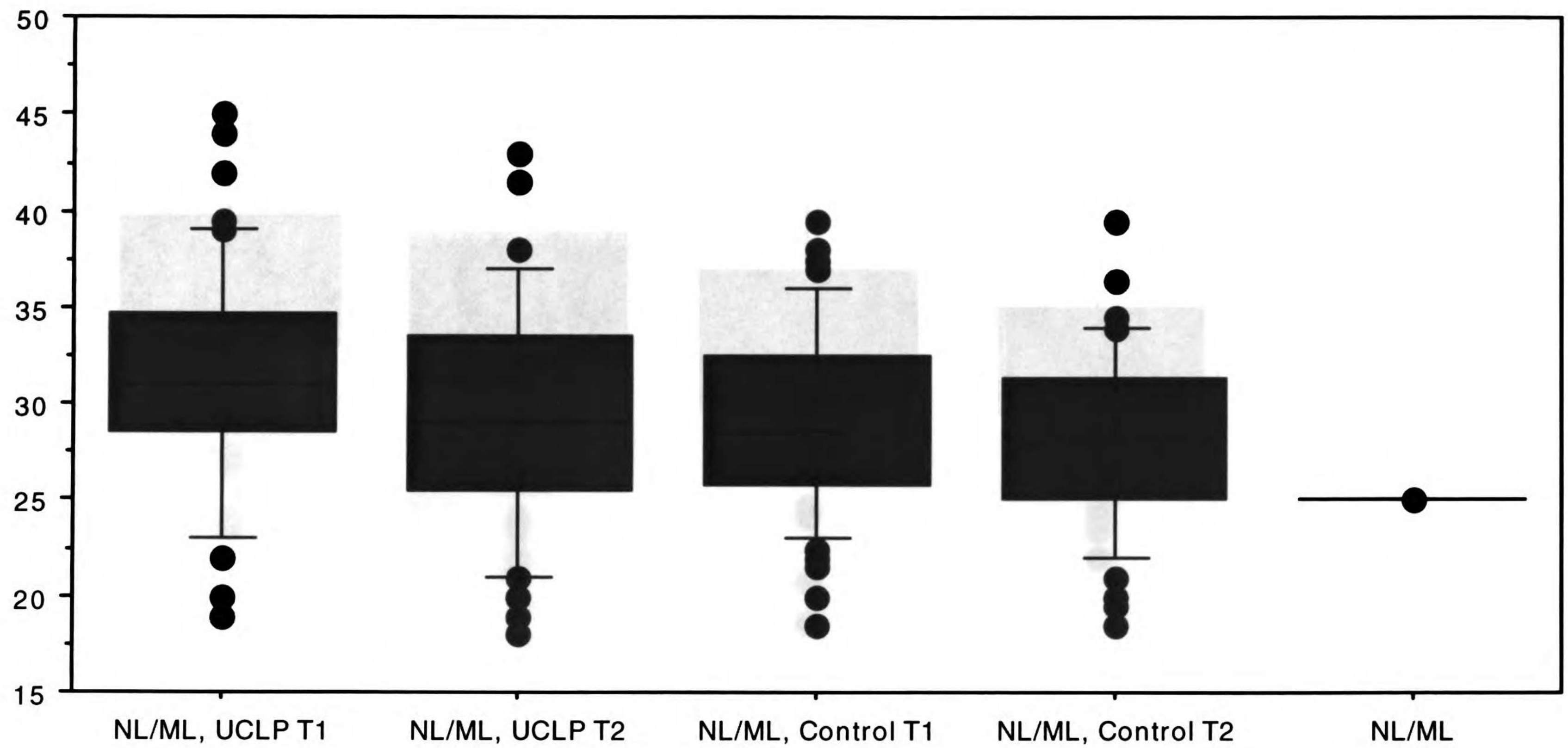


Fig. 27: Angle NL/ML for UCLP and Control Groups. Bjork mean included.

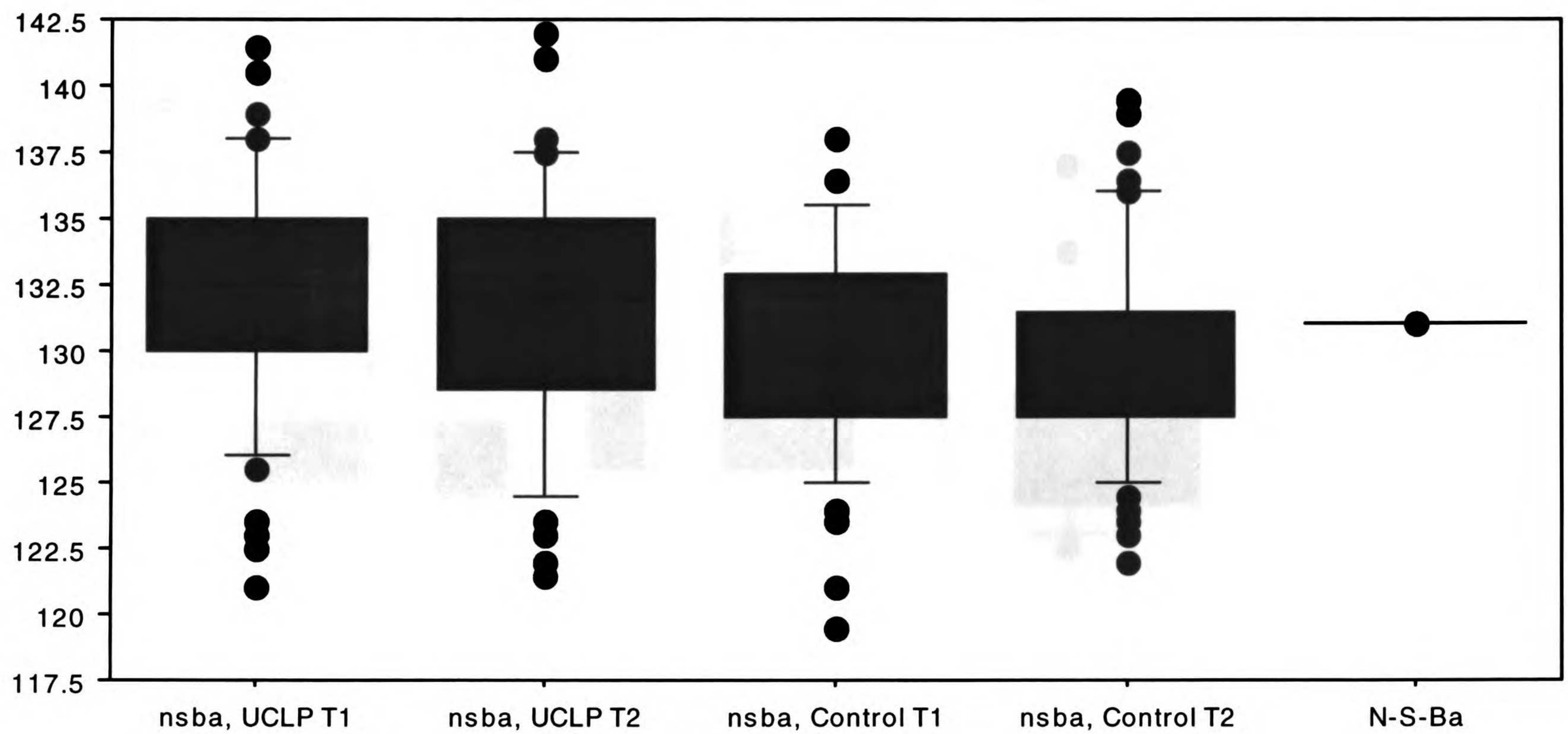


Fig. 28: Angle N-S-Ba for UCLP and Control Groups. Bjork mean included.

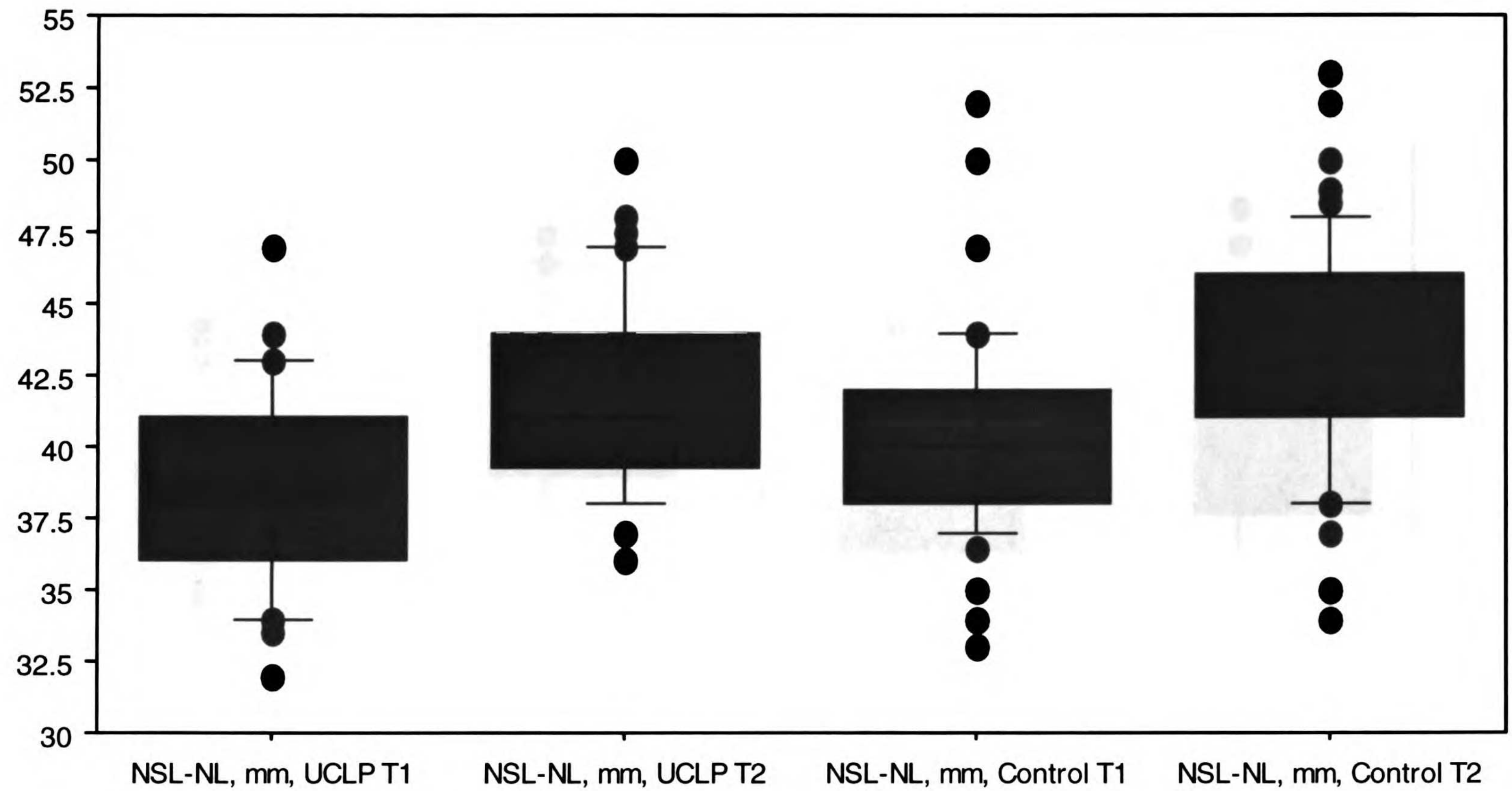


Fig. 29: Distance NSL to NL in mm for UCLP and Control Groups.

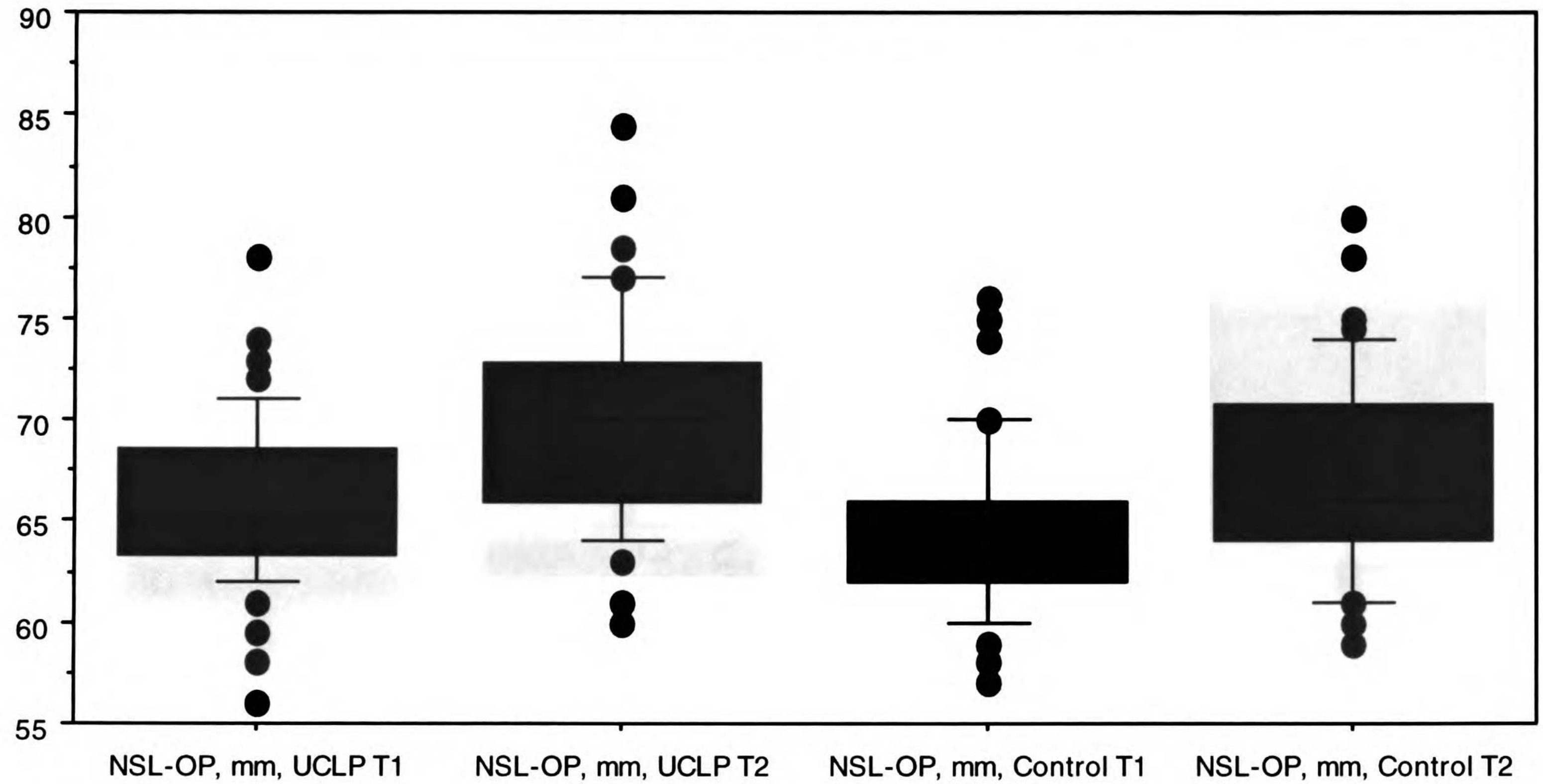


Fig. 30: Distance NSL to OP in mm for UCLP and Control Groups.

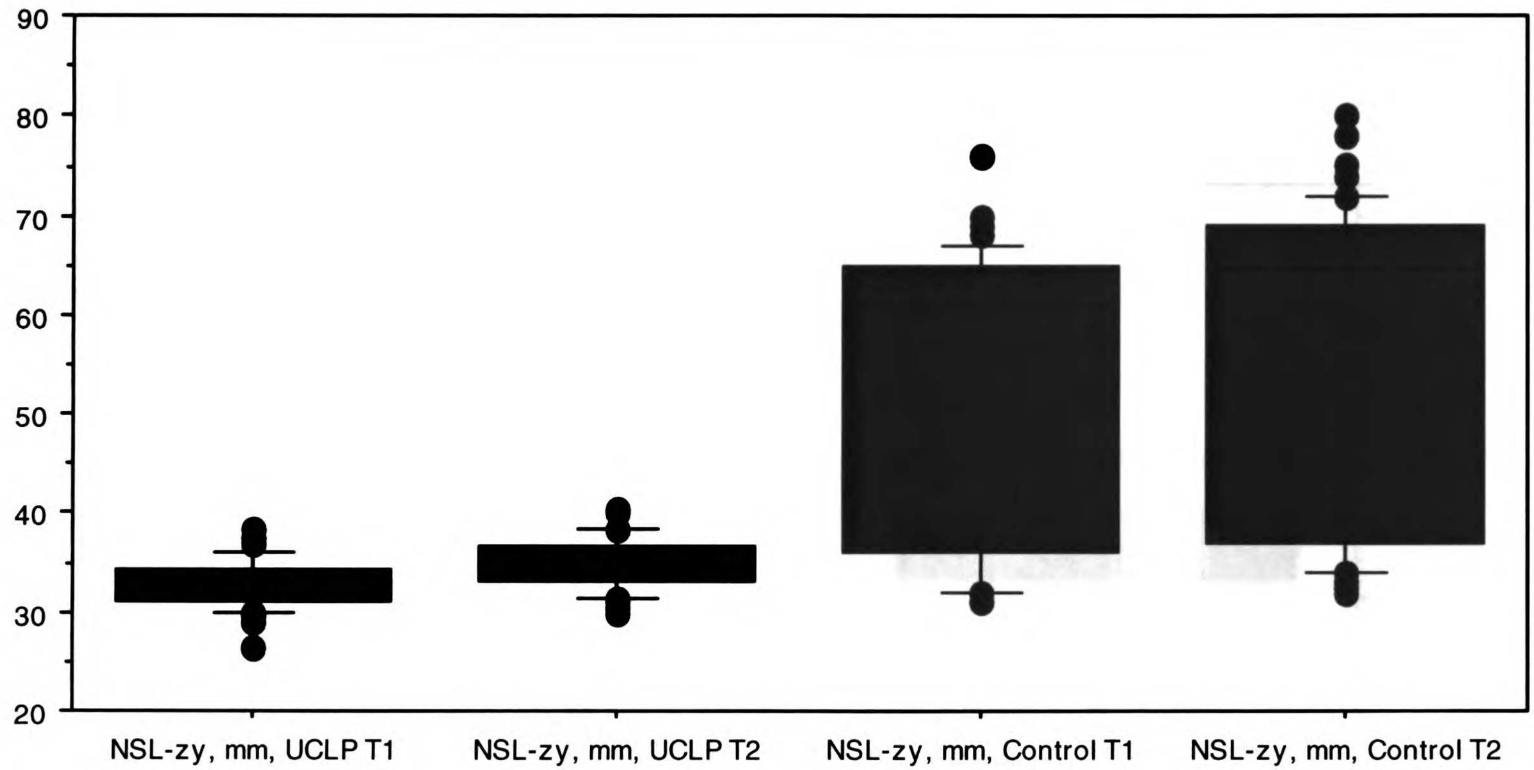


Fig. 31: Distance NSL to zy in mm for UCLP and Control Groups.

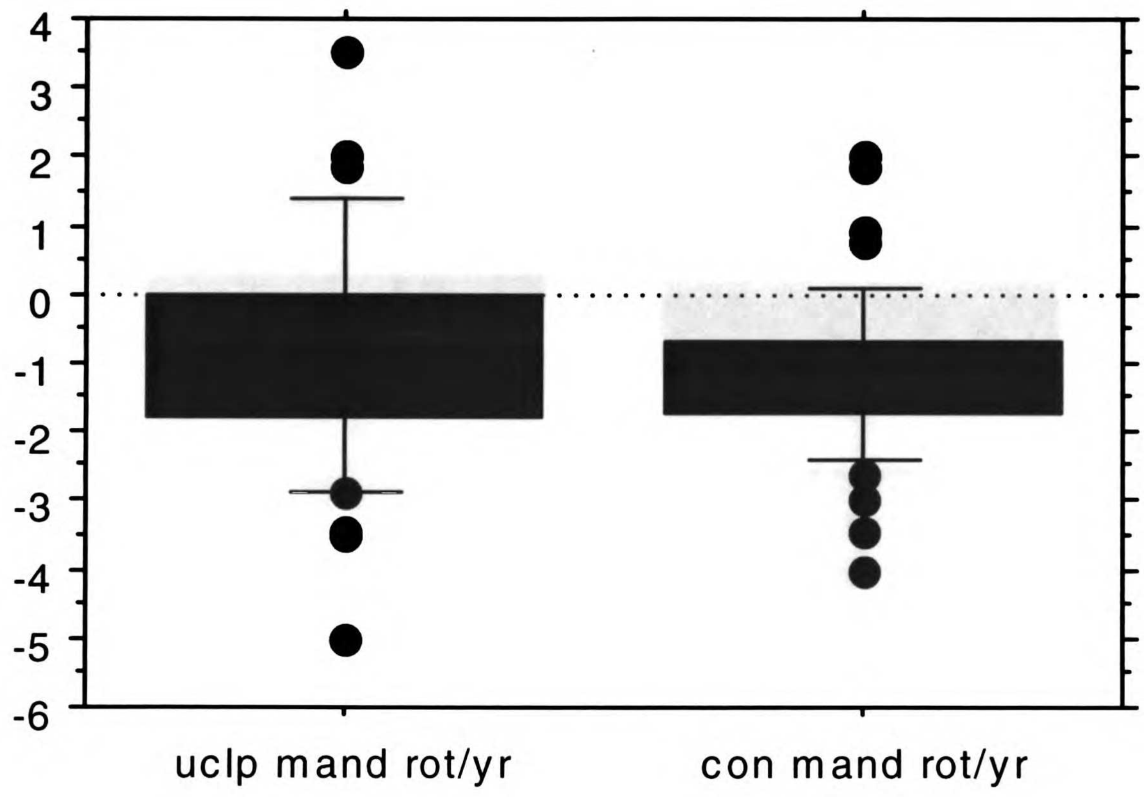


Fig. 32: Annualized mandibular rotation of UCLP and Control groups.

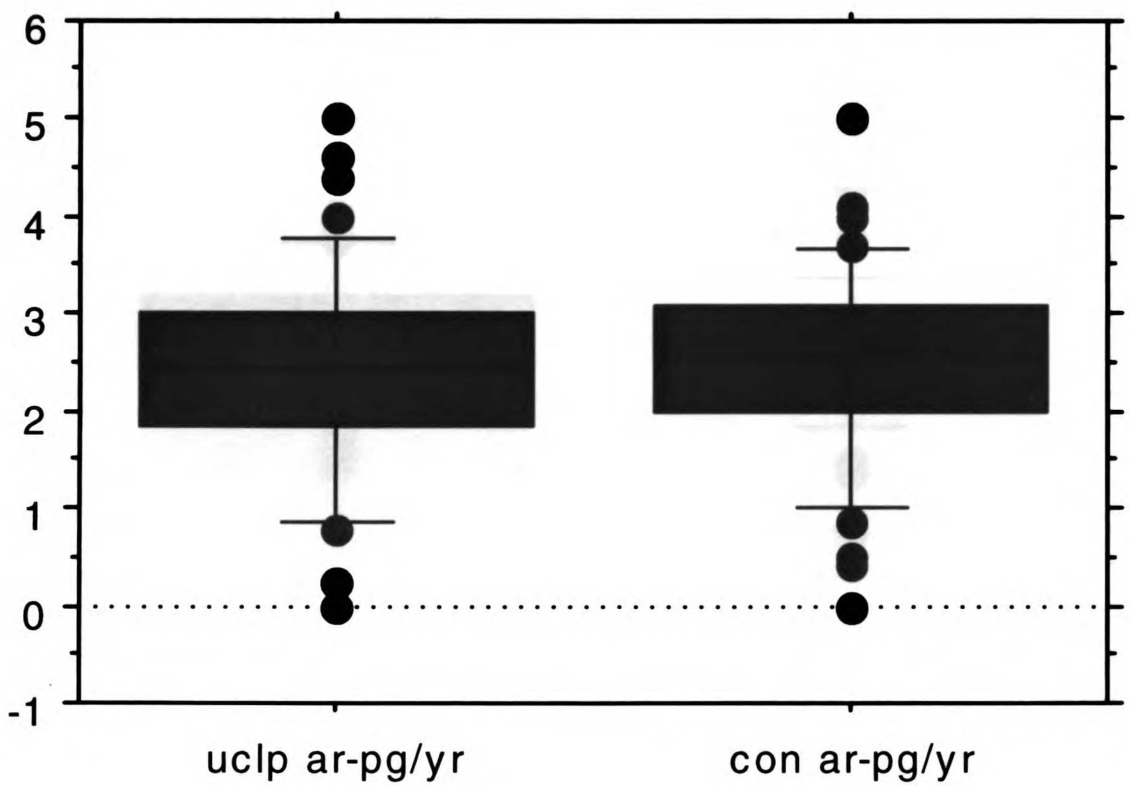


Fig. 33: Annualized changes of the measurement ar-pg, mm, for UCLP and Control groups.

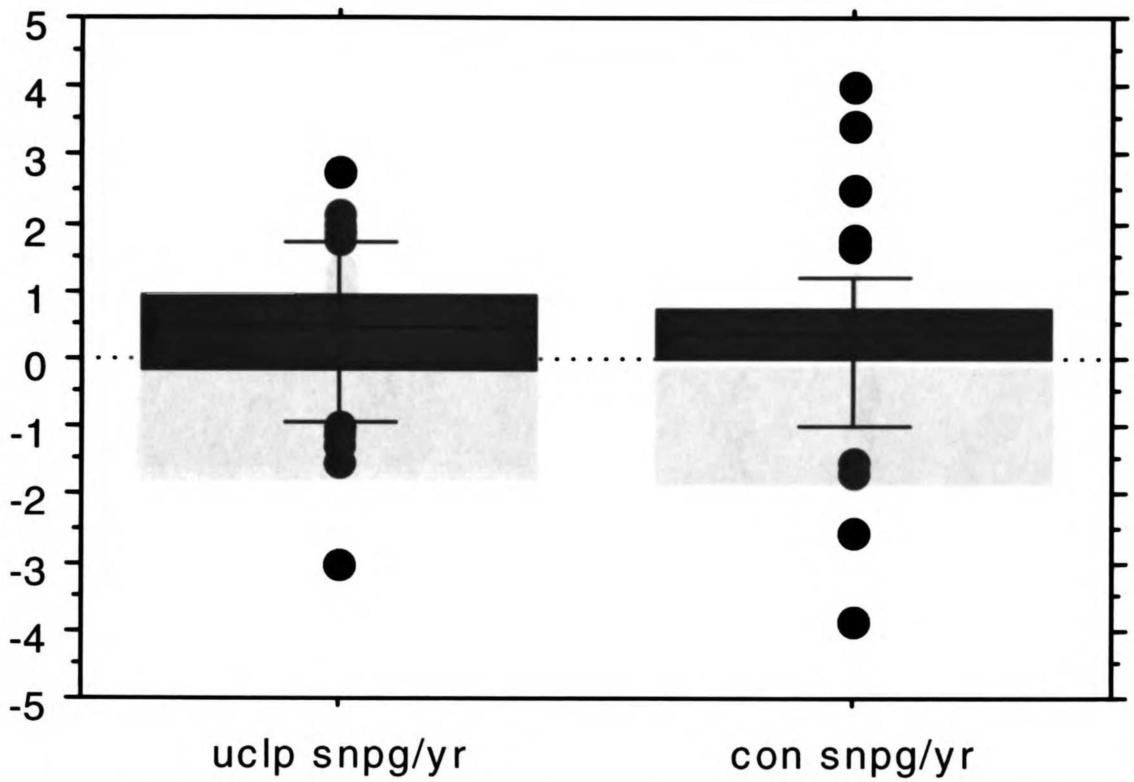


Fig. 34: Annualized changes of the angle SNPg for UCLP and Control groups.

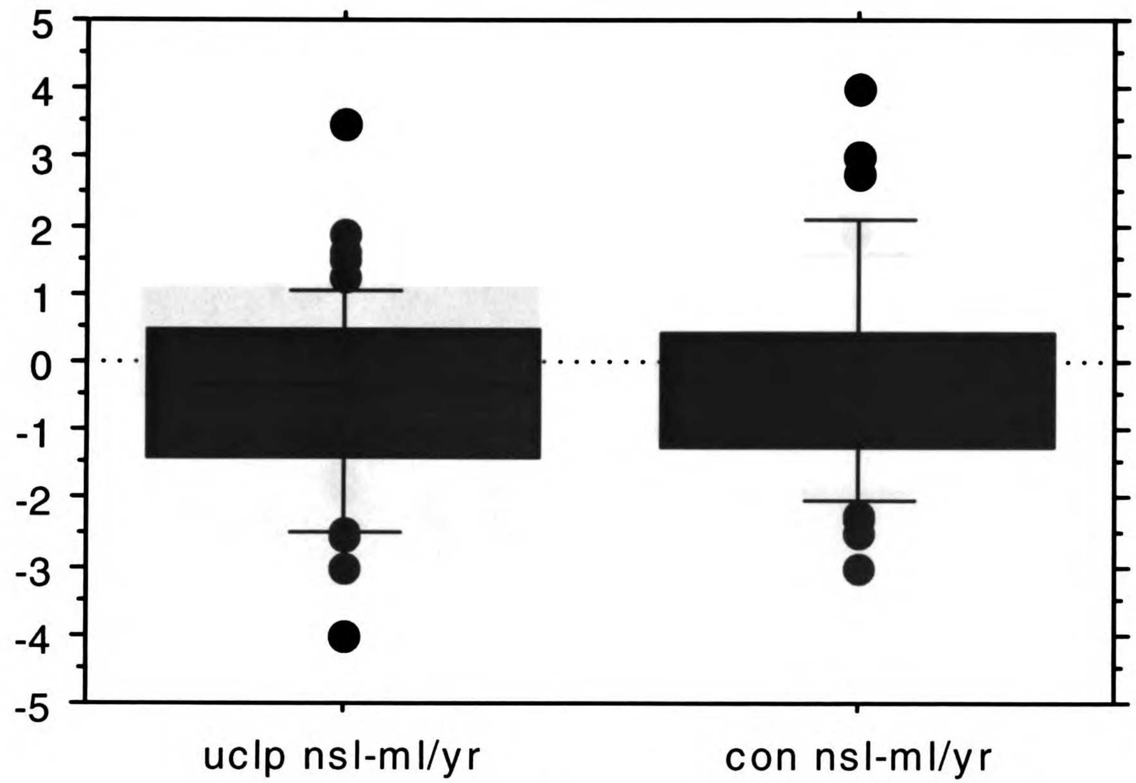


Fig. 35: Annualized changes of the angle NSL/ML for UCLP and Control groups.

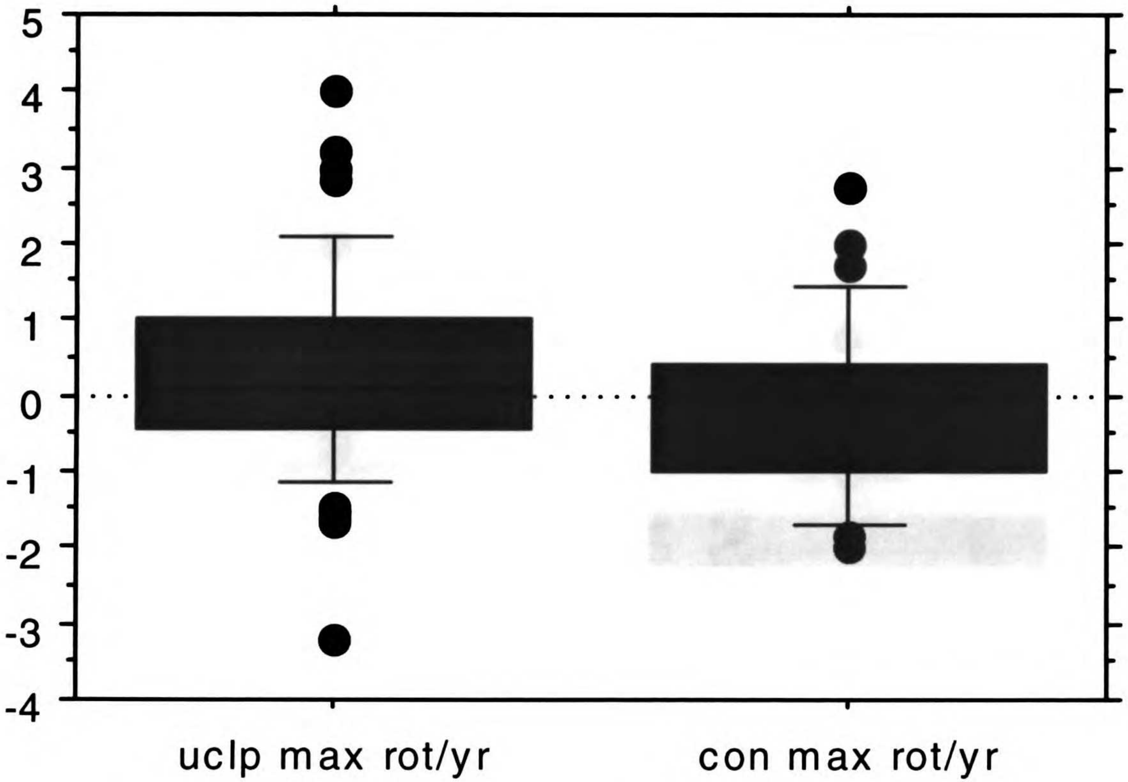


Fig. 36: Annualized maxillary rotation for the UCLP and Control groups.

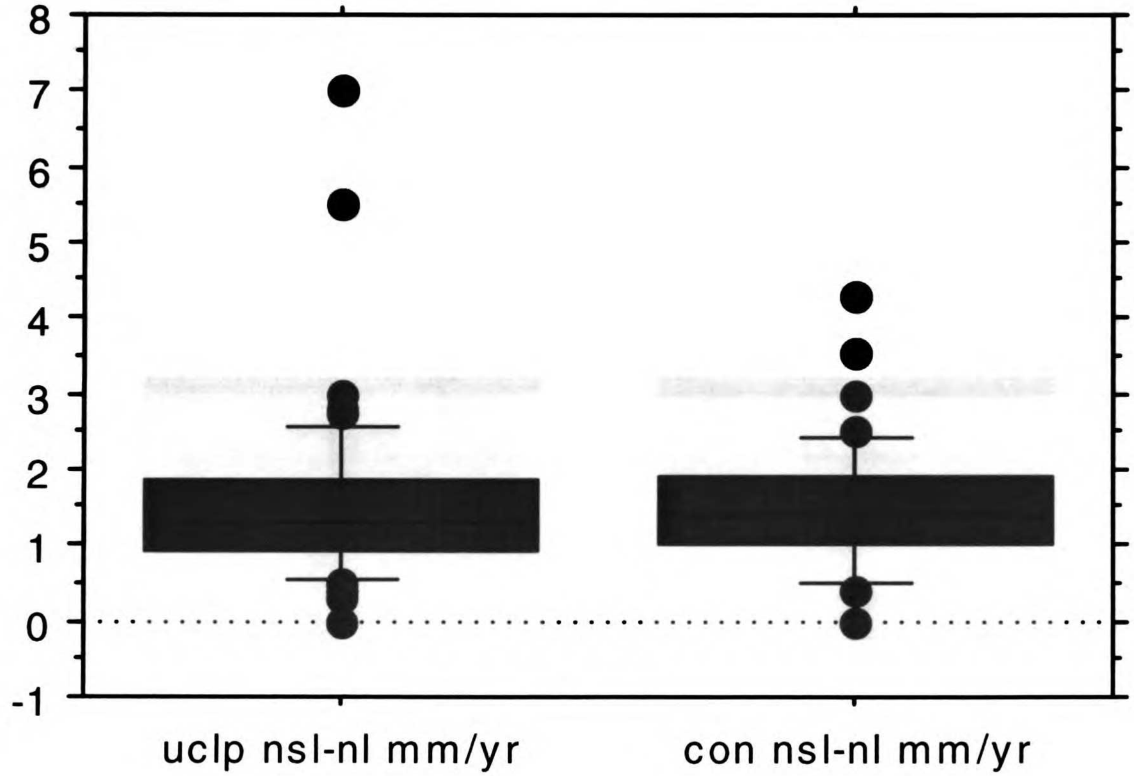


Fig. 37: Annualized changes for the measurement NSL-NL, mm, for the UCLP and Control groups.

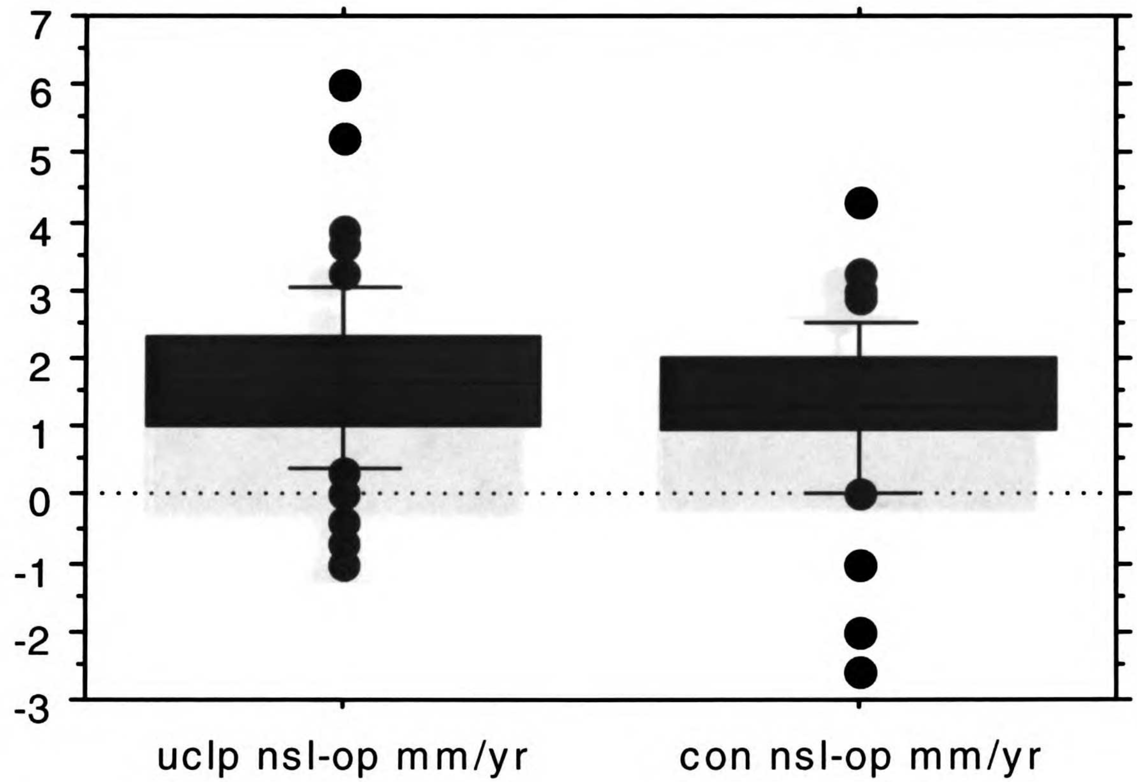


Fig. 38: Annualized changes of the measurement NSL-OP, mm, for the UCLP and Control groups.

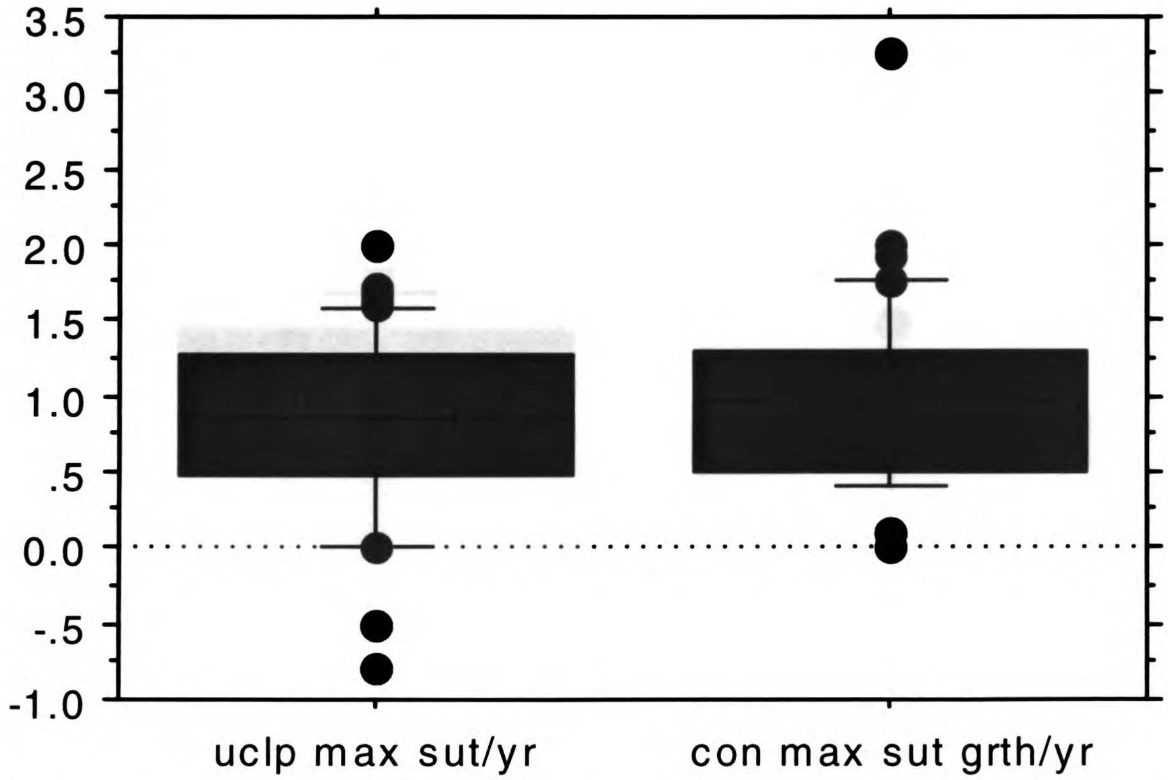


Fig. 39: Annualized changes in the measurement from NSL to zy, mm, for the UCLP and Control groups.

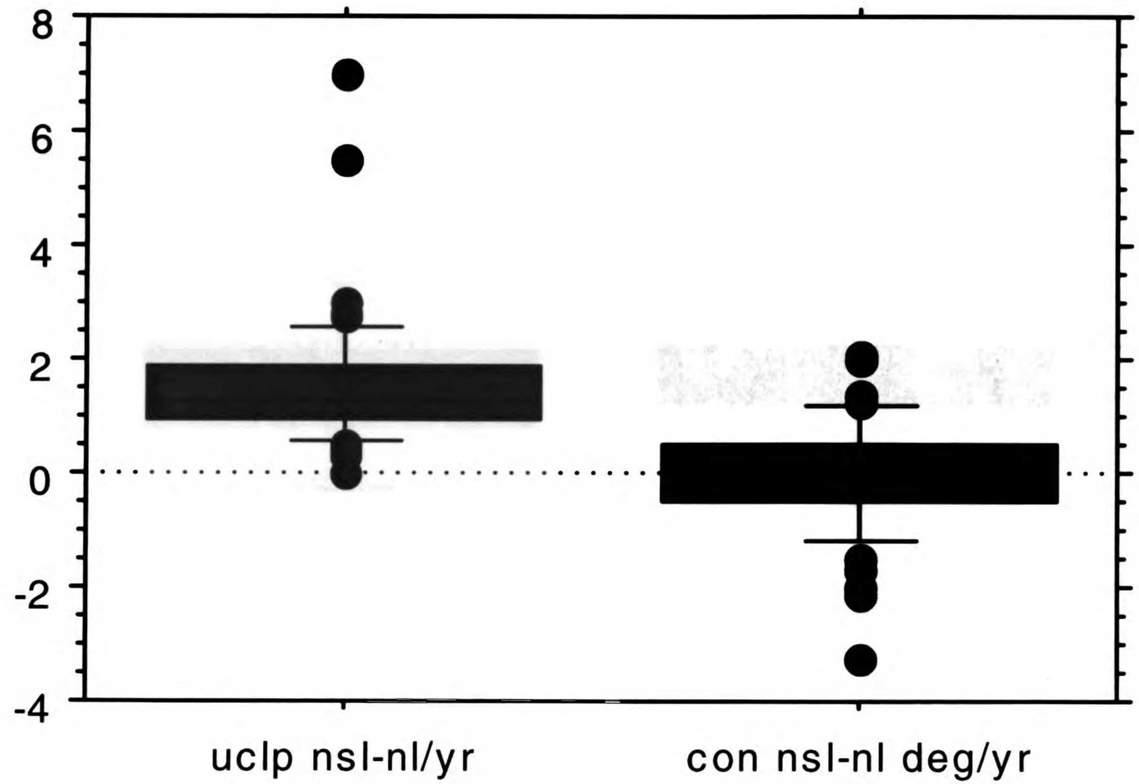


Fig. 40: Annualized changes for the angle NSL/NL for the UCLP and Control groups.

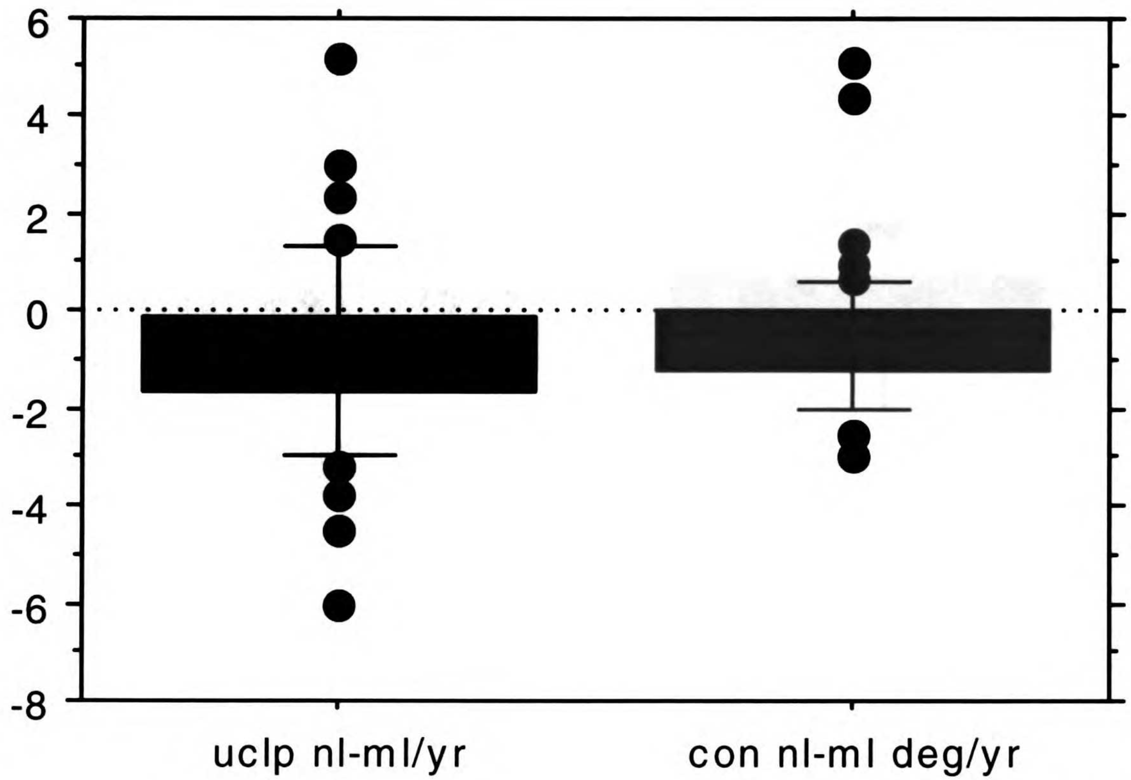


Fig. 41: Annualized changes for the angle NL/ML for the UCLP and Control groups.

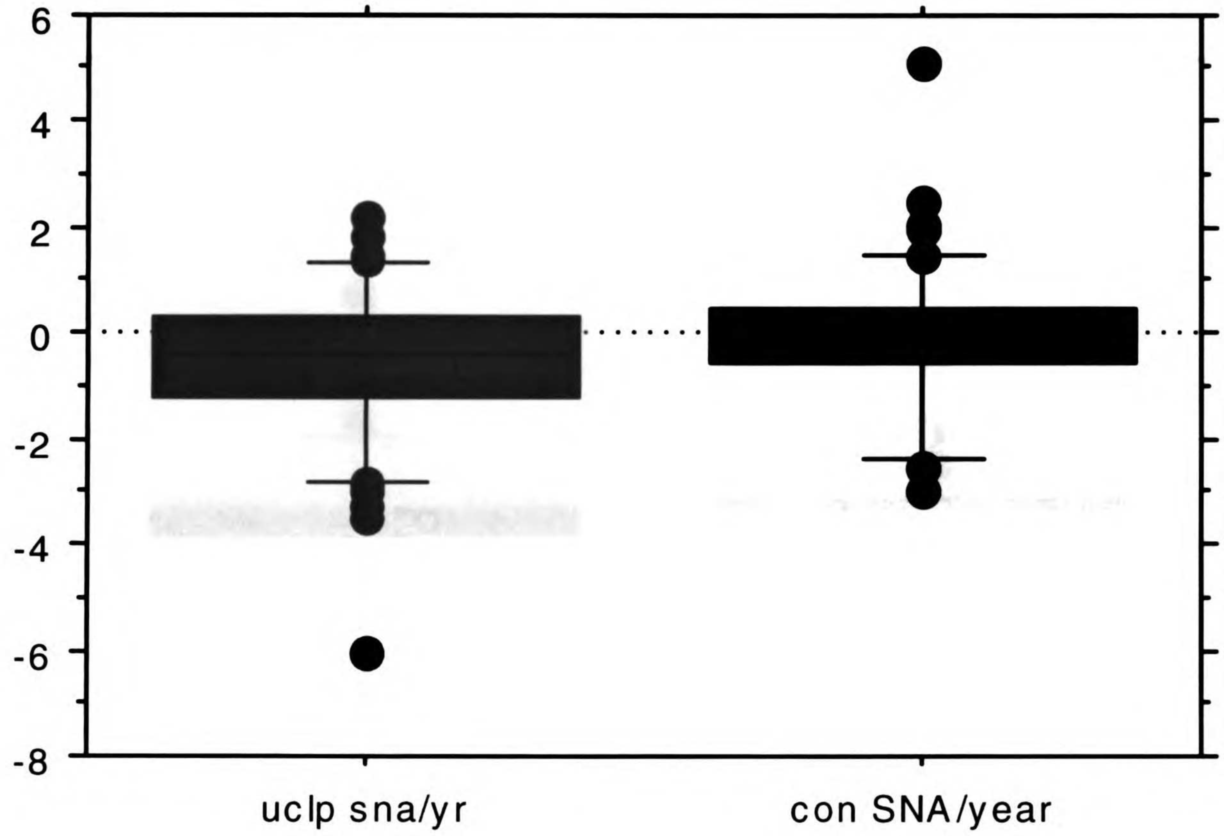


Fig. 42: Annualized changes for the angle SNA for the UCLP and Control groups.

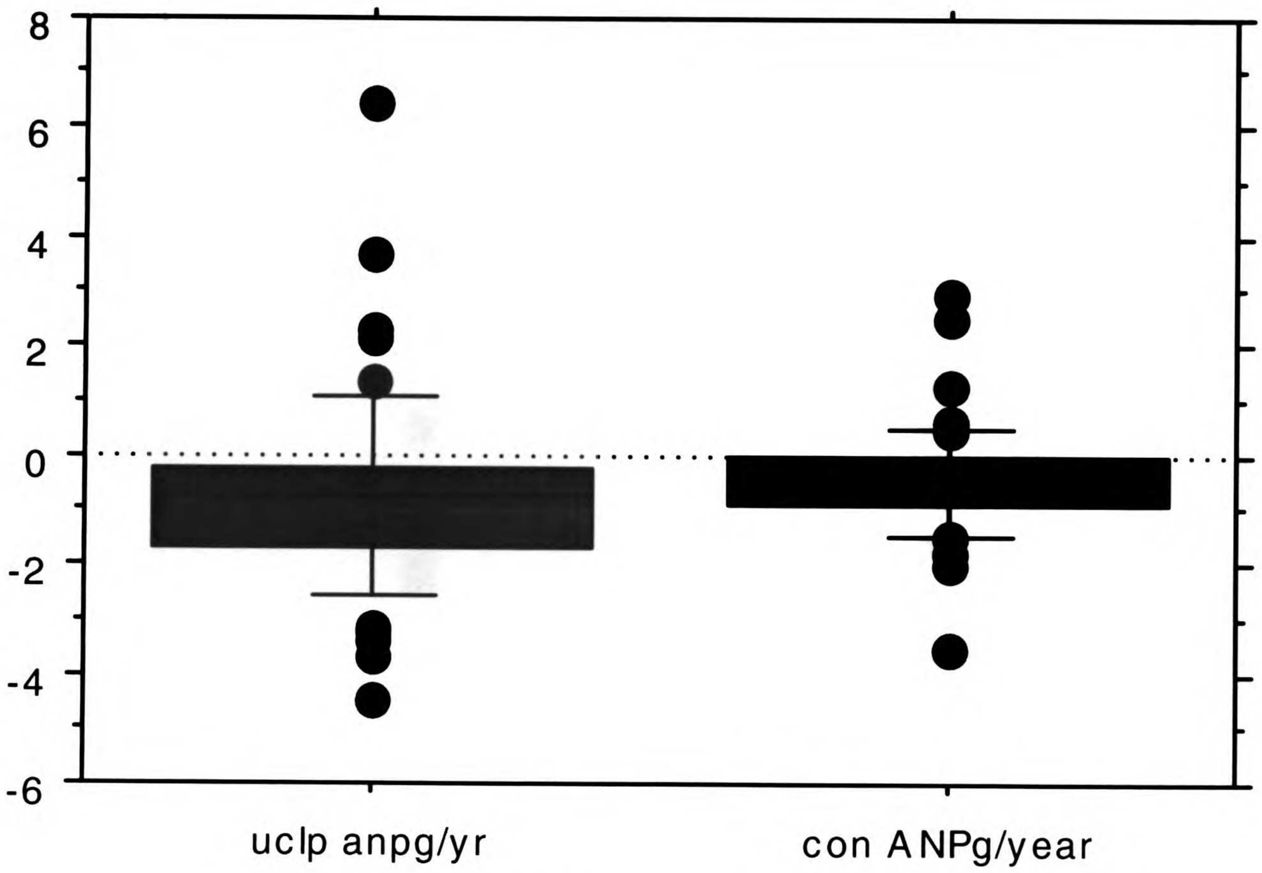


Fig. 43: Annualized changes for the angle anpg for the UCLP and Control groups.

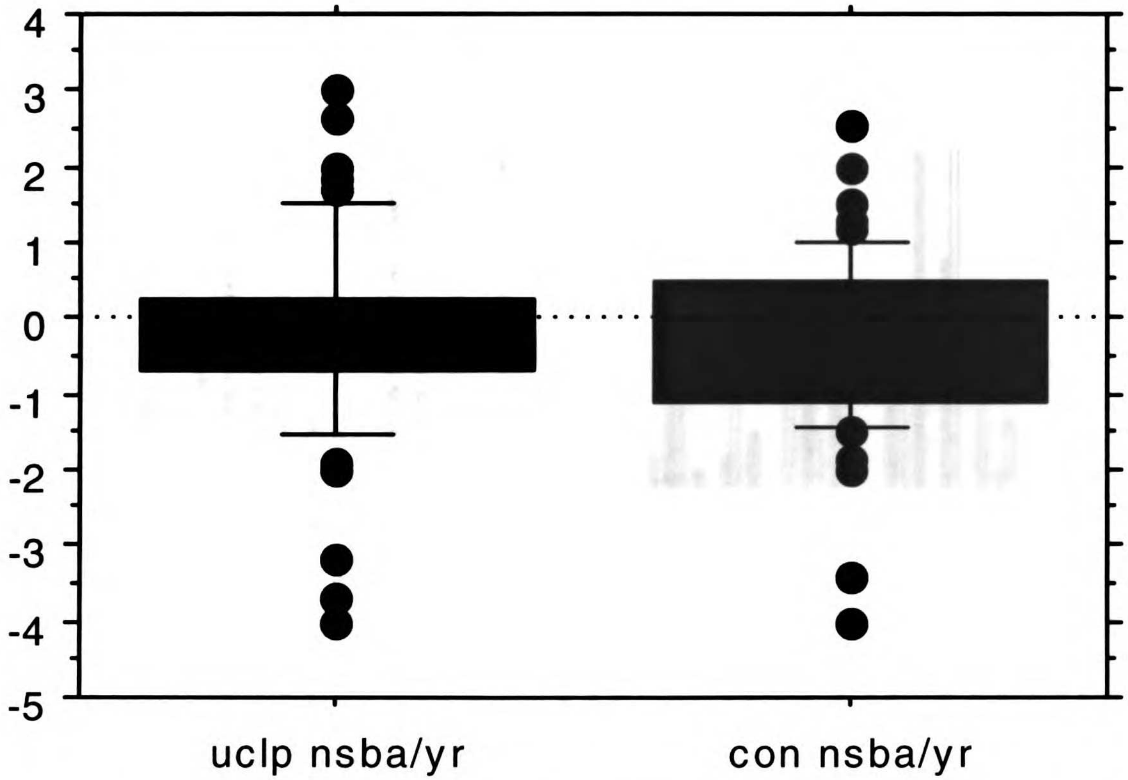


Fig. 44: Annualized changes for the angle nsba for the UCLP and Control groups.

Fig. 45: Matched Individual annualized changes from T1 to T2 for the measure ar-pg

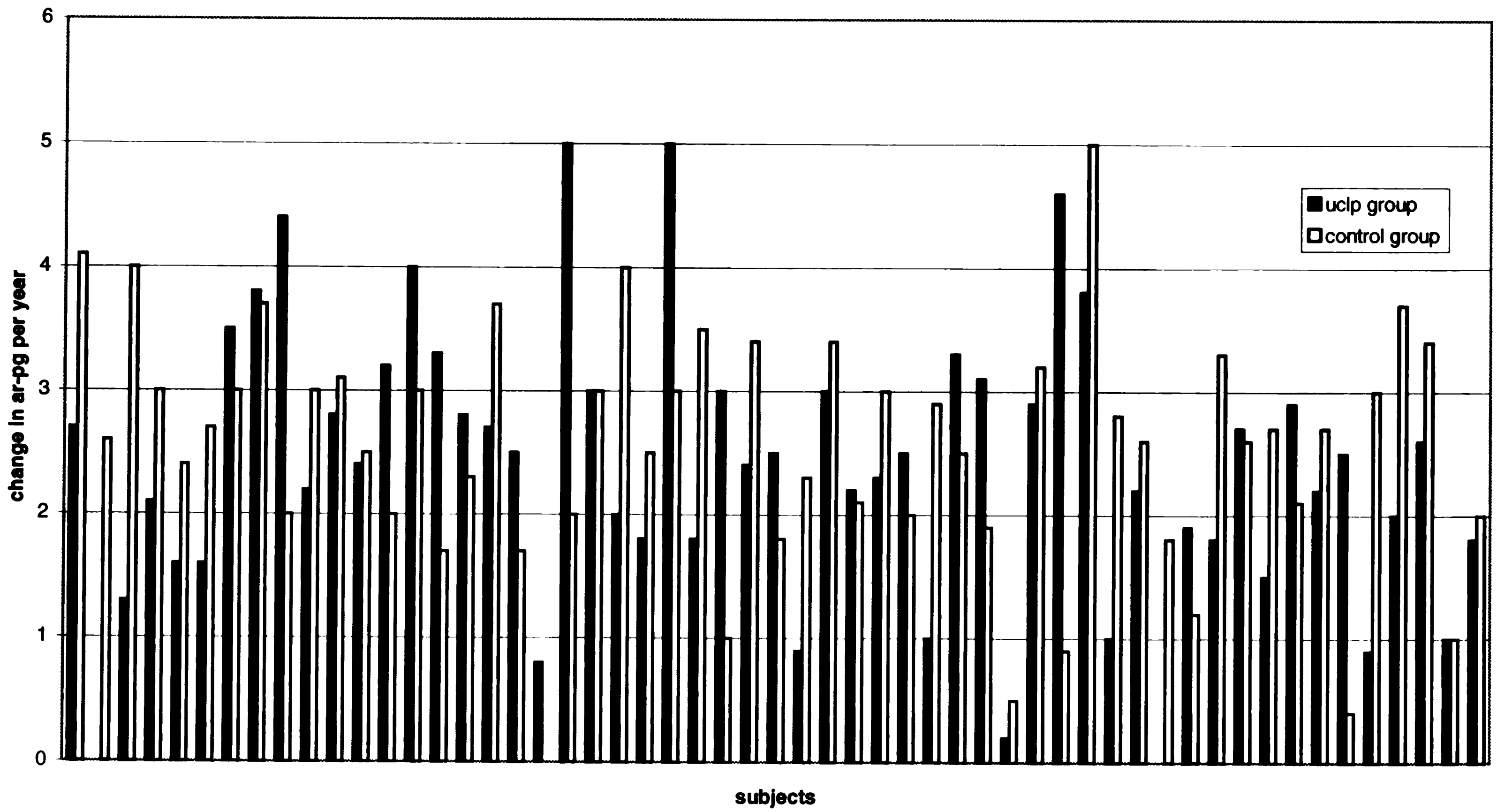


Fig. 46 : Matched Individual annualized changes for the angle SNPg

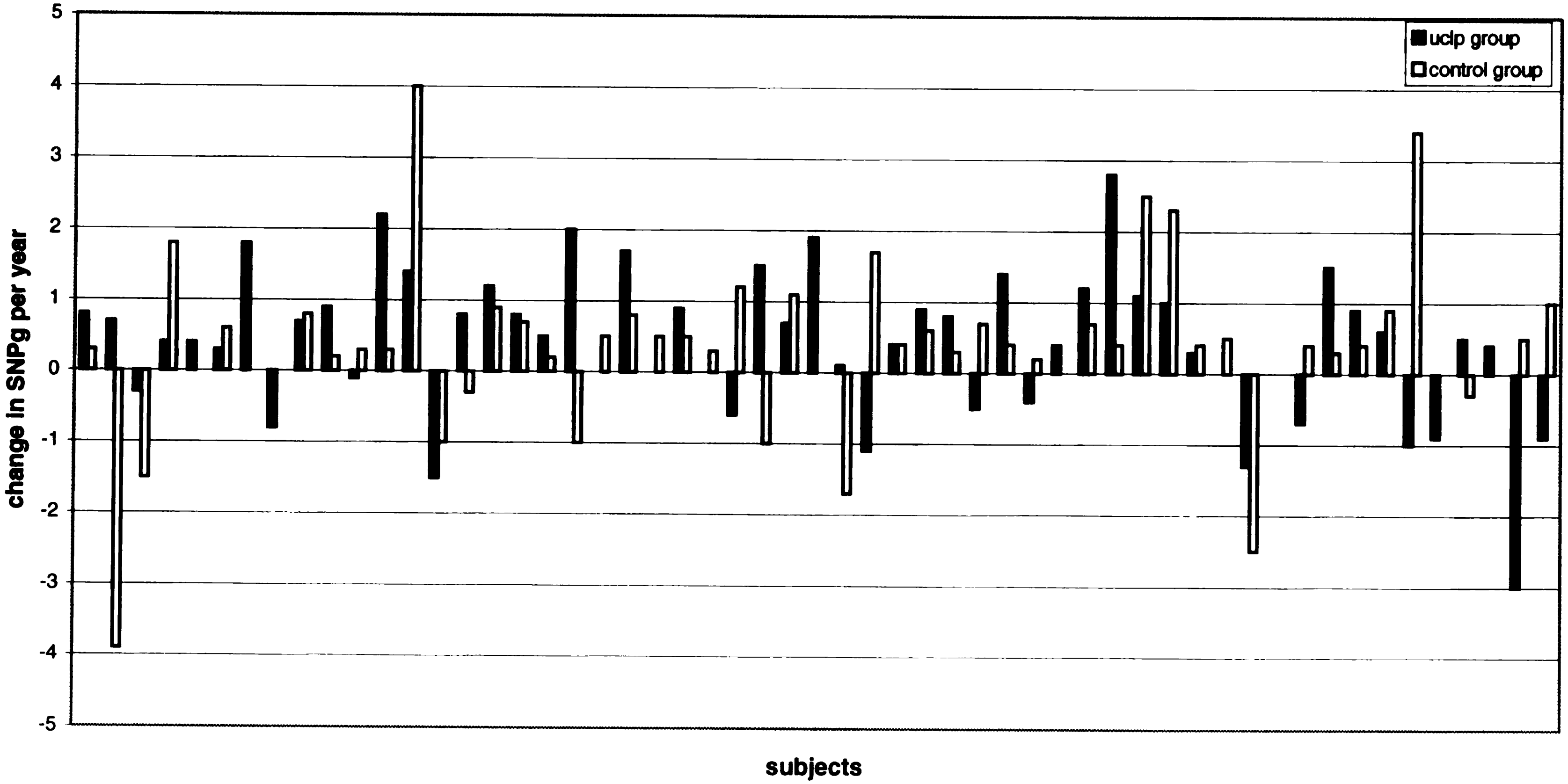


Fig. 47: Matched Individual annualized changes from T1 to T2 for the angle NSL/ML

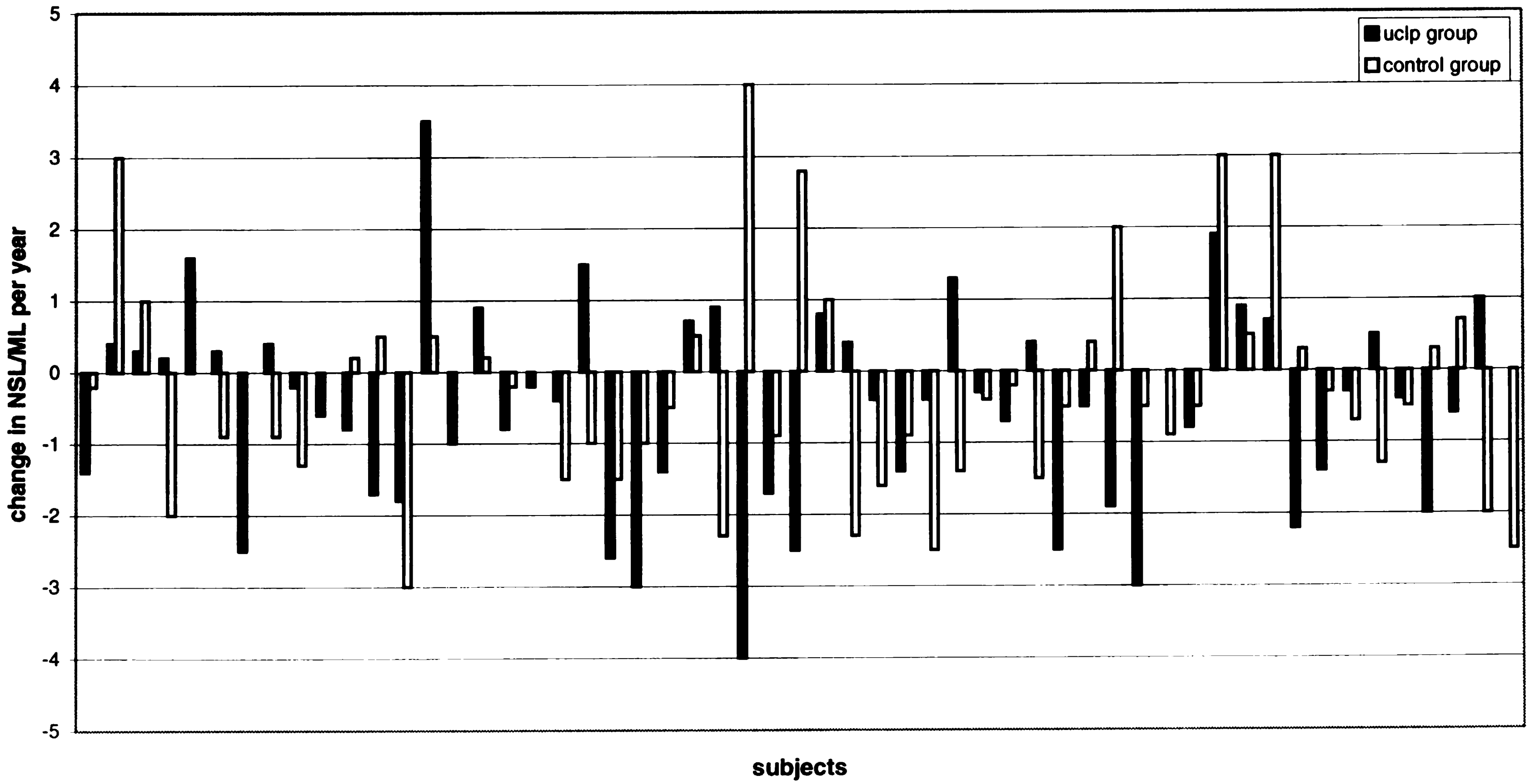


Fig. 48 : Matched Individual annualized changes from T1 to T2 for the measure of maxillary rotation

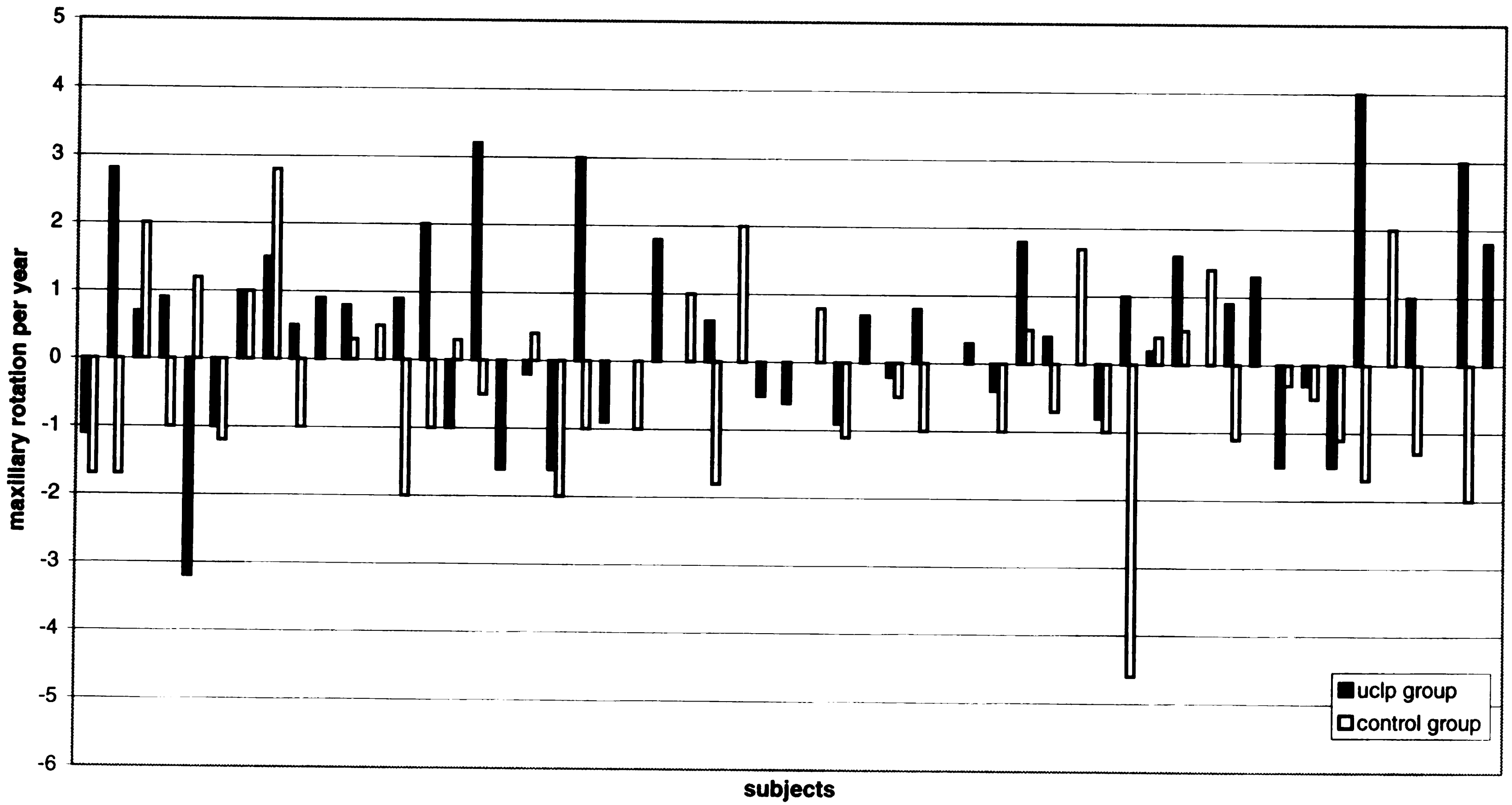


Fig. 49: Matched Individual annualized changes from T1 to T2 for the measure NSL-NL, mm.

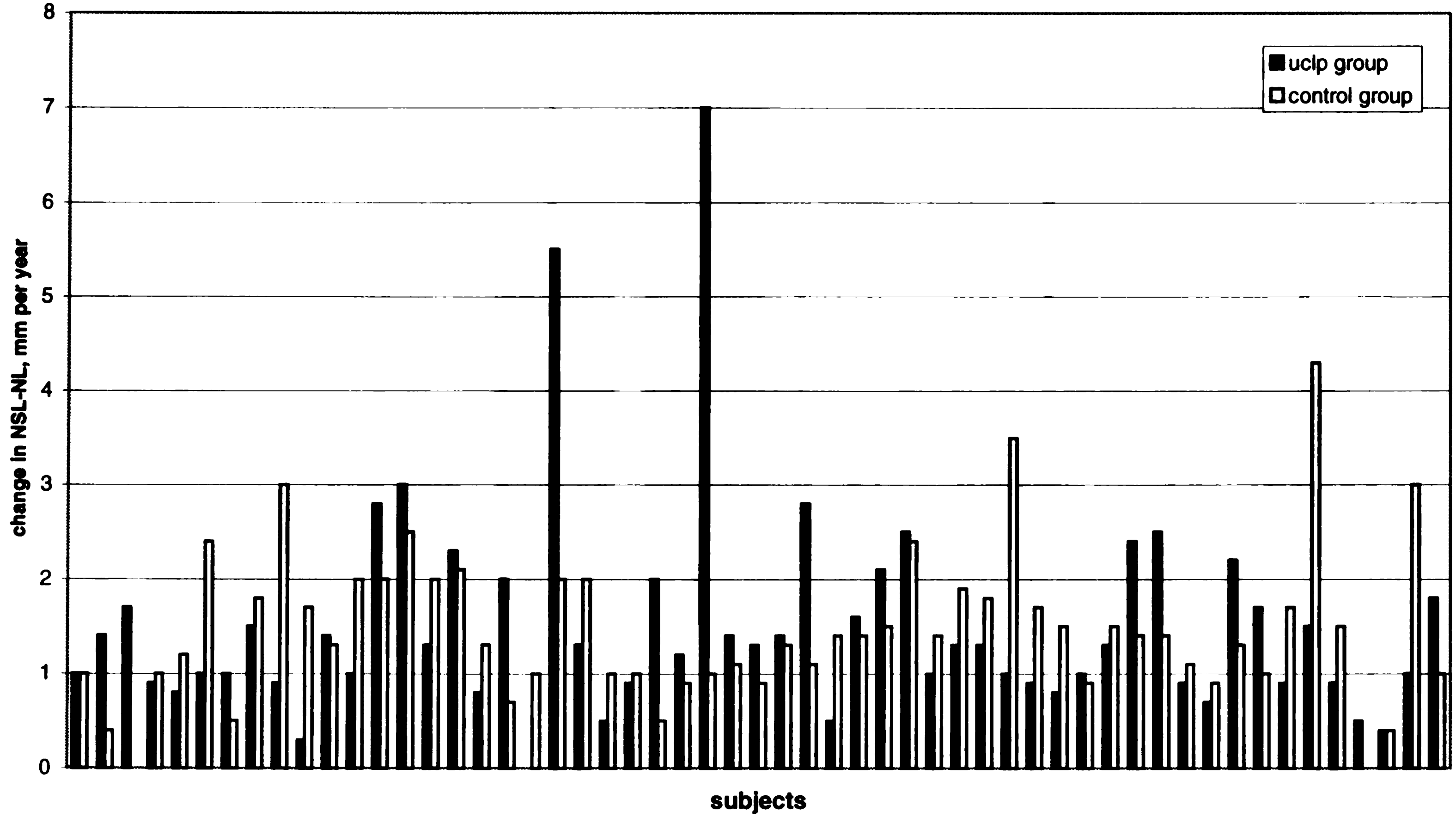


Fig. 50: Matched Individual annualized changes from T1 to T2 for the measure NSL-OP, mm

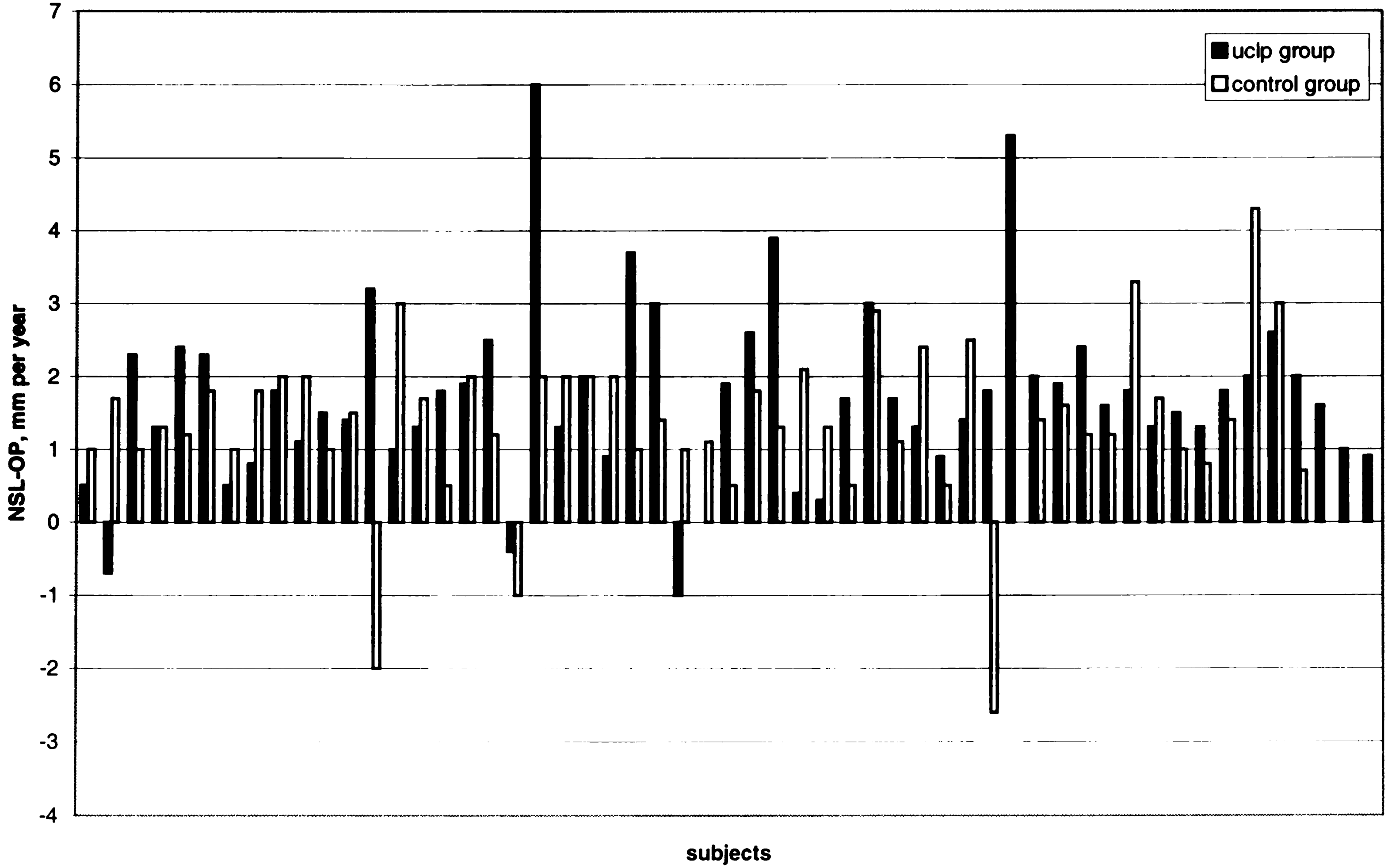


Fig. 51: Matched Individual annualized changes from T1 to T2 for the meaure NSL-Zy, mm

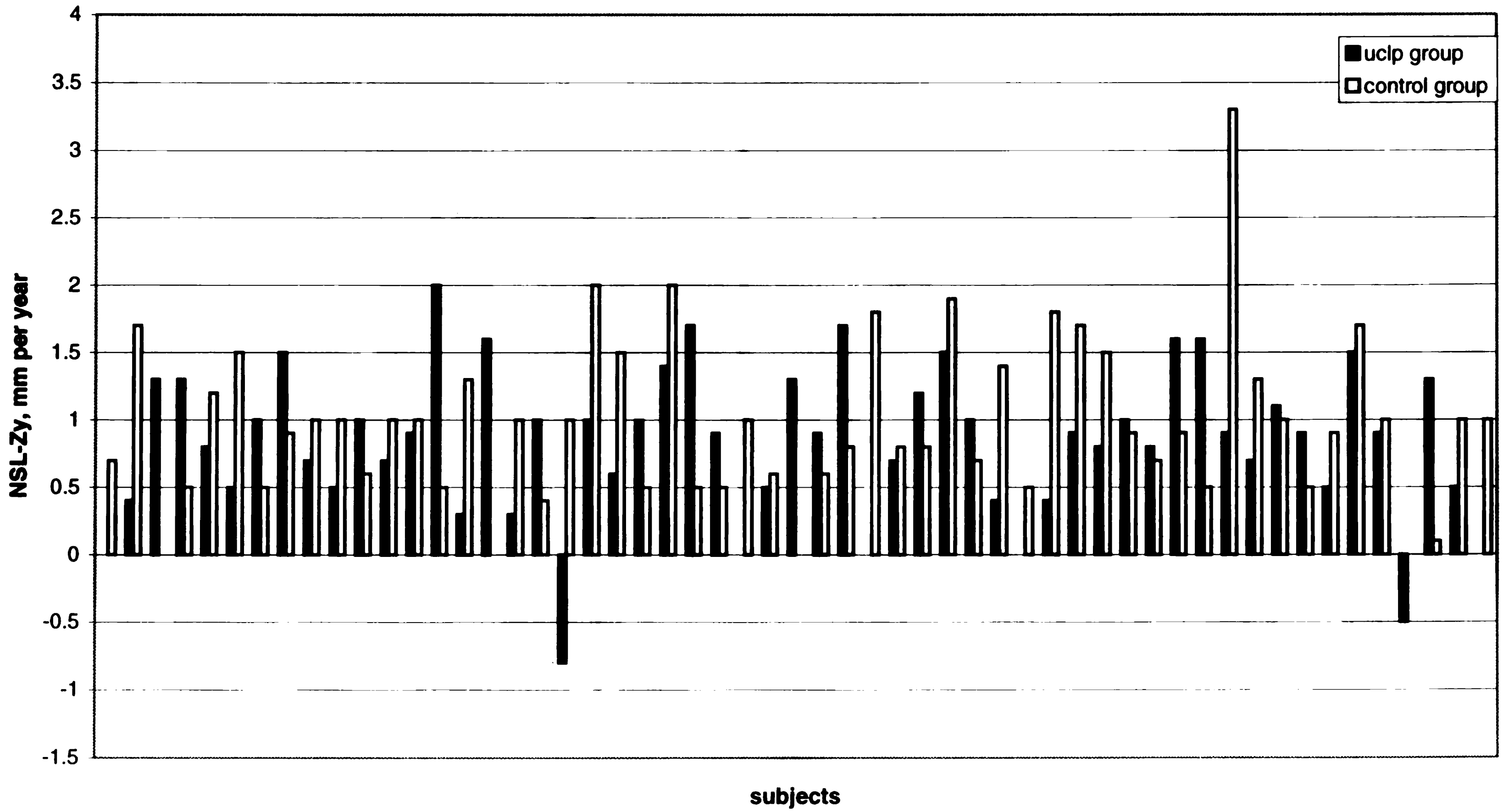


Fig. 52 : Matched Individual annualized change from T1 to T2 for the angle NSL/NL

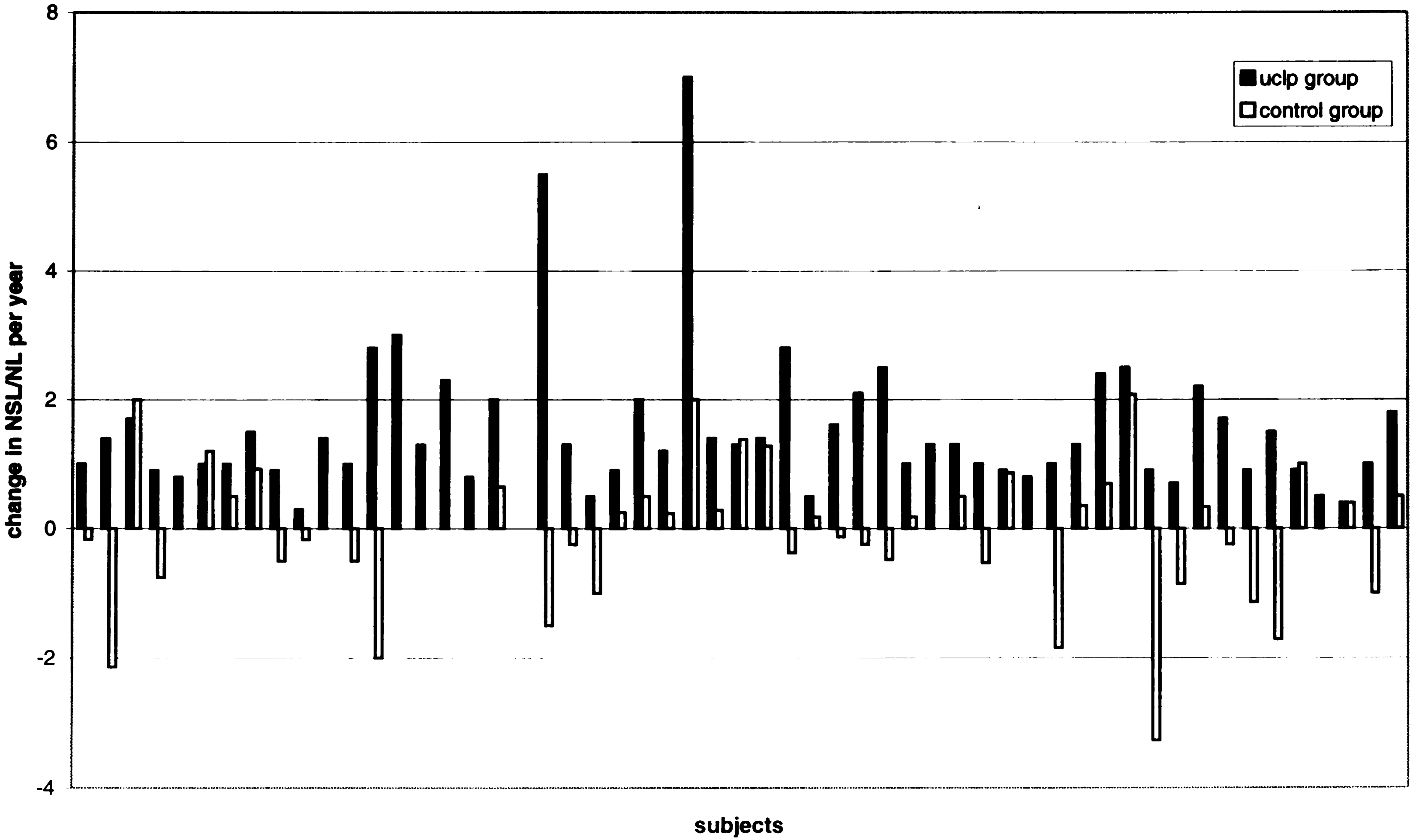


Fig. 53 : Matched Individual annualized changes from T1 to T2 for the angle NL/ML

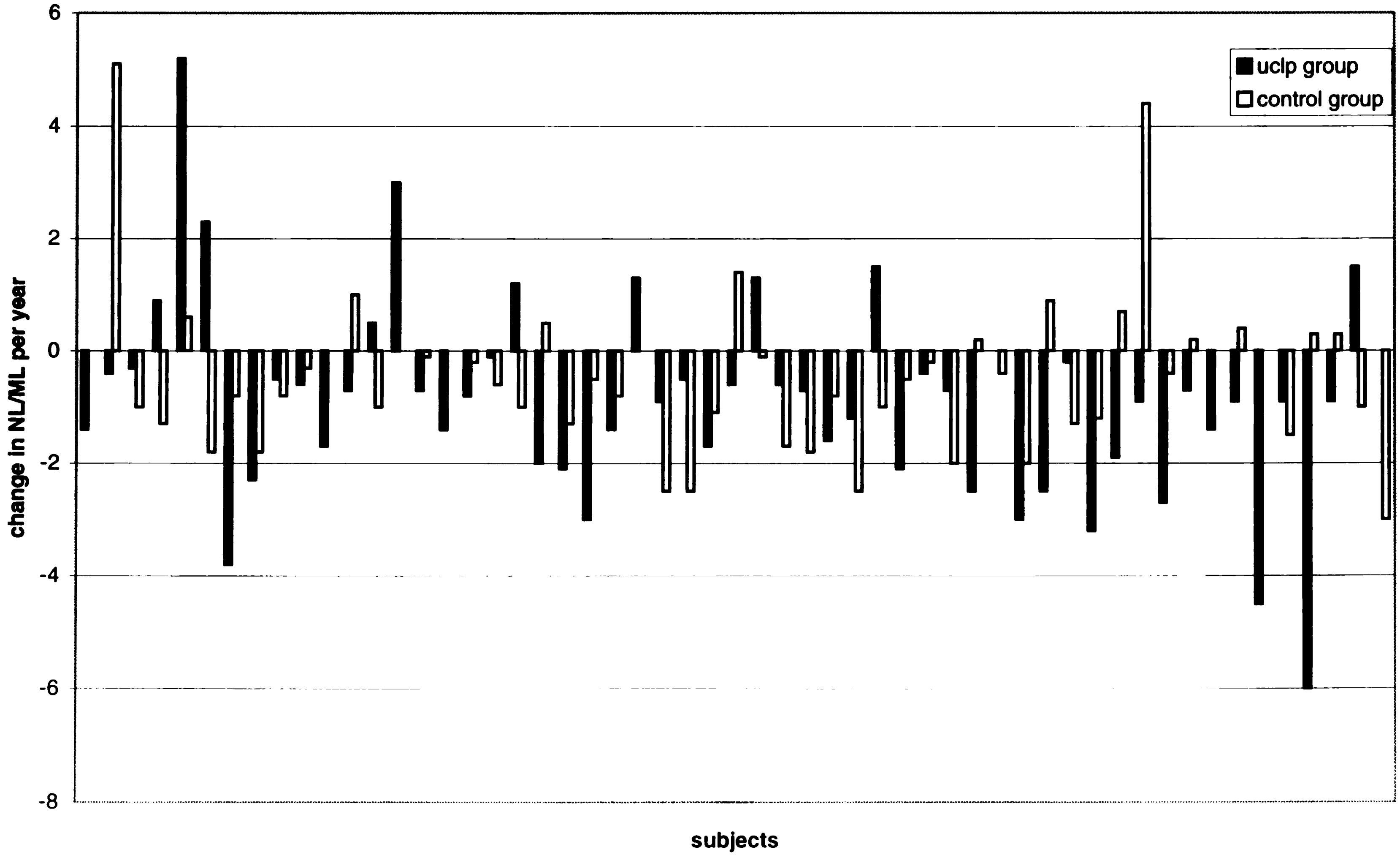


Fig. 54: Matched Individual annualized changes from T1 to T2 for the angle SNA

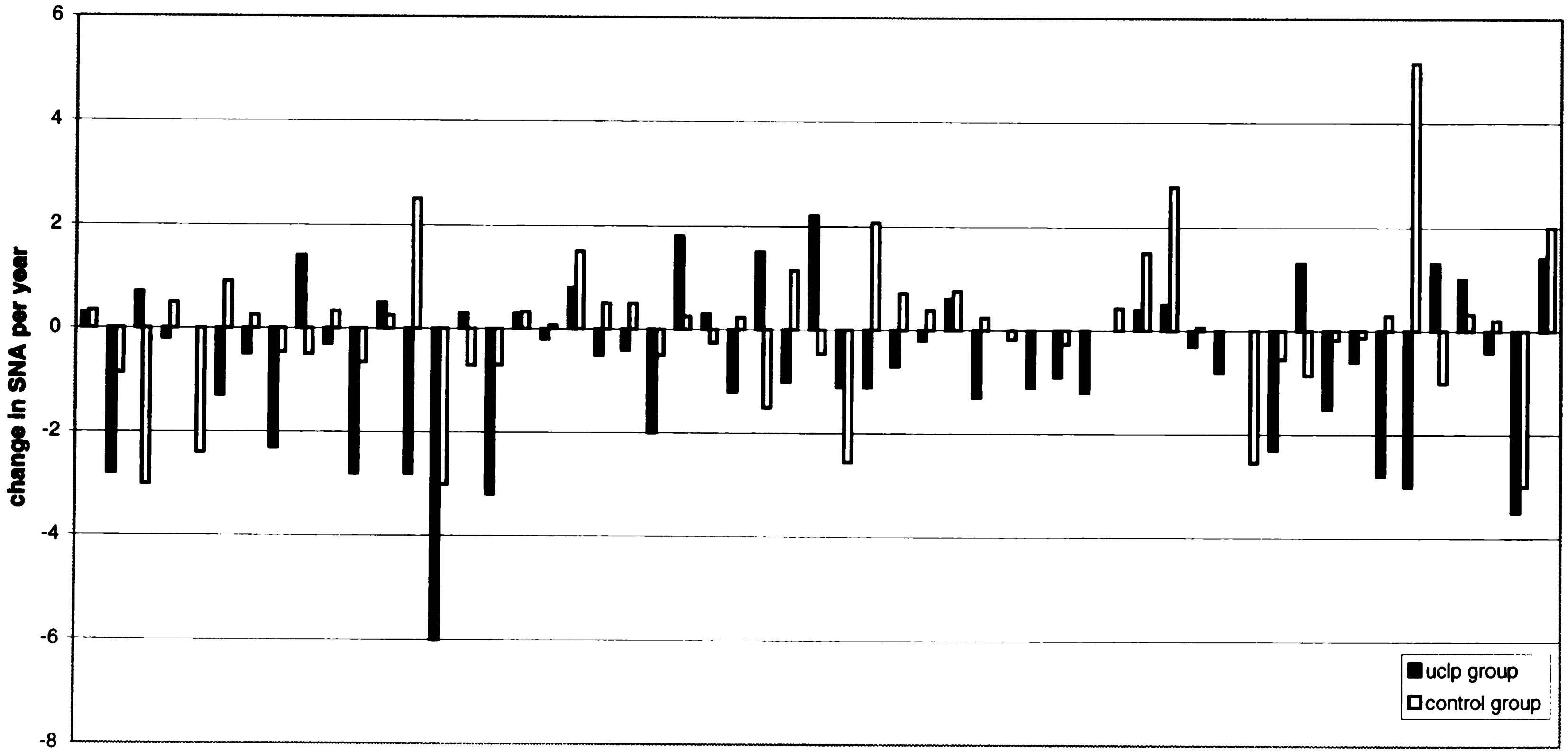


Fig. 55: Matched Individual annualized changes from T1 to T2 for the angle ANPg

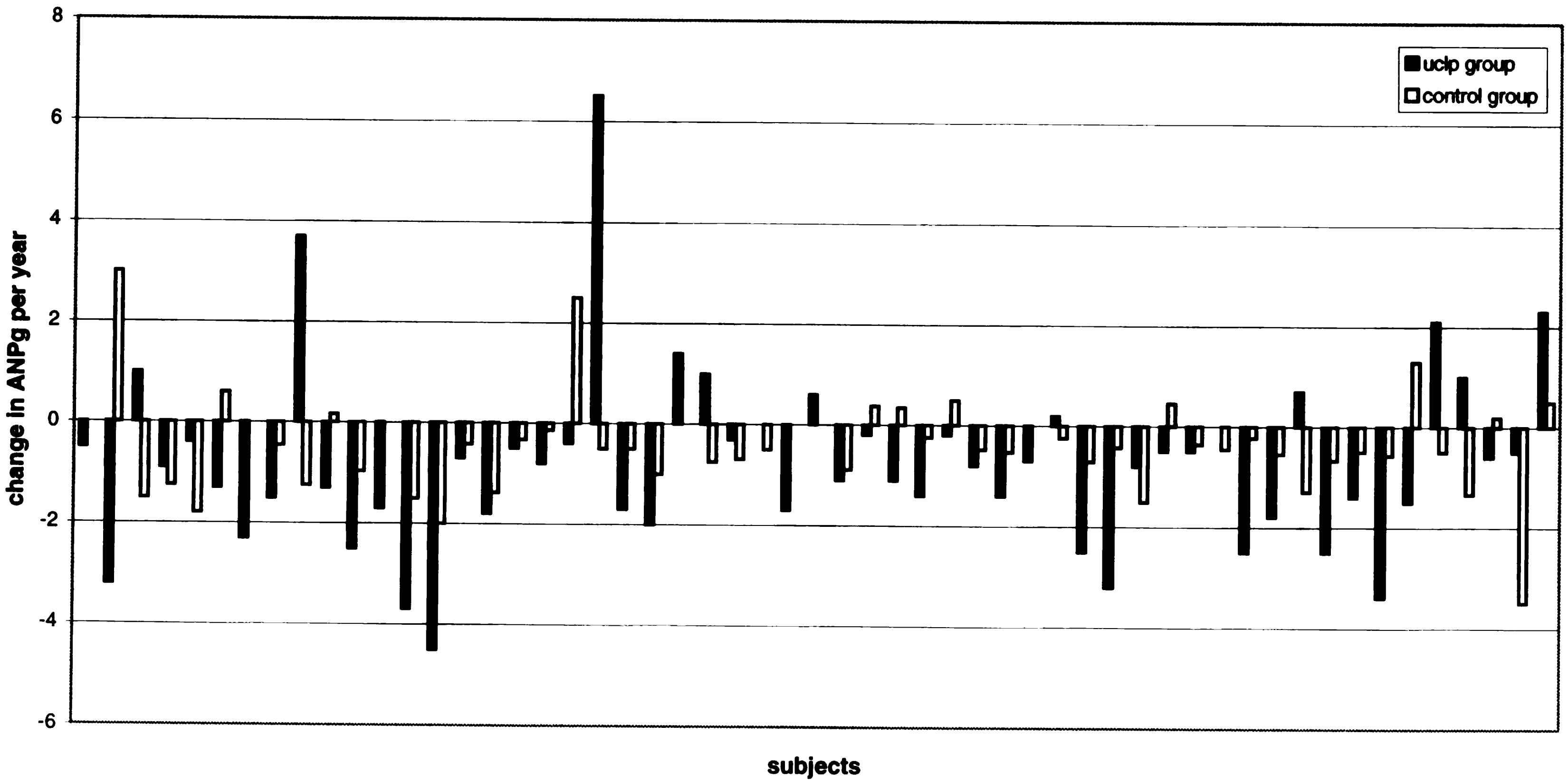
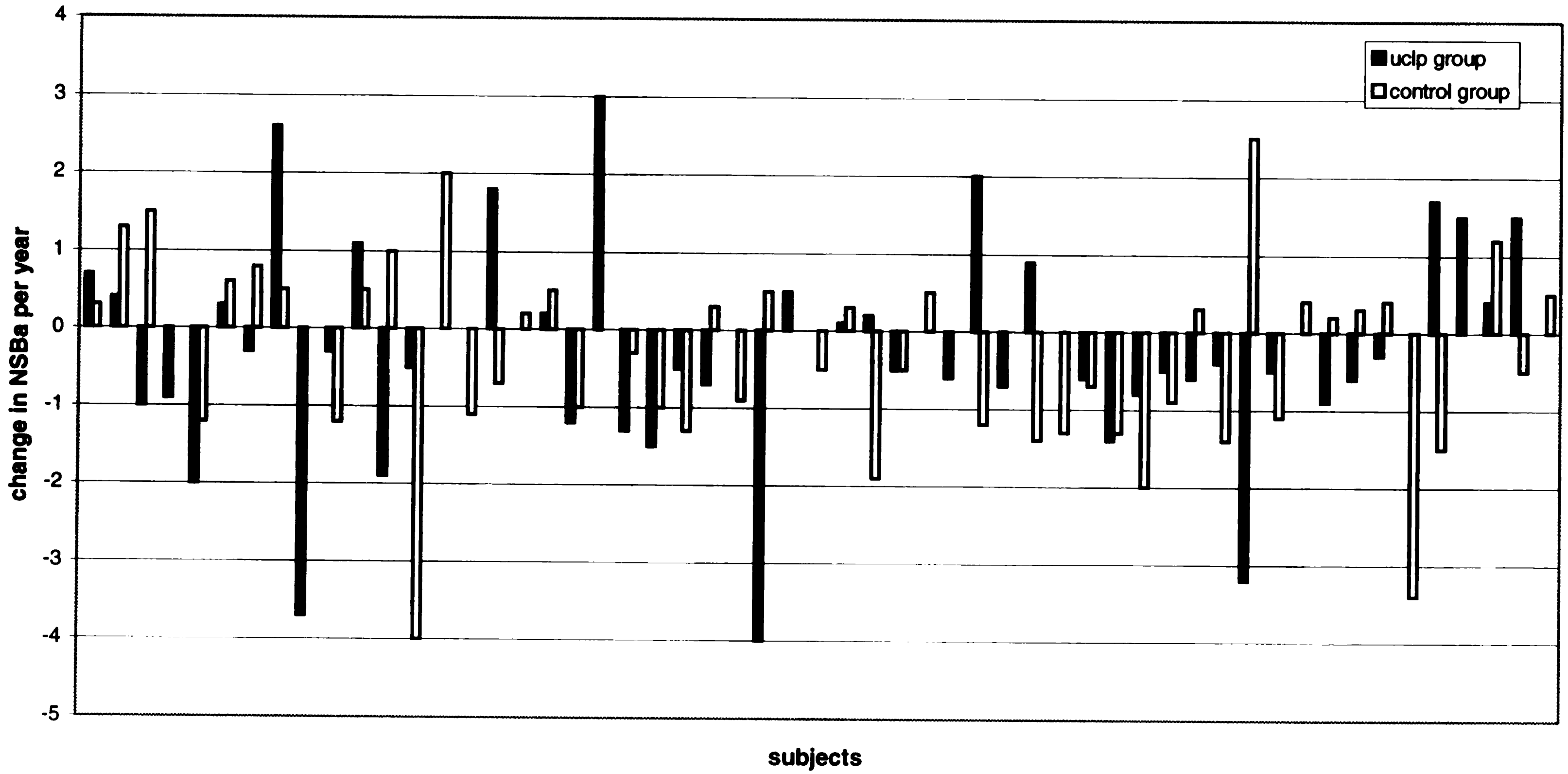


Fig. 56 : Matched Individual annualized changes from T1 to T2 for the angle NSBa



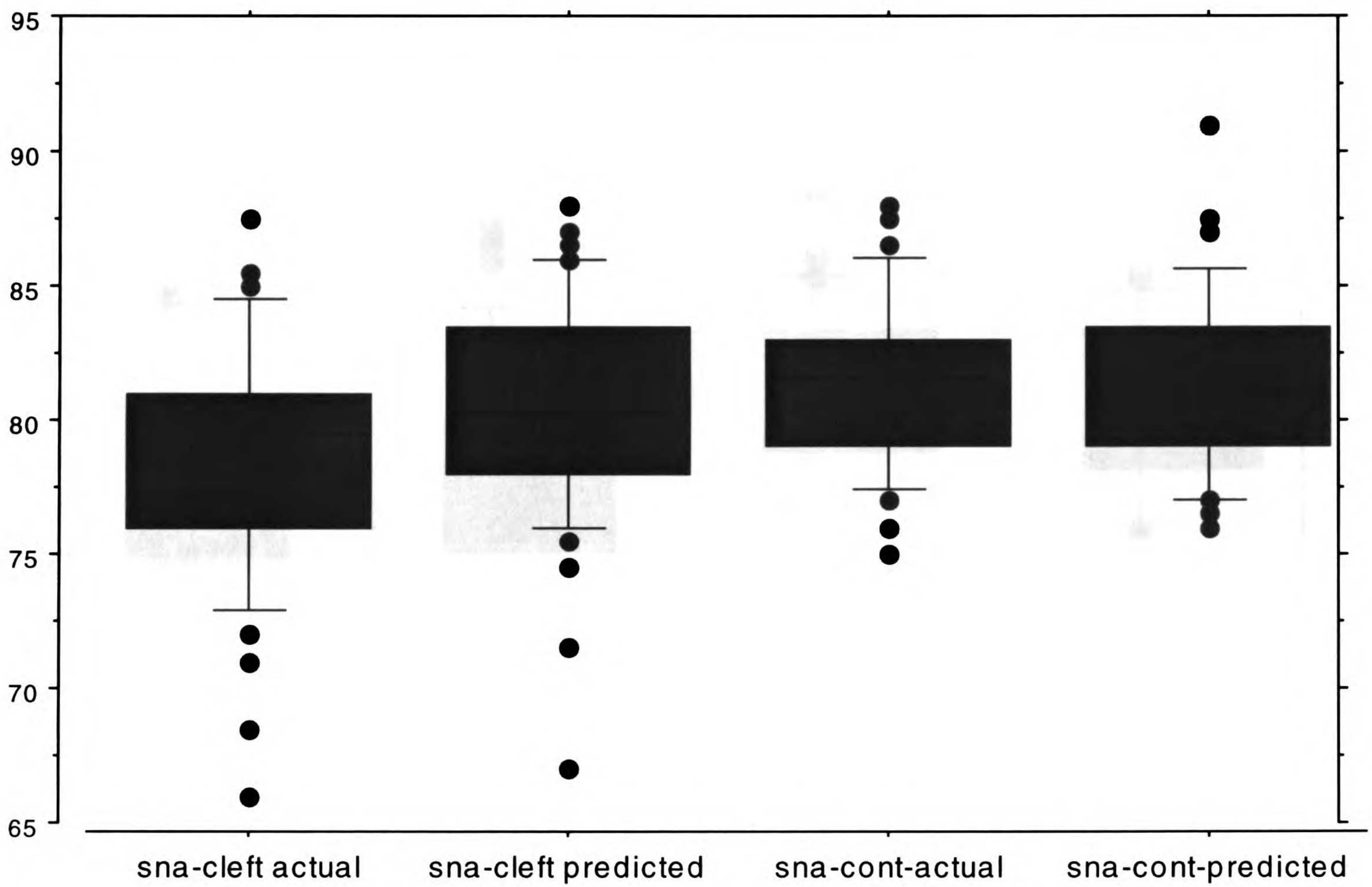


Fig. 57: Comparison of predicted growth values to actual growth values for the measure SNA.

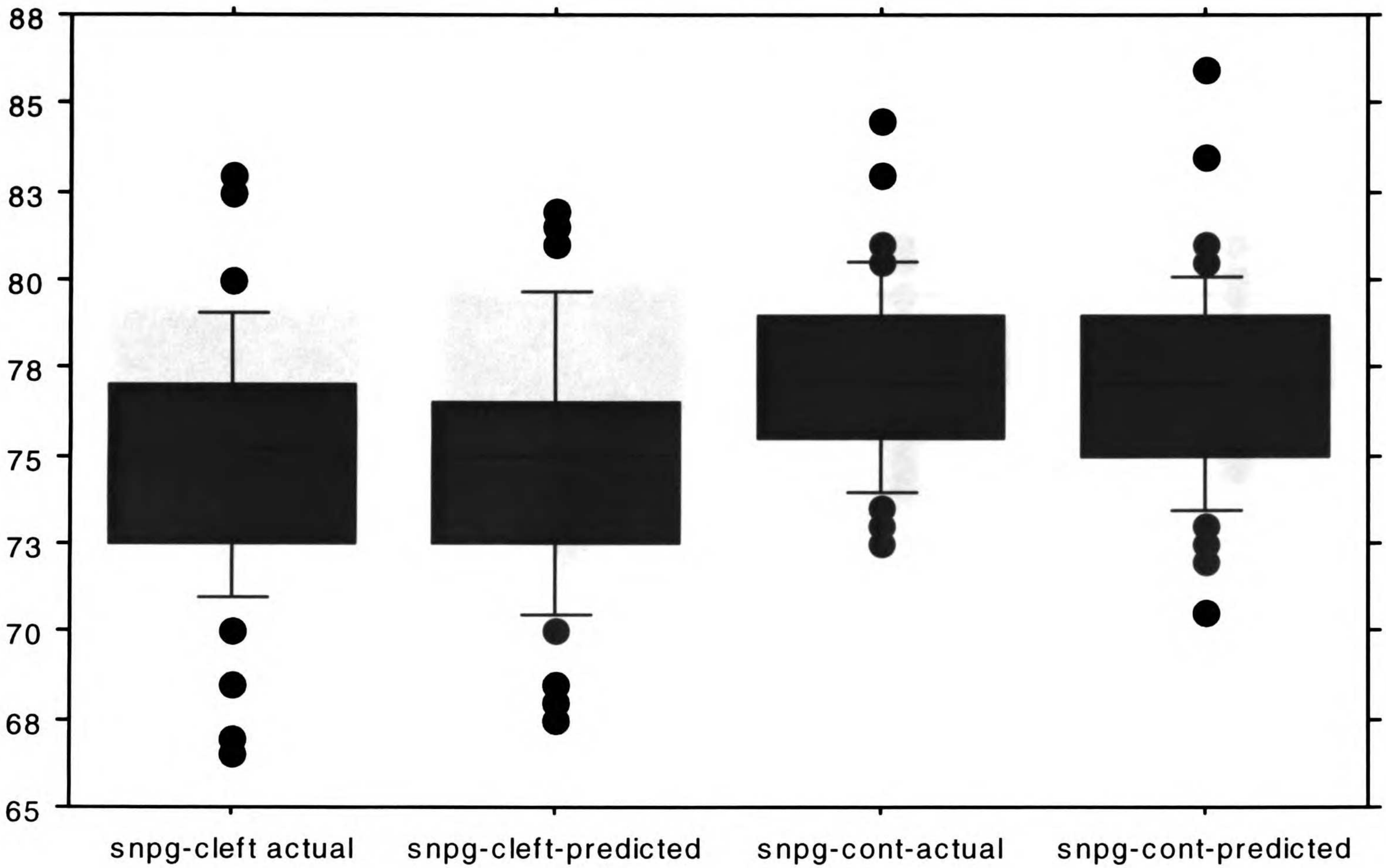


Fig. 58: Comparison of predicted growth to actual growth for the angle SNPg.

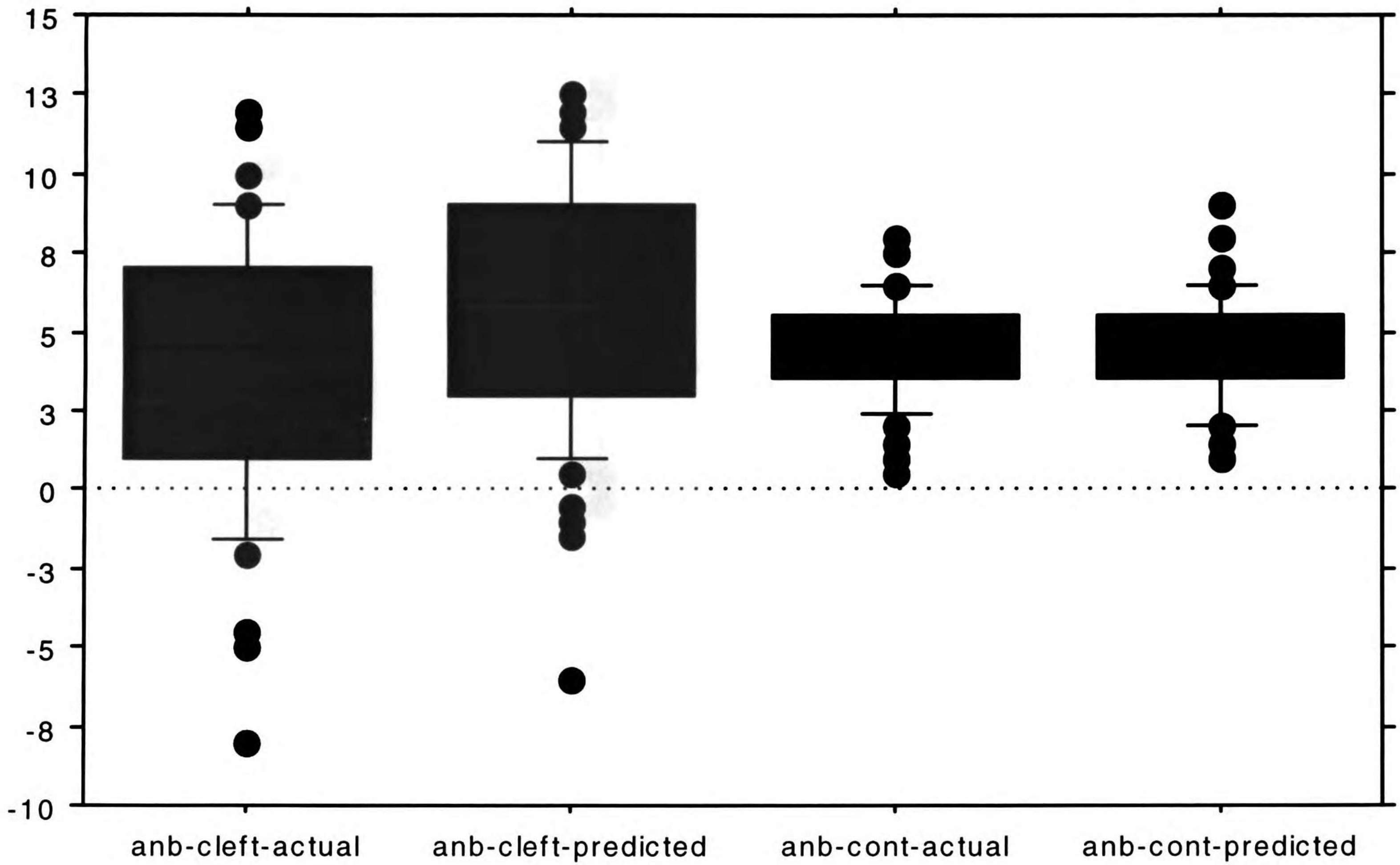


Fig. 59: Comparison of predicted growth to actual growth for the angle ANB.

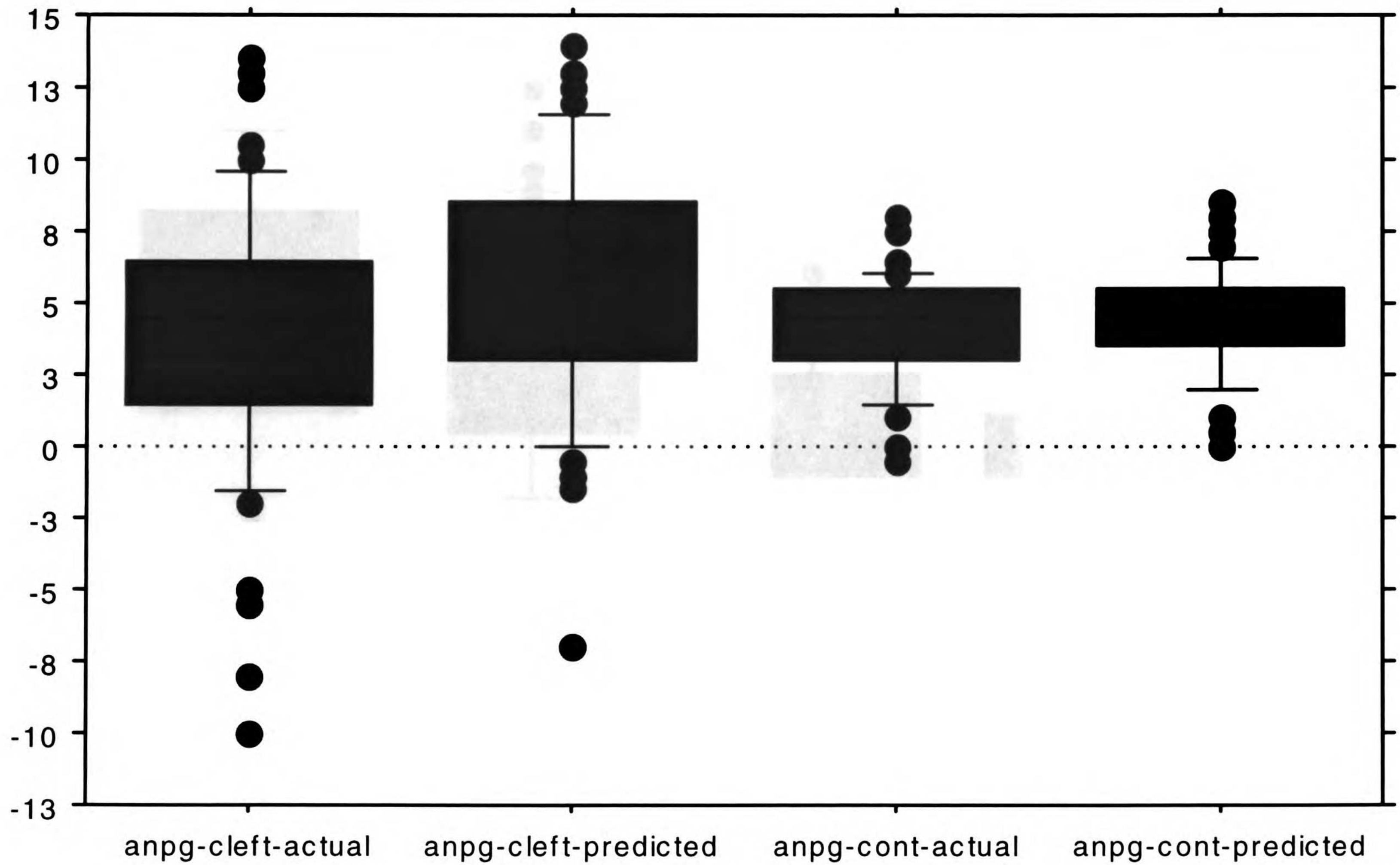


Fig. 60: Comparison of predicted growth to actual growth for the angle ANPg.

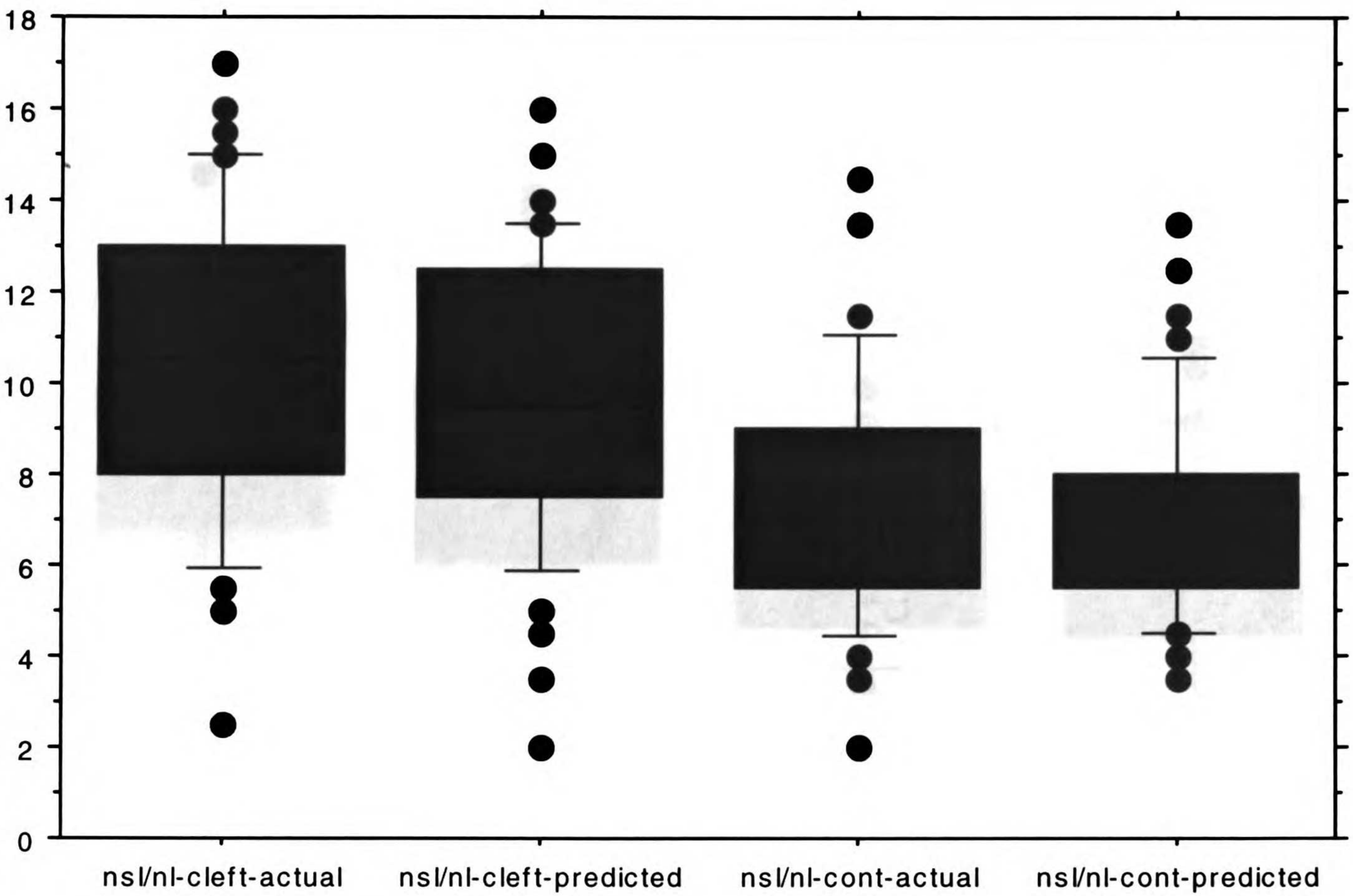


Fig. 61 : Comparison of the predicted growth to the actual growth for the angle NSL/NL.

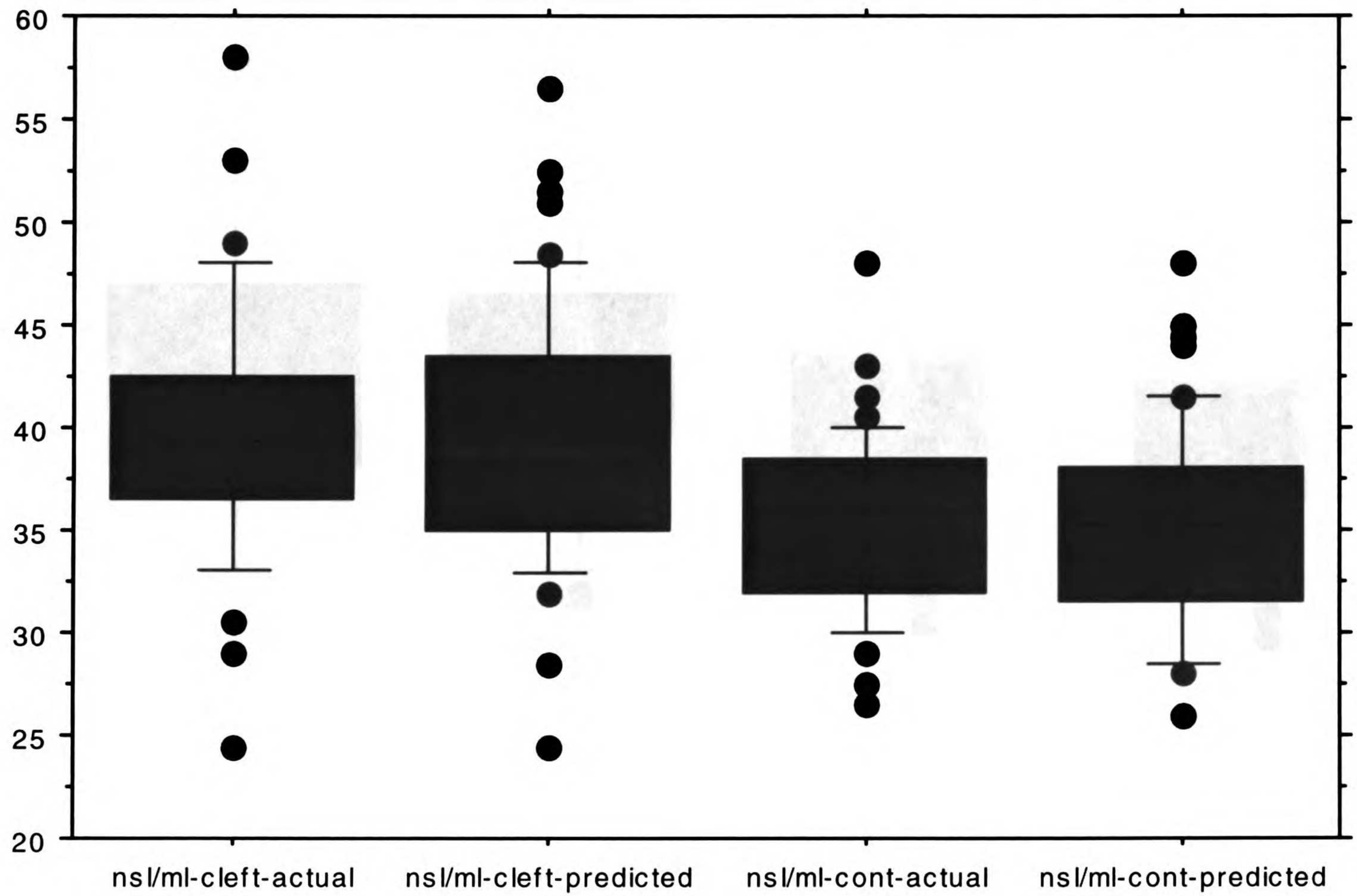


Fig. 62 : Comparison of the predicted growth to the actual growth for the angle NSL/ML.

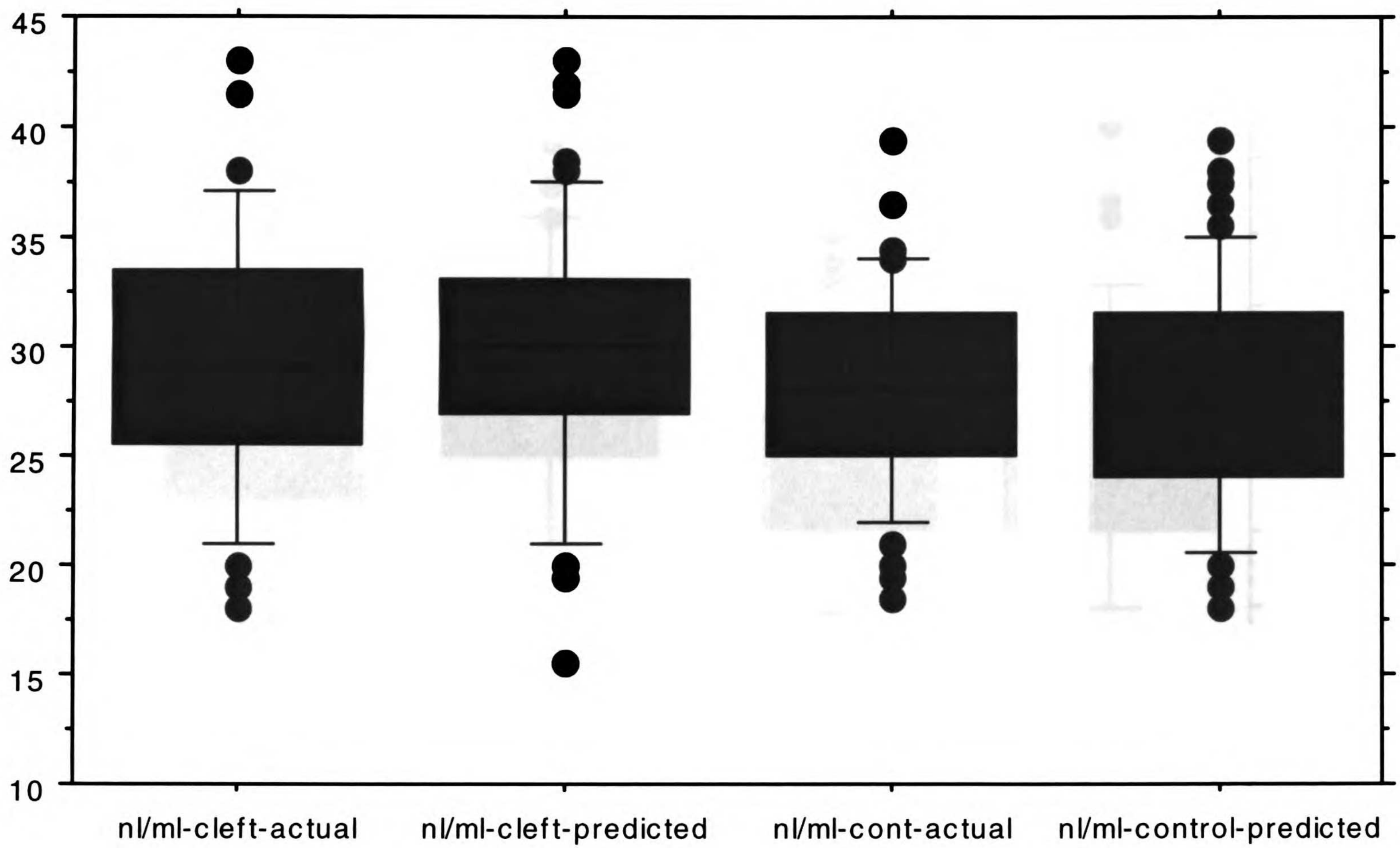


Fig. 63: Comparison of the predicted growth to the actual growth for the angle NL/ML.

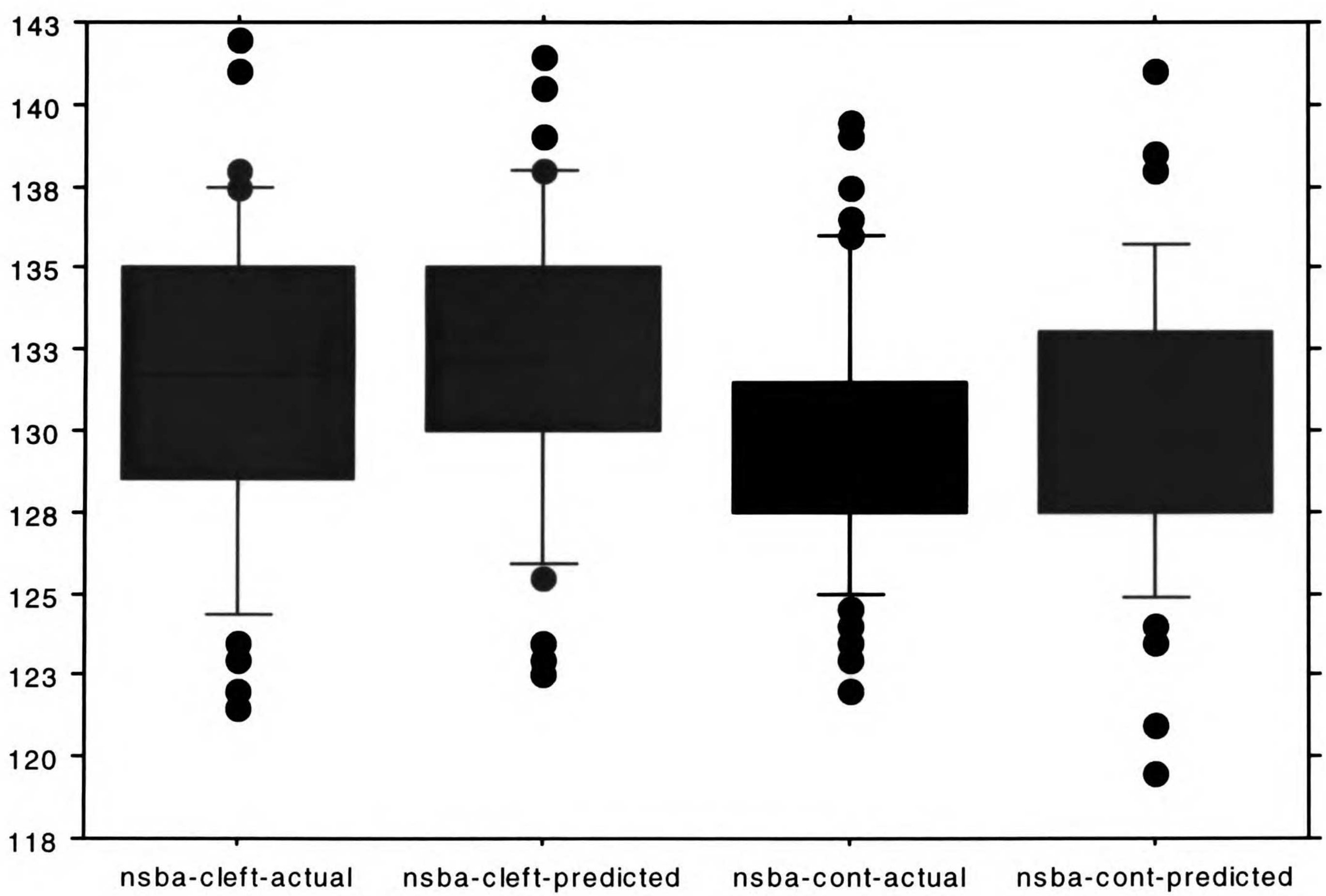


Fig. 64: Comparison of the predicted growth to the actual growth of the angle NSBa.