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SCHOOL OF DENTISTRY

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TRANSVERSE CHANGES IN THE ADULT CRANIOFACIAL COMPLEX

Martha A. Chun

Submitted in partial fulfillment of the requirements
for the Degree of Masters of Science in Dentistry

Department of Orthodontics
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August 13, 1993

TRANSVERSE CHANGES IN THE ADULT CRANIOFACIAL COMPLEX

ABSTRACT
by
MARTHA A. CHUN

The purpose of this study was to determine from serial P-A cephalometric radiographs, 1) if growth occurs in the transverse dimension of the adult craniofacial complex, 2) to locate areas of change and 3) to examine the pattern of change between the initial and final record by selecting a third set of records for a subsample of the subjects examined. A total of 30 subjects(22 males and 8 females) were selected from the Bolton Study, Behrents' 1985 adult recall and Update 2000 recall at Case Western Reserve University, Cleveland, Ohio. Posteroanterior cephalometric radiographs were selected of orthodontically untreated subjects with the initial film at least at 21 years and the final film at a minimum of 5 years or more beyond the age of the initial film.

Absolute linear distances were measured and corrected for magnification for the width of the cranium,

zygomatic arch, frontozygomatic suture, medial and lateral orbital rim, nasal aperture, maxillary and mandibular molar, mastoid process, gonion, and maxillary arch width. A Wilcoxon Matched-Pairs Signed-Ranks test was used to evaluate the data with respect to the direction of change. The results indicate that transverse changes do occur in the adult craniofacial skeleton. The variables that were significant for increased change ($p<.005$) with age were cranial width, mastoid width, zygomatic arch width, and lateral orbital rim width. No significant changes were found in gonial width, frontozygomatic suture width, width of the medial orbital rim, nasal aperture width, maxillary arch width, lower molar width, or upper molar width.

DEDICATION

This work is dedicated to my mother and father, whose guidance and support encouraged me to pursue my dreams.

I thank my husband, Richard for his patience, understanding and love during this past year.

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INTRODUCTION

Adult is defined in Stedman's Medical Dictionary (1971) as a fully grown and mature individual. This definition leads one to believe that growth and maturity have been fully attained. Can growth occur in adulthood as part of the aging process? The use of the word growth seems contradictory to what we think about aging. Aging is defined as the process of growing old especially by failure of replacement of cells in sufficient number to maintain function.(Stedman 1971) There are a variety of degenerative processes known to occur during aging. These include arthritis, decreased vital capacity, tissue atrophy and cell death. Other examples are the intervertebral discs, muscle weakening and decreased brain and bone mass. During the aging process there are also noted increases occurring. These include hair and fingernail growth, and bone expansion.(Garn 1970) Pathologic increases can occur in adulthood, such as in Paget's disease and in the hormonal growth disturbance, acromegaly.

The word growth is defined as the increase in size

of a living being or any of its parts occurring in the process of development.(Stedman's Medical Dictionary 1971) Baer (1971) in addition, adds that growth can be a decrease in size as part of normal growth, for example lymphoid tissue decreases in size and volume after adolescence. Maturation is intimately related to growth, but is qualitative, while growth is quantitative. It is an irreversible process defined as achieving full development or growth.(Stedman's Medical Dictionary 1971) Growth and maturation are two components of the process of development which Baer(1971) defines as the totality of physical change from conception to death. Enlow (1990) regards facial growth and development as

"...a morphogenic process working towards a composite state of aggregate structural and functional balance. The same underlying process then continues to work in order to sustain ongoing equilibrium throughout adulthood and old age in response to ever changing internal and external conditions and relationships. This morphogenic process of growth implies both negative and positive changes in establishing equilibrium."

There is a lack of knowledge of the detailed mechanism of adult craniofacial change. Calling these changes "growth", "adaptation", "maturation", or "post-maturational differentiation" is still an unresolved issue.(Enlow 1989) Behrents (1985) uses "growth" to describe adult craniofacial changes, as he feels it is a continuation of changes seen during adolescence, but at a

different rate, amount and demand.

While growth in the adult craniofacial complex has historically been assumed to be nonexistent, researchers such as Behrents (1985), Israel (1968,1973,1977), and Lewis and Roche (1988) have shown that changes in the craniofacial complex occur in early adulthood and beyond. They have been able to provide evidence of growth from serial lateral cephalometric x-rays of the neurocranium and viscerocranium. The changes are subtle but definitely do exist.

Since recent research has established that the adult craniofacial complex does undergo some degree of growth in the sagittal and vertical plane, it is logical to next investigate the possibility of change in the transverse plane. Adult transverse changes have been documented in the literature in somatometric and craniometric studies. Somatometric studies have the disadvantage of soft tissue covering the underlying skeleton and impeding assessment of true craniofacial skeletal growth. Craniometric studies have limitations due to the very nature of cross-sectional investigations as well as problems of assigning accurate ages. Cephalometric studies will enable one to assess longitudinal skeletal changes leading to a more valid indicator of growth trends while revealing individual variations in growth patterns. To date, no longitudinal P-A cephalometric studies exist for

transverse changes of the adult craniofacial complex.

It is important to understand adult growth changes in all 3-dimensions as cranio-facial surgeons and orthodontists treat the dento-cranio-facial complex in all three planes of space. Once transverse changes in the adult craniofacial complex have been described we will have a more complete picture of the effects of aging in the craniofacial complex. This will enable us to better predict and potentially control the aging effects and modify orthodontic and surgical treatment in light of what we know about adult craniofacial growth.

The purpose of this study is to 1) determine from serial P-A cephalometric radiographs if growth occurs in the transverse dimension of the adult craniofacial complex, 2) to locate areas of changes and 3) to examine the trend of changes in a subsample of the subjects examined.

LITERATURE REVIEW

Serial post-pubertal studies in the transverse dimension are few in number, most indicating completion or marked diminution in transverse growth by the adolescent growth spurt. Krogman (1979) found transverse growth to be completed before the adolescent growth spurt with minimal changes throughout adolescence. Growth in width was completed first, then in depth, and finally in length of the face. Goldstein (1936) found bizygomatic and bigonial widths to reach maximum development from 19 to 21 years. Bjork (1966) found from serial implant studies, that sutural growth in the transverse and sagittal plane appeared to be completed at approximately 17 years of age.

Post-pubertal studies utilizing lateral cephalometric radiographs are numerous, with most indicating a cessation in growth in the second decade. Bishara et. al., (1984) showed little change in craniofacial dimensions after 14 to 15 years except for standing height and mandibular depth in males. Longitudinal studies by Foley and Mamandras (1992) and

Love et. al., (1990) examined females and males, respectively, up to the age of 20 years, and found little change in facial parameters except for the mandible. Bjork and Helm (1967) found little change in facial parameters beyond 23 years, while Baer and Harris (1969) found slight increase in cranial length up to 24 years. Nanda (1955) found change in the craniofacial skeleton in his serial study up to age 20 years. Bambha (1961) also found the face to continue to grow while the calvaria and cranial base ceased growth. Hunter (1961) found facial growth changes to continue into the second decade for females and the third decade for males.

Longitudinal dental arch width studies utilizing dental casts have found molar and canine arch widths to remain stable after 13 years in females and 16 years in males.(Knott 1961, Sillman 1964, Knott 1972, and DeKock 1972) Molar widths have been followed from P-A cephalometric radiographs by Woods (1950), Bjork (1974,1977) and Athansiou et. al., (1992). Woods found maxillary bimolar width to markedly decrease in its rate of increase once teeth came into occlusion. Athansiou et. al., found maxillary and mandibular intermolar width from 9 to 12 years to remain constant throughout the period examined. Bjork (1974,1977) from serial implant studies found intermolar width stable after 21 years. Krogman (1951) found transverse development of the maxilla and

mandibular width and widths of the dental arches completed prior to adolescent growth and remained fairly stable post-pubertally.

No serial studies in the transverse dimension exist beyond puberty to document if any changes occur in the craniofacial skeleton. From longitudinal and cross-sectional studies utilizing lateral cephalometric x-rays, post-adolescent studies have shown facial growth to diminish or cease by the second decade while some studies have shown continued growth in various parameters of the calvaria and face.(Israel 1968,1971,1973,1977, Behrents 1985, Lewis and Roche 1988) Other studies have shown no continued cranio-facial growth in the adult.(Tallgren 1974, Forsberg 1979) As it stands from serial lateral cephalometric studies, it has been shown that changes in the adult do occur up to the second decade with conflicting results beyond the third decade, while no serial P-A cephalometric studies exist examining adult cranio-facial changes in the transverse dimension. Transverse dimensions have been examined in the adult utilizing craniometric and somatometric methods while P-A cephalometric studies have been conducted in young and adolescent children. The following section will review pertinent craniometric, somatometric and cephalometric studies in the transverse dimension as well as major adult studies from lateral cephalometric radiographs.

Craniometric Studies

The study of the transverse development of the craniofacial complex prior to the advent of cephalometry involved craniometric investigation of dry skulls. This approach is inherently limited to cross-sectional investigation and in many cases age verification resulted in only approximations. Keith and Campion (1922) analyzed where growth increments and differentiations took place through drawings of superimposed skull bones of the adult and child. They found the width of the skull and face increased from 5 years to adulthood by 34 mm in the bizygomatic region and by 8mm of growth in width at the intermaxillary suture during the eruption of permanent teeth.

In 1924, Todd looked at 448 male skulls spanning the ages of 20 to 84 years and found the calvarium increased in thickness up to the 6th decade with no change thereafter. He found cranial sutures to begin closure from 26 to 30 years, with the sagittal suture commencing to close at 23 years, the coronal suture at 24 years and the lambdoidal suture at 26 years. Closure was completed at 35 years for the sagittal suture, at 41 years for the

coronal suture, and 26 years for the lambdoidal suture. The masto-occipital suture commenced closure at 30 years and final closure occured in the eigth decade. The sphenotemporal and sphenoparietal sutures began closure in the third decade and closure occurred in the late sixth decade. The sphenofrontal suture began closure at 22 years, the greater wings at 25 years and the lesser wings at 27 years with final closure occurring in the sixth decade for the the greater and lesser wings. The posterior region of the squamous suture began closure at 30 years as did the anterior region. Final closure occurred in the eigth decade for the posterior region and never completely closed in the anterior region. The parietomastoid suture began closure at 37 years and final closure occurred in the eigth decade. Todd found minimal increase in the dimension of the frontal sinus and minimal change in cranial thickness. Ruff (1980) examined 136 adult male skulls and found small but significant increases in size of the craniofacial skeleton during aging. He found marked calvarial and gonial angle change with old age and a more gradual and even change in face breadth and bigonial breadth. He stated there was actual enlargement of the craniofacial dimensions and not just simple morphologic change from remodeling with age.

Israel (1979) examined 90 dried mandibles from the Terry and Todd collection with known age, sex, and race

for each specimen. All mandibles had nearly complete dentitions and age range was 20 to 69 years. Israel found continued expansion of the mandible with age of approximately 2% per decade in the width of the ramus and mandibular thickness in the region of the mental foramen.

Bartlett et. al. (1992) saw enlargement in almost all transverse dimensions with increasing age in the female population but not the male population. They examined 80 European female and 80 male skulls collected between 1880 and 1930 of differing ages. The males showed little sagittal change but females showed increased length of the calvarium, upper face and midface depth. Males exhibited a pronounced supraorbital region. No change was seen in the gonial angle in either sex.

Somatometric Studies

According to Broadbent (1931) and Goldstein (1936), anthropometric investigations of transverse development of humans were open to error due to overlying soft tissue but it afforded a good estimate of size. Hrdlicka's studies in 1925 on Old Americans and in 1935 on American Indians, found an increase in the dimension of the adult head until the sixth decade in the Indian sample. In his

study in 1938, he attributed the increase in head size to the increase in brain size which occurred well into the thirties, particularly in males. Hrdlicka (1936) concluded growth continued into the fifth decade but at a slower rate. He stated that stature increased up to the fourth decade, while skull and face dimensions increased into the fifth or sixth decade, with length and breadth of the nose, length of the ears, width of the mouth, and depth of the chest increasing up to the sixth decade.

Goldstein (1936) longitudinally looked at 50 American Jewish males from 2(1/2) to 3(1/2) years old to 20(1/2) to 21(1/2) years old as well as 50 Jewish males with mean ages of 74. He made biannual examinations and analyzed them with respect to age according to Hellman's dental classification. In his study he found bizygomatic and bigonial widths to be fairly similar in total relative increments and in general growth curves but found no clear cut adolescent growth spurt as he found in other diameters of the head. He found increases in bizygomatic, bicondylar, and bigonial widths from 3 to 19 years old with maximum development from 19 to 21 years. He found cranial growth the greatest, then facial length, width and height. Growth was completed first in the head, then facial width, length and lastly depth. In contrast, in the adult group he found all facial width measures increased whereas facial length decreased due to loss of

teeth. He also found that head diameter decreased and nose height increased. In this older sample the head had greater length than width, and total face length was greater than maxillary width.

Krogman (1951) cross-sectionally examined 50 males and 50 females 7 to 12 years of age with varied occlusions. Data was based on Hellman stages of dental development. At Hellman stage IIIA to IVA there was bicondylar increase, bizygomatic increase and bigonial increase in males and females with breadth gains greater in the midface than lower face. Females tended to gain in width earlier than males whereas male absolute dimensions were greater at each stage than the females. The most gains were in the bicondylar and bizygomatic widths with the bizygomatic breadth gain related to the skeletal structural support of the muscles of mastication. Krogman examined the 3-dimensional growth pattern and timing of the craniofacial complex. He stated that at birth, the width dimension was 50-60% of adult value, the height was 40-45% and depth 30-35% of adult value. From birth through puberty, growth was the most in depth, then height and the least in breadth. He also stated that the transverse development of the maxilla and mandible including the width of the dental arches was completed prior to the adolescent growth spurt and remained fairly stable post-pubertally.

Meredith (1954) looked at 156 males and 153 females from 4 to 10 years of age in a mixed-longitudinal growth study at the University of Iowa where selection was not based on dental conditon or orthodontic need. He followed the bizygomatic breadth change during childhood and found a continuous increase throughout childhood and adolescence with the greatest increase from 2 to 6 years. Male mean dimensions were consistently larger than females and the difference was no less than 2.5mm. As the child grew older, the sexes differed by slightly increasing amounts. Meredith (1953) citing his mixed-longitudinal study of North American caucasian males found that at birth the bizygomatic width had reached less than 55% of its size at 2 years of age. By 4.5 years the width reached approximately 80%, by 12.5 years it reached 90% and by 16 years it had reached 95% of its adult size.

Farkas et. al. (1990) cross-sectionally examined 1,537 N. American caucasians ranging in age from 1 to 18 years. Head width and circumference showed continued growth in both sexes throughout the age range examined. Bizygomatic width and mandıbular width attained 92% of their adult sizes at 5 years. Intercanthal width reached its full maturation in males at 11 years attaining 99.1% of the mean value at 18 years, and at 8 years for females, attaining 96.5% of the mean value at 18 years.

Biocular width (right and left exocanthion) was fully matured at 15 years in males and 13 years in females with minimal additional growth increments for both intercanthal and biocular widths. Nose width matured at 14 years in males attaining 95.4% of the mean size at 18 years and at 12 years for females attaining 98.4% of the mean size at 18 years.

Buchi (1950) longitudinally examined 200 Swiss adults from 20 to 70 years of age. He found a steady increase in diameter of the head and face and in long bone dimensions with aging, even after epiphyseal union, up to ages 56 to 64 years. He found increase in facial height in the 38 to 47 year age group and increase in facial breadth in the 56 to 64 year age group. Increase in head length and circumference occurred in the 47 to 56 year age group and increase in head breadth occurred in the 29 to 38 year age group.(cited from Baer 1956) Susanne (1977) longitudinally examined 44 Belgian males followed from the ages of 25 to 60 years. He found an increase in head length and breadth and an increase in bizygomatic width until the age of 60 which he thought was due to periosteal apposition. Bruchner et. al., (1987) conducted the Basel longitudinal study on opthalmologic aging from 1955 to 1978 of 123 Swiss men from 6 to 61 years of age examined every two years. They found variability in the growth cessation of the

interpupillary distance ranging from 17 years to 30 years but no change was noted beyond the thirtieth year.

Hooton and Dupertuis (1951) cross-sectionally examined 10,000 Irish males and found the maximum face height was reached in the 30 to 34 year age group while facial breadth reached its maximum size in 60 to 64 year age group. Increase in head length and circumference occurred in the 35 to 39 year age group and maximum head breadth occurred in the 30 to 34 year age group. Lasker (1953) cross-sectionally examined adult Mexicans and found an increase with age in cranial breadth, bigonial breadth and bizygomatic breadth for both sexes up to the fifth decade. Due to the problems encountered in somatometric studies, he stated it was not clear if size increase was due to appositional growth of bone or changes in overlying soft tissue. Baer (1956) cross-sectionally examined 5,688 males and 3,430 females, 19 to 33 years old from Ft. Meade. Male total face height, nose height, and bizygomatic breadth showed significant size increase during the third decade of life but head length, breadth, and circumference did not signficantly change with age.

Cephalometric Studies

Since the advent of cephalometrics, investigators have been able to examine the transverse development of the skull quantitatively and assess the growth patterns of the craniofacial complex. Cross-sectional and longitudinal studies have been carried out each having its own set of limitations. Interpretation of cross-sectional data can be confounded by secular trends, disease states, timing of measurements, selective survival effects, individual changes, and sexual and racial effects. In addition, cross-sectional data point out trends and age differences between groups, not age changes, and can also reveal false trends. Longitudinal studies on the other hand point out individual patterns and give clearer indications of trends. The difficulties found in longitudinal studies are often the short age spans evaluated, the small sample size, and the technical limitations which have hindered their use in growth studies. Broadbent (1931) was first to use the frontal x-ray as a tool for evaluating the general growth changes in a serial study of a set of twins. Frontal analyses were developed by Sassouni(1958) and Ricketts(1981), and by Broadbent Sr., Broadbent Jr., and Golden(1975) who developed their Bolton Standards for dentofacial developmental growth.

Costaras, Pruzansky and Broadbent Jr. (1982)

published normal standards for age and sex for bony interorbital distance, head size, and level of cribriform plate relative to orbital height. This longitudinal study found that males had larger mean bony interorbital distance values than females at most ages past 4 years. The BIOD growth plateaued at 14 years in females and 16 years in males with a highly significant age-dependent correlation between BIOD and cranial width especially in females. Morin et. al., (1960), cross-sectionally examined interorbital growth in 50 children 3 to 12 years and 25 adults who were the parents of the children and found total growth of 9.9mm from infancy to adulthood with 50% of interorbital growth completed by 3 years. There was a slight increase in the interorbital distance from 12 years to adulthood.

Woods (1950) was the first to quantitatively examine changes that occurred in the transverse dimension of the dental arches. He longitudinally examined 14 males and 14 females from 3 to 15 years with annual/semiannual records up to 15 years with varied untreated malocclusions. P-A radiographs were taken using the Bolton-Broadbent cephalometer and distortion was corrected with the Wylie-Elsasser compensater. He found bizygomatic and bigonial widths to increase steadily from 3 to 15 years with the male values consistently greater than the females. Newman and Meredith (1956) longitudinally examined skeletal

bigonial width changes during the 5 to 11 year old period of 36 males examined annually and 36 females examined semianually from the University of Iowa growth study. P-A radiographs were taken using a Higley head positioner and correction for enlargement was made. In a group trend analysis they found the bigonial width to increase throughout the period examined at a declining rate, with the males exhibiting larger mean dimensions than the females, as in Wood's study, with the sex difference increasing with age.

Athanasiou, Droschl and Bosch (1992) did a cross-sectional study providing norms of dentofacial P-A cephalometric measurements and patterns of transverse dentofacial structures. 157 Austrian girls and 431 Austrian boys from 6 to 15 years with various occlusions and no prior orthodontics were selected. Linear dimensions and ratios as well as angular data were measured from the P-A cephalographs, with standardized magnification combining male and female results. They found inner orbital width, nasal width, and maxillary skeletal base width and intergonial width to increase in a progressive manner.

Implants have been used to study the growth of the maxilla in the transverse dimension. Bjork and Skeiller (1974,1977) have shown post-pubertal growth in the median suture with growth in that area being the most important

factor in the transverse development of the maxilla. They longitudinally examined the transverse growth of the maxilla in males with normal occlusion followed from 4 to 20 years. 2 metallic implants were inserted laterally in the infrazygomatic crest in 14 males at the age of 4, and 2 implants were placed at the age of 10-11 years into the maxilla below ANS on each side of the median suture on a level with the apices of the central incisors. 8 were eventually followed for 16-20 years and one for 12 years. Annual lateral and frontal radiographs, hand/wrist films, dental casts, photos, and standing height measurements were taken. No corrections were made for magnification. The cumulative growth in width in the median suture meaured between lateral implants followed the same pattern as growth in standing height. Bjork found cessation of growth in the median suture to occur 2 years prior to cessation of maxillary growth in height. Sutural growth in the transverse and sagittal plane coincided in all cases. The growth between the lateral implants was on average three times greater than the the growth between the anterior ımplants. The median suture in the posterior maxilla exhibited greater separation than ın the anterıor regions rotating the two halves of the maxilla towards each other in a transverse plane. With lateral rotation of the maxillary halves, there was shortening of the length of the maxilla in the midsagittal plane. Bjork

(1974) saw a possible correlation between shortening of the upper dental arch in the median plane due to transverse rotation of the 2 maxillary halves. He correlated the difference in width of the dental arches at the canines and first molars to a greater posterior growth in the median suture. Lowering of the maxilla along with vertical and transverse rotation occurs in the transverse suture of the hard palate, as well as sutures between the vertical plates of the palatine bone and maxilla. The extent of appositional remodeling in the increase of the width of the maxilla could not be determined though it appeared to play a minor role compared to sutural growth.

Bjork (1974,1977) examined the transverse development of the maxilla at the median suture and the transverse changes occurring in the dental arch. Intercanine and molar widths were measured between the mesial contact points. The first molar width showed a pubertal increase followed by a smaller decrease so that by the age of 21 years the width was only 1mm greater than at the time of eruption of the first molars at age 6. The intercanine width increased until the full eruption of the permanent incisors then continued to decline until adulthood. From the time of eruption of the first molars, the intercanine width increased only 1.1mm versus 3.1mm increase between the first molars. Bjork

found a significant correlation between first molar width increase and the increase of the median suture at the lateral implant. From 6 to 7 years to adulthood, growth between the lateral implants was 4.8mm and at the first molars the growth was 3.1mm. The median sutural growth at the lateral implants was greater than between the first molars. The variability of increase in the molars was twice as big as the variability of increase in the lateral implants indicating greater compensation in the development of the dental arch. From 10-11 years to adulthood, the molar width increased on average 25% that of the growth at the sutures.

Adult Studies

Researchers such as Behrents (1985), Isreal (1968,1973,1977), Lewis and Roche (1988) and others have studied adult craniofacial growth. Israel (1968) examined serial lateral cephalometric radiographs of 43 males and 53 females in the age range of 24 to 56 years and did a second study of the same sample 13 to 25 years later. Isreal found a dimensionally symmetrical enlargement in the cranium of 1% per decade with a differential increase of 6% in the upper face, 9-14% in the frontal sinuses,

and 5-7% in the mandible. Israel also found continued growth of the adult skull with increases in the thickness, approximately 6% beyond 24 years of age over a mean period of 18 years, in diameter he found a 3-5% enlargement of uniform size gain in outer and inner tables and in intersutural distance. He observed large increases in the thickness of the frontal and parietal bones and skull enlargement peaked in the seventh decade with a decline thereafter. He found an increase in skull diameter of 5mm, an increase in the middle third of the face (N-ANS) of 1mm in females and 3mm in males and an increase of 3mm in the cranial base (N-Ba). The gonial angle, measured from Me-Go and posterior condyle, did not increase with age nor did the dental status affect the angle. Forsberg (1979) longitudinally examined of 26 male and 24 female Swedes from the ages of 24 to 34 years and also found no change in the gonial angle. Israel (1977) longitudinally examining 26 males and females, between the third and eigth decade, found a dichotomous pattern of enlargement with a 4-5% generalized expansion and a 10% increase in skull thickness in the frontal region, size of paranasal air sinuses, and dimension of sella turcica. Israel has been criticized Tallgren (1974) for not correcting for magnification, not using a head-holder to ensure fixed film-focus distance and constant distance from the midsagittal plane of the head to film, and the

inability to quantify enlargement. He did comment in his 1977 study that his finding of a dichotomous enlargement pattern proved there could not have been improper radiographic methods which would have lead to erroneous biologic reasoning for expansion.

Tallgren (1974) longitudinally examined 32 Finnish females who had been wearing dentures. They ranged in age from 20 to 73 years at the initial observation and 35 to 88 years at the final exam. Tallgren found no significant changes in dimensions of the cranial base, vault, and frontal bone thickness revealed on lateral radiographs with no correction for enlargement. His results were in agreement with Bambha (1961) that neurocranial growth is completed during adolescence or soon after. He did find slight appositional thickening in the glabella region in half the subjects. There was no significant increase or decrease in skull thickness and no significant remodeling of the neurocranial bones with increasing age.

Neurocranial changes in adulthood were also investigated by Kendrick and Risinger (1967) who found increases in posterior cranial depth from lateral cephalometric radiographs of 71 males, 22 to 34 years of age. Increase in head length was also seen in studies by Hrdklicka (1936) in mid-adulthood but found the opposite results in a later study of Pueblo Indians ranging from 28 to 50 years of age. Lasker (1953) and Baer (1956) also

found head length stable in adult males. Boersma (1974) in cross-sectionally examining 150 Dutch males and females between the ages of 58 and 91 years, found few statistically significant differences in skull dimensions and almost all linear dimensions in females were smaller than males. Adeloye, Rattan and Silverman (1976) cross-sectionally examined 300 American Blacks and 200 caucasian males and females from 5 weeks to 80 years of age using lateral cephalometric radiographs. They found the skull thickness to increase rapidly in the first 2 decades of life reaching a steady peak in the fourth to sixth decade after which measurements oscillated, either due to small sample size or sporadic thickening of the skull in later life. Todd (1924) found skull thickness stable between 30 to 50 years of age with oscillations thereafter. Adeloye et. al., (1976) found males had greater skull thickness at the vertex than females and females had greater thickness at the parietal region in the third decade and at the parieto-occipital region after the fifth decade. Todd (1924) postulated skull thickness as being related to brain weight with a thinner walled cranium being one that is completely filled with brain tissue.

Forsberg (1979) longitudinally examined 25 male and 24 female Swedes using lateral cephalometric radiographs taken during the second decade and then 10 years later.

He found an increase in facial height but no dimensional changes in the maxilla and mandible. He attributed vertical increase in facial height to the posterior rotation of the mandible. He postulated this increase was due to the eruption of the third molars increasing the vertical dimension of the face.

Behrents (1985) longitudinally examined 163 adults from 17 to 83 years using lateral cephalometric radiographs and found that there was minimal change in the cranial base, moderate change in facial bones and significant change in the frontal sinus, with the most change in soft tissue. The female dimensions in the study were consistently smaller by 5-9% than those of the males throughout the period examined. The females exhibited vertical changes attributed to the backward rotation of the mandible, which was also in agreement with Forsberg's 1979 study. The males also exhibited a vertical change but this came about as a result of a forward rotation of the mandible.(Behrents 1985)

The midface of the adult exhibited little change in the region of the PTM fissure but a relocation of the anterior palate in males was seen to move forward and downward.(Behrents 1985) In contrast, Forsberg (1979) found no change in the A-P dimension of the maxilla. The midface region had the most development anterior to the frontomaxillonasal suture and the key ridge relocated

anteriorly at all ages. The orbit was more upright in females and the superior lateral and inferior aspect of the orbit moved anteriorly increasing the size of the orbital cavity as well as the dimension of the zygomatic process. Behrents (1985) speculated that the cause of the continuous growth in adulthood was from increased respiratory demands from decreased pulmonary efficiency with aging. This would possibly result in an increase in the nasorespiratory area. Gonion relocated in an anterior and inferior position in males with counterclockwise rotation of the mandible and in an inferior and posterior position in females with clockwise rotation of the mandible. The mandible grew in length, body, ramus, and in the alveolar regions with less deposition on the posterior border and continuous resorption on the anterior border of the ramus. The posterior ramal border did not change in females but in males it moved anteriorly and decreased in width.

Dental changes also were found where the upper incisor for both sexes became more upright and the lower incisor became more stable with a slight proclination tendency in the females. The upper molars uprighted in the males and inclined distally in the females. The lower molars in males became more upright and in females inclined mesially.(Behrents 1985) The maxillary arch revealed an increase in the posterior and anterior height

of the alveolus with continuous eruption of the teeth. In the mandible there was also an increase in the height of the alveolus with continued eruption of the teeth. Males had larger alveolar processes than females but it was uncertain if it was the result of bone deposition on the inferior aspect of the body.(Behrents 1985)

Lewis and Roche (1988) criticized Behrents' (1985) study indicating that he did not adjust for the effects of multiple comparisons resulting in an overestimation of the statistical significance of the observed differences. Due to the small sample size, the increases in mean lengths after the age of 40 were not statistically significant. Although Behrents showed evidence of continuous enlargement in all dimensions of the cranial base and mandible after 30 and 35 years of age for some of the sample, it did not provide the estimates of the ages at which growth ceased in these dimensions.

Lewis and Roche (1988) mixed-longitudinally examined 8 males and 12 females from 17 to 18 years through 40 to 50 years, with at least 3 to 8 serial lateral cephalometric x-rays for each subject with one being between 40 to 50 years old. Because of the problems inherent to longitudinal studies, the x-rays for the subjects were taken at irregular intervals. The authors admit that their data do not allow a definitive analysis of growth in the craniofacial skeleton after 18 years but

they do point to a continuous growth of the cranial base and mandible into adulthood until the second and third decades.

To date no known longitudinal cephalometric data have been investigated for caucasian adults in the transverse dimensions. Weinstein (1948) cross-sectionally examined adults from 18 to 45 years of age with normal occlusion. P-A radiographs were taken using the Broadbent-Bolton cephalometer with no correction made for enlargement. In addition, no classification was made according to sex, race or cephalic index. He measured several linear and angular dimensions of the face and dental arches and correlated several pairs of measurements representing widths of the cranium. High positive correlations were found for all pairs of dimensions. Although his methods indicate several flaws which prohibit interpretation of his data, he was one of the first to look at adults utilizing angles in analyzing the frontal radiograph.

Remodeling activity in the adult craniofacial skeleton has been thought to continue into adulthood based on histologic and cephalometric studies. Kokich (1976) in his histologic study, found continuous periosteal deposition on the surface of the zygoma and resorption at the orbital surface during adulthood inidicating transverse widening and possibly an increase

in bizygomatic breadth with a decrease in thickness of the zygomatic bone with age. Enlow (1978) stated that the remodeling process in adults was basically static but could be altered by environmental factors such as change in function, in biomechanical circumstances and loss of teeth, leading to gross remodeling changes. Behrents (1985) Histologic studies by Enlow (1981) found remodeling occurring in the edentulous mandible with the medial and lateral surface of the corpus depository and lateral posterior and anterior surface of the ramus resorptive making the corpus longer. Serial cephalometric studies on adult craniofacial growth by Behrents (1985) and Israel (1973,1977) have demonstrated adult growth attributed primarily to remodeling with Behrents (1985) speculating the possibility of sutural adjustments taking place. Israel (1973) did not believe in the existence of sutures in adult cranial growth. He saw a symmetrical magnification in all dimensions which he attributed to deposition of new bone onto existing osseous contours. In contrast, Enlow (1968) stated that osseous enlargement involves a combination of sutural deposition and remodeling to maintain the morphology and position of the bone with respect to its adjacent bones. It was stated by Behrents (1985) that the process of remodeling occurring during adolescence may be the same process occurring in adulthood but at a different rate, amount, and demand on

this mechanism.

Israel (1968,1973) described remodeling of the cranium as a unique process differing from remodeling seen in other parts of the skeleton. The cranium was found to increase in thickness well beyond 60 years of age although it was not known whether growth was attributed to the two cortical layers, the inner or outer tables, or the intervening cancellous bone, the diploe. The outer cranial diameter as well as the inner cranial diameter was found to peak at 70 years and then regress. This inferred periosteal apposition was occurring on the outer table until age 70 as net resorption was occurring on the inner table. Beyond 70 years the opposite process occurred.

Garn et. al., (1967) has shown from cross-sectional and longitudinal P-A radiographs adult skeletal remodeling in the second metacarpal. Garn et. al., (1967) stated bone gain in adulthood is a general occurrence in humans and is not population specific nor sex-specific nor a factor of genetics, socioeconomic, or environmental factors. Bone apposition was not restricted to weight-bearing bones, flexion-stress bones nor was it a compensatory response to endosteal resorption. He stated that continued growth of different bones in the adult may have been a response to different mechanical and hormonal stimuli, in particular to the adult enlargement of the

anterior pituitary. Garn et. al., (1968) found increase in cortical thickness and maximal bone mass between 30-40 years of age with continued subperiosteal and endosteal deposition in both sexes up to the fourth decade. Linear increase of the second metacarpal, femur, rib, skull and vertebrae were small in the range of 2-4 % .

Endosteal bone loss occurred after the fourth decade, more so for females, with continued subperiosteal deposition decreasing cortical thickness and increasing medullary cavity with age. Cortical decrease began slowly in both sexes and peaked between the fifth and sixth decades and declined thereafter.(Garn 1970) Deposition was found to occur at the end of the second decade up to the tenth decade in females.(Garn in Carlson 1988) Epker and Frost (1966) found periosteal deposition to occur even in the seventh decade from in-vivo tetracycline labeling of the human ribs. Females have been found to undergo loss later than males, expanding twice as much and twice as fast per decade than men.(Garn in Carlson 1988) They had 10% increased outer bone volume from the third to the ninth decade compensating in part for 30-40% loss of bone at the endosteal surface after the fourth decade.(Garn et. al.1967) At menopause, the rate of bone loss was rapid at 1.5-2.2%/year during the first 2 to 5 years. The rate gradually decreased by the seventies to 0.3%/year equivalent to the rate of males.(Heaney 1982)

Adult bone expansion has also been seen in the ribs (Epker and Frost 1966), humerous (Pfeiffer 1980), and skull (Israel 1973).

Adult endosteal resorption differs in onset and rate from adult subperiosteal deposition.(Garn et. al.1968) The cause of bone loss in adulthood is thought to be related to decreased osteoblast function due to osteoblast senescence or impaired regulation of osteoblast function by one or more of the various bone-derived growth factors.(Riggs et. al.1988)

Manson and Lucas (1962) microradiographically examined human mandibles and its pattern of pneumatization, bone deposition, and resorption and osteoporosis from 8 weeks to 76 years. Adults from 50 years onward appeared to have increased bone activity. There was an increase in mineralized osteons between 30-56 years, increase in deposition and a larger increase in resorption and porosity. Arnold et. al., (1966) found mineralization at its maximum in the femur between 35 to 50 years of age with a slight decrease in the sixth through the eigth decades of life. The supraorbital ridge also exhibited increased cortical porosity in adulthood as well as an increased number and size of osteons with increasing age. (Bartlett et. al.1992) The frontal and zygomatic bone exhibited an increase in the number of medullary spaces from 22 to 95 years.(Kokich 1976)

Studies on age changes in bone have shown decreased bone mass and physical density.(Trotter and Peterson 1955) Water content reduces to 10% and there is an increase in apatite and crystal size.(Dequeker 1972)

Sarnat (1971) summarized the bone growth and remodeling throughout life. He states in infancy and childhood, cartilaginous and sutural growth are active and in adulthood and old age, they are inactive. Apposition is greater than resorption in remodeling in infancy and childhood where skeletal mass is increasing. In adulthood, apposition equals resorption and skeletal mass is in equilibrium while in old age, apposition is less than resorption and skeletal mass decreases.

The patency of sutures beyond puberty and adulthood and the role of sutural activity in adult growth has met conflicting evidence. Histologic studies of sutural patency have been investigated by Wright (1911), Latham (1971), Persson (1973), Melson (1975), and Kokich (1976). Latham and Burston (1969), and Latham (1971) found no synostosis of the midpalatal suture at the age of 18 due to masticatory movements causing constant slight movements of the bones. Wright (1911), claimed intermaxillary and palatal sutures remained patent as late as 35 years old. Melson (1975), in examining 33 boys and 27 girls at autopsy, found midpalatal growth to cease at the age of 16 in girls and 18 in boys which was

similar to Persson's (1973) findings of age 15 in girls and 17 in boys. Melson (1975) made note that her small sample size and methodology of her research did not give validity to the exact timing of growth cessation. Kokich (1976), histologically examined the frontozygomatic suture of 61 human cadavers from 20-95 years of age. By the eigth decade of life, he found the initiation of synostosis in the suture, but no complete fusion even up to the age of 95. Sicher (1965), found the midsagittal suture to close in the mid thirties but the frontozygomatic suture remaining open in old age. Todd (1924) also showed closure of other sutures to commence many years before the frontozygomatic suture. Kokich attributed continued frontozygomatic patency to the transmission of tensile forces from the functioning masseter muscle. Craniometric studies found fusion of sutures to occur past puberty into early adulthood and some at old age.(Todd 1924) Todd attributed late closure of cranial sutures due to the growth of the brain. Implant studies by Bjork and Skieller (1977) found sutural growth to cease at age 17 for males and age 15 for females. Cephalometric studies by Krogman (1930) stated when the wisdom teeth have erupted all sutures will have synostosed, cranial sutures closing first, then facial sutures and the last to close were the sutures connecting the viscerocranium to the neurocranium.

Hrdklicka (1938) believed his observations of increased skull size with age were related to increased brain activity from intensive mental work resulting in brain and cranial enlargement, as long as cranial sutures remained patent, with internal thinning to the fifth decade and beyond. He found maximum brain weight relative to stature in males was 30-40 years and in females 20-30 years. It is doubtful significant sutural activity takes place in the adult craniofacial skeleton as it did during childhood and adolescence. Studies mentioned above show conflicting results and wide variation in sutural patency of the craniofacial complex.

The aging muscle has been reported to decrease in mass of at least 30% up to the age of 80 years.(Hyatt et. al. 1990) Muscle strength and fiber numbers also decrease with age being more pronounced in males. Studies have shown diminution in the number of motor fibers, alteration in enzymes involved in catecholamine synthesis and degradation and lapses in activation of single motor units with aging.(Baum et. al. 1983) Studies that examined masticatory function with aging have found those with complete or partially compromised dentitions did not have significant alterations in masticatory function.(Feldman et. al. 1980) There was a positive correlation between increased age and the number of chewing strokes necessary to prepare food for swallowing

in the aged with complete or partially compromised dentition.(Feldman et. al. 1980)

Garn (1970) suggested that age-associated loss of bone is a product of loss of muscle based on examining the tibia. Females had less bone loss than muscle mass loss with age from 22 to 80 years.

Transverse growth processes in childhood and adolescence

Scott (1958) attributed transverse growth of the facial skeleton to growth of the nasal cavities, orbital cavities, palate, mandible, cranial part of the skull and muscles of mastication. Scott (1957) described the midline sagittal suture system, which is complete during fetal life and at birth, to have a major role in the transverse growth of the craniofacial skeleton. It was composed of the metopic suture separating the frontal bones, the interparietal and internasal suture, the intermaxillary suture which extended into the hard palate as the midpalatal suture, the frontoethmoidal suture, the cribriform plane sutures, the synchondroses between the body and great wings of the sphenoid, and the mandibular symphysis. At the base of the skull the sagittal suture system divided and ran along each side of the midline

cranial base.

Scott (1957) described two mechanisms of growth in the sagittal suture system, 1) the growth of the brain as the most important factor in the separation of bones of the cranial vault and 2) growth of the cartilage between the body and greater wings of the sphenoid primarily, and secondarily the cartilage of the cribriform plate, roof of the nasal capsule anteriorly, and posteriorly the cartilage between the temporal bones and the occipitosphenoidal midline axis. The cartilage on each side of the body of the sphenoid uniting the greater wings of the sphenoid played an important role in regulating growth in the width between the eyes.(Scott 1957)

By the first year of life, the metopic suture united to join the two halves of the frontal bone. There was also obliteration of the mandibular symphysis as well as union of the greater wings to the body of the sphenoid. By the third year, the cribriform plate ossified uniting the facial part of the ethmoid to the perpendicular plate, forming a single unit between the orbital cavities. By approximately the third year, the medial orbital width and upper nasal regions had reached adult dimensions. Continued growth of the eyeball resulted in outward growth of the zygomaticomaxillary sutures in association with deposition at the zygomatic arches,

maxillary and mandibular alveolar processes, and the mandibular rami. The zygomaticomaxillary suture had a longer duration of growth than other sutures of the face and was probably due to the growth of the orbital cavity and transverse growth of the cranium connected via the zygomatic arch.(Scott 1958)

Calvarium

Growth of the neurocranium as described by Moss and Young (1955) occurs within a functional matrix consisting of the cerebral capsule, skull base, and meninges. The calvarium is broken down into functional components, the outer table, a diploe, and an inner table. The cerebral capsule is formed by tissues which surround and are responsive to the functional demands of the neural mass. The entire capsule enlarges at a rate determined by the expansion of the brain while the calvarial bones undergo osseous expansion. The inner surface of the calvarium is determined by the form of the dura of the brain. The outer table is functionally independent. It is locally modified by the mechanical forces acting on it. The diploe layer is also functionally independent, having a role in hematopoiesis and with pnuematization by

respiratory sinuses.

The outer table of the cranium is depository and bone drifts outward in contributing to cranial expansion. The inner surface is also depository. There are areas of resoprtion on the inner surface because remodeling serves to maintain the shape of the curvature of the bones. The vault of the cranium can be appositional on both sides of the bones because sutural response alone is capable of accommodating brain expansion.(Ranley 1980)

Orbit

Morin (1960) described interorbital growth to involve several growth processes; sutural growth, appositional growth, and pneumatization. Interorbital growth is distinct from other transverse dimensions of the neurocranium or facial skeleton. Rapid growth of the interorbital region occurred until 4 years of age, 1 to 2 years after closure of the fronto-ethmoidal suture and before extensive pneumatization. The naso-maxillary suture contributed to interorbital growth following enlargement of the maxillary sinus with dental eruption. The internasal suture, which fused in adolescence when the perpendicular plate united with the ethmoid, and the

fronto-maxillary suture also contributed to interorbital growth. Ford (1958) stated 75% of the adult interorbital width was attained by the end of the first year of life. After the age of two, the interorbital septum increased in width due to the increased thickness of the ethmoidal labyrinth associated with an increased pneumatization of the ethmoidal air sinuses. Appositional growth on the medial orbital walls increased the width of the interorbital region.(Ford 1958), Enlow 1965) Enlow (1965) stated that resorption of the lateral orbital wall is entirely responsible for the lateral enlargement of the upper orbit, where the lateral movement exceeds that of the medial orbital surfaces. Moss and Greenburg (1967) felt that primary growth of the eyeball would result in passive relocation of the adjacent skeleton to maintain anatomic and functional continuity. Costaras et. al., (1982) found negligible growth change in the orbital roof with age but there was a downward and forward displacement of the inferior orbital margin during growth of the midface with the cribriform plate remaining stable.

Enlow (1966) described the remodeling changes of the orbital regions during growth. Periosteal deposition occurred on the medial part of the orbital floor as it was lowered with the maxilla from growth at the frontomaxillary suture. Deposition also occurred along

the medial orbital wall moving it more laterally. Bone growth at the zygomaticomaxillary suture, raised the zygomatic portion of the orbital floor, resulting in periosteal resorption to maintain its position with the maxillary part of the orbit. As the orbit enlarged, the level of the lateral orbital rim dropped with increasing age with resorptive activity of the lateral part of the orbital floor and lateral orbital wall. At the lateral portion of the orbital roof was endosteal resorption which resulted in lateral enlargement of the upper orbit as well as in a forward direction. The lower portion of the orbit had both sutural and endosteal bone growth. Deposition occurred at the supraorbital rim lowering the orbital roof in adjustment for bone growth at the frontomaxillary suture. This also brought the medial orbital wall laterally corresponding to lowering of the orbital floor.

Maxilla

Weinmann and Sicher (1955) described transverse growth of the facial skeleton involving the palatal suture and pterygoid processes. Posterior widening of the maxilla was coincident with its anteroposterior growth.

The pterygoid width adjusted to the increasing maxillary width by the downward divergence of the pterygoid process. Growth at the pterygoid process postnatally occurred by selective apposition and resorption. The increase in length of the processes in turn increased the width between the two processes. Growth in the median palatal suture was correlated with the widening and downward shift of the maxillary complex.

The width of the lower end of the pterygoid processes lagged behind the width of the posterior area of the maxilla. Lower nasal width lagged behind the width of the alveolar processes which was expressed by the lateral movement of the developing molars resulting in the lateral bulge of the maxillary tuberosity. With the continuous downward growth of the maxilla, hard palate, and divergent lengthening of the pterygoid processes, and widening of the nasal cavity, the posterior end of the alveolar process became more in line with the lower end of the pterygoid process. The posterior surface of the maxilla did not buttress against the pterygoid process until adulthood. The pyrimidal process interposed between the pterygoid process and maxillary body maintained its constant relation throughout the growth process.(Weinmann and Sicher 1955)

Enlow and Bang (1965) described areas of structural remodeling occurring in the growing maxilla. Along with

maxillary displacement as a whole downward and forward from deposition at the frontomaxillary suture, the maxilla also underwent sequential, localized remodeling to maintain its morphology and relative positions to its adjacent articulations. The growth of the maxilla was an ongoing simultaneous process of both sutural and remodeling growth mechanisms. The stimulus for sutural growth stemmed from the growth of the enclosed or adjacent soft tissue and growth of the cartilage of the nasal septum which separated the sutural interface and stimulated new bone deposition at these sutural surfaces. Growth of the maxillary arch followed the V-principle in which simultaneous growth movement occurred with enlargement by bony deposition on the inside and resorption on the outside.(Enlow 1965) As the maxilla relocated down and forward the section of the maxilla anterior to the zygomatic process, representing the apex of the V, undergoes resorption while the inner or lingual surface undergoes bone deposition contributing to the downward growth. The lateral dimension increased by bone deposition along the alveolar crests. The section of the maxilla located underneath the zygoma has its surface facing the downward direction of growth as well as laterally as opposed to the anterior section of the maxilla which faces opposite the downward direction of growth. This posterior maxillary surface is depository

bringing about downward as well as lateral growth.(Enlow and Hunter 1966) In the tuberosity, the dominant area of growth in the maxilla, there is periosteal deposition posteriorly and laterally, lengthening and widening the dental arch posteriorly. Bone growth at the zygomaticomaxillary suture displaced the zygoma laterally along with deposition on the lateral surface of the zygomatic arches with resorption on the medial side widening the arch as it moves posteriorly.(Enlow 1965, 1966)

Sinuses

The frontal, ethmoid, sphenoid and maxillary air sinuses developed as outpocketings from the walls of the nasal cavity.(Morin 1960) The expansion of the sinus was secondary to the growth of the bone.(Weinmann and Sicher 1955) Initially the ethmoid air cells occupied most of the lateral nasal wall. At 7 years, half the nasal wall was occupied by maxillary and ethmoid air cells. At 10 years, the anterior and posterior ethmoid air cells grew towards the cribriform plate and encroached upon the frontal and sphenoidal sinuses. The ethmoid air cells primarily affected interorbital dimension. The frontal

sinuses developed from anterior ethmoid air cells and appeared 6 to 12 months postnatally. They developed as supraorbital ridges develop as buttresses for the muscles of mastication, with the outer plate developing away from the inner plate.(Weinmann and Sicher 1955) The frontal sinuses continued to expand into the fifth and sixth decade.(Morin 1960) The sphenoidal air sinuses located in the posterior part of the interorbital region, continued to enlarge until 3 years of age. The maxillary sinuses enlarged in width between 3 to 4 years until 15 years and was dependent on the eruption of the deciduous and permanent teeth. Growth of the lacrimal gland, extraocular muscles and eye counteracted the expanding forces of the air sinuses.

Nasal

Transverse lengthening of the nasal cavity occurred by appositional growth of the frontal processes of the maxilla which grew in a superior, lateral and anterior direction.(Enlow 1965) Also, bony deposition on the glabellar region of the frontal bone, as well as the nasal part of the maxilla and adjacent nasal bones widened the nasal bridge.

Moss and Greenburg (1967) and Moss and Rankow (1968) described the role of the functional matrix in maxillary and mandibular growth, respectively. The skeletal units of the maxilla and mandible all have intrinsic, genetic origin but its final dimensional growth, spatial relocation, size, shape and its very existence depended on its extrinsic (environmental) factors forming the functional matrix. Primary growth was the functional matrix and the resultant skeletal growth of the face was by primary expansion of the splanchnocranial (orofacial) matrices (oral, orbital, nasal matrices) passively relocating the facial bones downward, forward, and laterally to maintain anatomic and functional continuity between the maxilla and adjacent bones.(Moss and Greenburg 1967) Another type of bone growth involved alterations in bone size and shape from changes in the absolute volume, size, shape or spatial position of any (or all) of the several relatively independent functional matrices. There were also bone changes involved in the maintenance of the form of the bone itself. All of these growth processes occurred differentially in an effort to maintain relative constancy of proportion.(Moss and Greenburg 1967)

Petrovic (1974) introduced his servosystem theory of craniofacial growth. He created models of the biological systems involved in craniofacial growth and corresponded

them cybernetically to a servosystem. Petrovic et. al., (1990) In accounting for the growth in the width of the maxilla, Petrovic described a sequential analysis of maxillary growth controlled by somatotropic growth hormone and somatomedin. Somatotropic growth hormone provided direct stimulating action and increase of cell responsiveness to various stimulating effects leading to appositional growth and growth of the midpalatal suture resulting in transverse growth of the maxilla. Somatomedin indirectly stimulated the outward growth of the lateral cartilaginous masses of the ethmoid and of the cartilage between the body and greater wings of the sphenoid. This led to outward growth bilaterally which stimulated outward appositional bone growth. Lateralization of the alveolar ridges led to transverse separation of the horizontal maxillary and palatine plates which in turn separated the premaxillary bones which led to growth of the interpremaxillary suture, the intermaxillary and interpalatal sutures which all resulted in transverse growth of the upper jaw.(Petrovic 1974)

Enlow and Harris (1964) histologically examined 25 human mandibles from 4-12 years. The exact age and sex of the mandibles were not known. They discussed three basic principles of structural remodeling of the mandible which maintained the constant shape and relationships during

the progressive increase in size. In area relocation,whereby parts of the mandible occupy new locations as it increases in size, the size, shape, and axis of the mandible are changed from deposition or resorption of cortical bone at selected areas of the mandible. Deposition or resorption on bone surfaces is determined by regional direction of growth, and the V-principle. This growth mechanism is found in the ramus and the coronoid process. The posterior mandibular body grows upward and outward at the level of the tuberosity from endochondral growth in the basal half of the body. The mandibular body lengthens by relocation and direct conversion of the lingual growing basal part of the ramus into the lingual tuberosity. Periosteal deposition on the buccal side forms the trihedral eminence. There is bone deposition on the inferior surface of the mandibular body except in the area of the antegonial notch. The endosteal bone on the cortex of the lingual side of the ramus lying below the ridge of the mandibular neck and the mylohyoid line is resorptıve sınce the growth direction is posterior and buccal. Periosteal bone deposition occurs on the posterior border of the ramus and the angle of the ramus adding to the growth in these areas.

The role of the muscle force and function in the development of the cranio-dento-facial complex still remains a topic not fully understood. It is believed by

some that the forces of the lips and cheeks are equally counterbalanced by the force created by the tongue and the erupting dentition is molded by both forces in a state of equilibrium.(Lear and Morrees 1969, Slagsvold 1971) Discrepancies that occur due to abnormal muscle patterns or abnormal relationship between basilar parts of jaws, prohibit adequate compensations by teeth and alveolar processes.(Slagsvold 1971) Scott (1967) proposed that postural or functional activity of the orofacial or masticatory muscles play no role in the form of the dental arch development. He also stated the tongue does not influence the position of the teeth but adapts to the space it is confined in provided there is adequate space. Thus the dental arch form and dimension are mainly genetically determined.

Lear and Morrees (1969) examined the role of muscle force and dental arch form in 7 18-32 year old males with normal occlusion and no prior orthodontic treatment. They examined buccolingual muscle function to the symmetry and stability of the dental arches by looking at the magnitude of tongue and cheek forces in the maxillary and mandibular premolar regions, the frequency of swallowing, the duration of all oral activities, and head posture during sleep. They found that balance between buccal and lingual muscle forces do not always determine dental arch form. They concluded the lack of a relationship between

dental arch form and head posture during sleep and the lack of relationship between arch shape and the symmetry of buccal and lingual muscle activity does not answer the question of the existence of a relationship between dental arch form and muscle function. Slagsvold (1971) from examining association in width dimensions from adult skulls supported the role of soft tissue in molding the dental arches.

Bone remodeling exists at birth and continues until death: it does not cease at skeletal maturity.(Caniggia 1990) The concept of continuous remodeling in adults implies that living bone is constantly changing its matter. Remodeling serves to maintain mineral homeostasis and structural alteration. Osteoclasts bring about bone destruction and osteoblasts bring about bone formation. This process occurs at the interface of the periosteal and endosteal surfaces.(Caniggia 1990) Periosteum is the fibrous tissue covering the outer surface of bone containing osteoblasts and osteoblast precursor cells. The osteoblasts enclose themselves in their own secretions and become osteocytes. During resorption, periosteal osteoclasts develop. The endosteum is capable of apposition or resorption and consists of osteoblasts and various puripotential cells capable of differentiating into bone, hematogenous, or connective tissue cell lines.(Ranley 1980)

In biomechanical remodeling, bone remodeling cells react to an altered extracellular calcium activity in their local environment. In response to changes in calcium activity, the cells could either build up bone to redistribute an increased stress or remove surplus bone during reduced stress.(Enlow 1977) A major source of physiologic biomechanical forces exerted on bone arises from function of its associated muscles. Epker and O'Ryan (1981) states that genetics play a major determinant of adult facial bone morphology. Environmental factors exert subtle or dramatic effects on facial bone structure. Intramembranous bone growth responds to tension and pressure by either bone deposition and resorption. Tension produces bone formation while pressure can trigger bone resorption. Bone grows locally from muscle tension. As muscle grows, bone is stimulated to grow because of continuous biomechanical imbalances due to expansion in muscle mass and resultant increased force.(Enlow 1990) Bone transduces mechanical energy to electric energy called the Piezo electric effect where deformation of a bone, causing a concavity, causes osseous deposition and convexity causes resorption. The bone cells attempt to remodel the bone so the new load no longer bends the bone and all cell activity returns to equilibrium.(Moss 1975)

STATEMENT OF THESIS

Specific Aim- Serial P-A cephalometric radiographs of adults from the Bolton Study will be used to determine whether transverse dimensional changes occur after the age of 21.

Objectives- The objectives of this study are to 1) assess if changes occur in the transverse dimension of the adult craniofacial complex, 2) locate areas of transverse dimensional change, 3) to examine the pattern of change among a subsample of the subjects examined with a third data point between the initial and final time.

Hypothesis- There is change in the transverse dimension of the craniofacial complex in the adult after the age of 21.

MATERIALS AND METHODS

STUDY POPULATION

This observational study used longitudinal data to examine transverse dimensions of the adult craniofacial complex. P-A cephalometric radiographs were selected from 30 subjects enrolled in Behrent's 1985 study and the update 2000 project at the Bolton Brush Growth Study at Case Western Reserve University in Cleveland, Ohio.

Individuals enrolled in Behrents' 1985 study and the Update 2000 project were originally part of the Bolton Study which was conducted from 1928 to 1959. The Bolton Study was signed to examine the craniofacial growth of "normal" and healthy children. All subjects were from Northeast Ohio and about one-half were followed longitudinally with yearly examinations. The original Bolton population consisted of subjects of primarily or predominantly European ancestry, from middle class as well as more economically advantaged, educated families.

From 1978 to 1982, Behrents examined 113 individuals of the original Bolton population in order to serially examine the aging process utilizing lateral cephalometric radiographs. His sample consisted of males and females of European ancestry, educated and healthy, orthodontically untreated with the initial age at or greater than 17 years and the final age cephalogram at or greater than 25 years. In 1992, Broadbent Jr. and Hans recalled approximately 53 individuals (at the time of this study) 10 of whom had been recalled by Behrents a decade earlier. Lateral and P-A cephalometric radiographs were taken, as well as hand-wrist x-ray, height, weight, dental impressions, dental and physical exams and medical history.

Selection criteria

Thirty subjects were selected from the total of 166 subjects available.(Behrents' 1985 study and the Update 2000 project) Out of 113 subjects included in Behrents' study, 41 had no records beyond the age of 25 years and 48 subjects had no time 1 records beyond the age of 20 years if a record existed at a later age.

Selection was based on the following criteria:

1)The absence of pathology, trauma, bone disease, or surgeries affecting the craniofacial complex except tonsillectomy and adenoidectomy.

2)Orthodontically untreated

3)The presence of the same molar in the respective jaw on the right and left sides at time 1 and time 2. Due to the loss of molars in some of the subjects at time 2, the same molar was not followed in both the maxillary and mandibular arch.

4)Lateral and P-A cephalometric radiographs of sufficient quality to allow identification of selected landmarks and P+ and ML distances recorded in the subject record.

5)P-A and lateral cephalometric radiographs available at or beyond the age of 21 years with the final films taken at a minimum of 5 years after the initial film.

A subset of five subjects from the total sample with a third data point between the initial and final time period was also examined. This subset was used to determine if any oscillations in the growth pattern of the selected landmarks occurred or if growth occurred in a linear relationship. If no change occurred, the landmark width dimension was stable. Oscillations in growth were defined as increases or decreases at time 2 and corresponding decrease or increase at time 3.

SAMPLE SIZE

The sample used for the present study was a subsample of the original Bolton Study population. Initial and final records of the selected individuals were selected from individuals enrolled in the Bolton Study. The later (time 2 or 3) radiographs were obtained as part of Behrents' study (1985) or from the Update 2000 recall. The range of time one radiographs included in the present study (1931-1976) represents a generation (more than 25 years).

Thirty subjects met the selection criteria.

The age of 21 years was set as the initial age to minimize the growth effect of late skeletal maturation.

Description of the variables

The following landmarks were located on the P-A cephalometric radiographs as defined by Solow 1966, Wei 1970, and Bass 1971. The variables were measured as linear distance between the right and left landmark. (**Figure 1 and 2**)

1) *frontozygomatic(zf) suture*- The most lateral point on the right and left frontozygomatic suture

2) *mastoidale(mas)*- The most inferior point on the right and left mastoid process.

3) *gonion(go)*- The maximum distance between external surfaces of the gonial angles.

4) *maxillare(mx)*- The most concave point on the left and right contour of the maxilla.

5) *nasal wall(na)*- The most lateral aspect of the right and left lateral bony wall of the nasal cavity.

6) *medial orbital wall(mo)*- The most medial aspect of the right and left orbital rim.

7) *lateral orbital wall(lo)*-The most lateral extent of the right and left orbital rim.

8) *zygion(z)*- The most lateral aspect of the right and left zygomatic arches.

9) *euryon(eu)*- The most lateral extent of the right and left cranium.

10) *upper molar/lower molar(um/lm)*- The most lateral extent of the buccal crown of the posterior molar identified bilaterally in the maxilla and mandible at the initial and final time period examined.

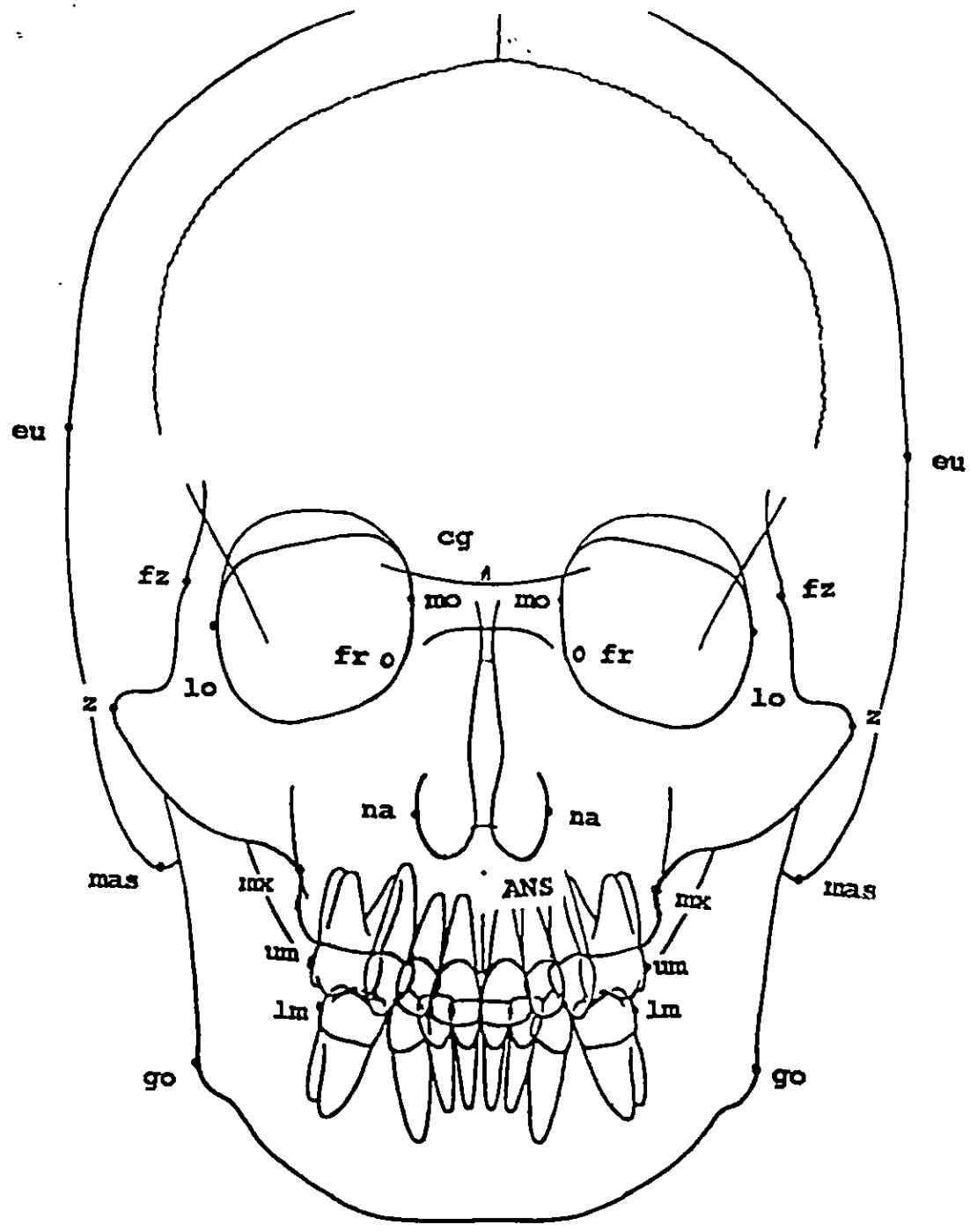


FIGURE 1. Landmarks identified on the P-A cephalometric radiographs.

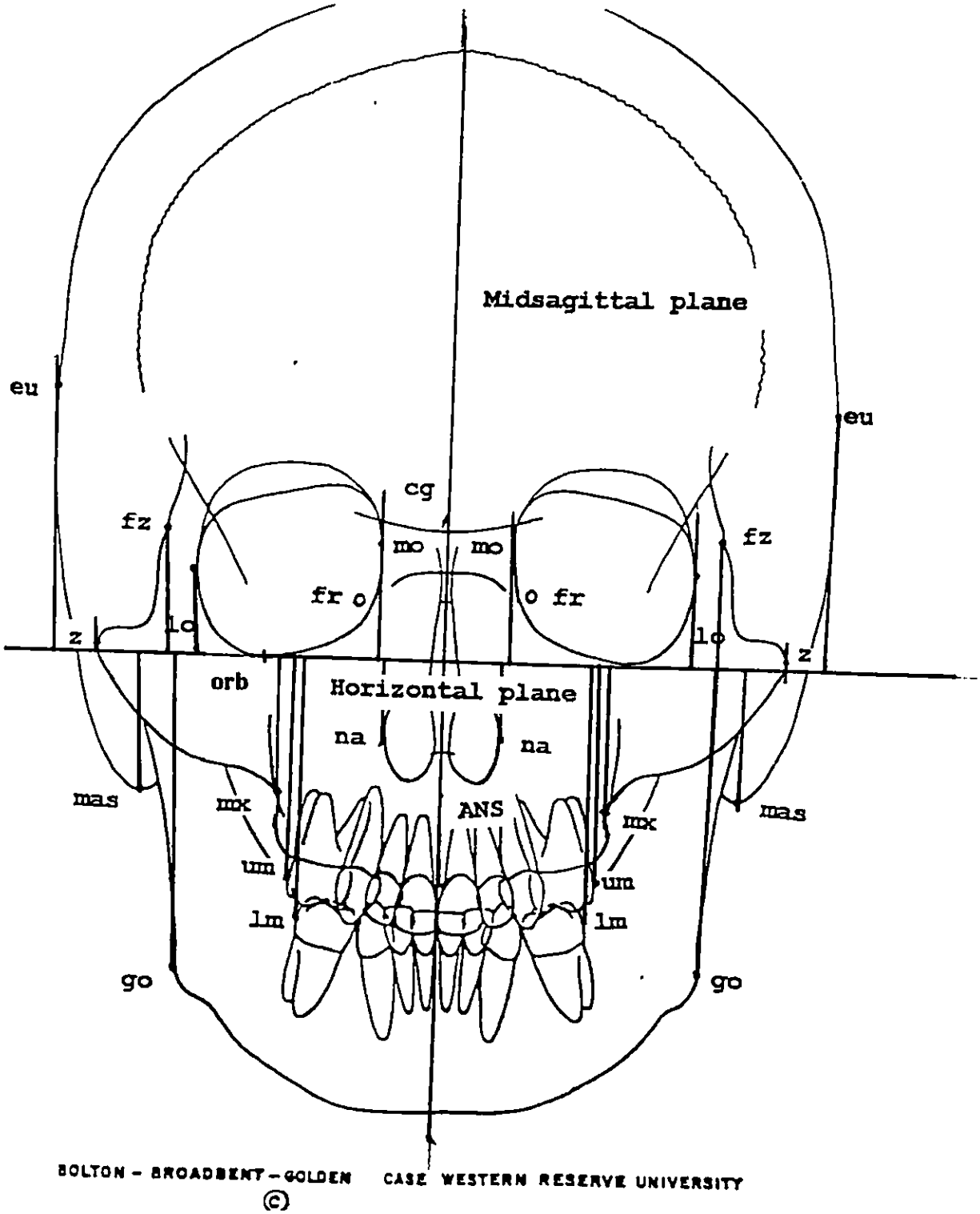


Figure 2. Midsagittal and horizontal planes and bilateral dimensions measured.

Bilateral dimensions were measured from the most lateral extent to the midsagittal plane and all measurements were made on the horizontal plane between perpendicular projections from the appropriate landmark (described in the cephalometric technique section).

The variables were selected based on the operators ability to identify bilateral landmarks on P-A cephalometric radiographs and the reproducibility of the landmarks. The radiographic landmarks selected best represented the anatomic landmarks of interest while maintaining consistency and reproducibility.

Error due to landmark identification and tracing technique were estimated by performing a double determination for 10 randomly selected subjects.

PROCEDURE

Radiographic Technique

Lateral and P-A cephalometric radiographs were taken using the Broadbent-Bolton Roentgenographic Cephalometer, #7-AKS 60 adhering to the method previously described.(Broadbent Sr. 1931) Radiographs were taken using a standardized source to ear rod distance of 5 feet

in the frontal and 5 feet from the source to midsagittal plane. All P+ and ML distances were recorded in order to adjust for magnification.

The participants were in maximum intercuspation with Frankfort horizontal plane aligned parallel to the floor. Trimax 8 (3M) rare earth screens with XUD film (3M) were used with 90KVP and 15MA at one-half second exposures for the lateral view and 1 1/2 seconds for the P-A view. The original study utilized par speed screens and medium Blue Brand film. This technique produced films that had less grain than seen on the faster film screen combinations used today. However, they also required longer exposure thus leading to increased exposure for the patient. Recall films were developed in an automatic processor, films taken before 1978 were developed manually. Radiographs were taken by different investigators during the three recall periods. Some of the participants who were unable to return to the Bolton Study for the examination had the records taken by their local orthodontist with magnification controlled using the technique described by Adams (1940).

Cephalometric Technique

Head Rotations

Vertical and horizontal rotations of the head in the frontal view about the midporionic axis or from side to side about the midsagittal plane were evaluated and the records discarded if the rotations were severe.(greater than ten degrees). Weinstein (1948) examined positional effects of the skull on various linear and angular measurements on P-A cephalometric radiographs. He found 5° lateral rotation and 12° vertical rotation to have minimal to no effect on linear dimensions. Ishiguro et. al., (1976) found a change within 10 degrees of vertical or horizontal rotation negligible. Costaras et. al., (1982) found up to 20 degree lateral rotations and less than 10 degree horizontal rotations to be negligible. The records evaluated in this study had minimal horizontal and vertical head rotations due to the nature of the radiographic technique using the Broadbent-Bolton cephalometer. The lateral and P-A films were taken immediately after each other while the head was fixed in the head holder. Any movement that occurred would have been within the limits of the ear rod and nasal rest which are firmly secured in place.

a. Head rotation evaluation- Head rotation was evaluated by observing several areas of the skull:

1. The distance between the most lateral extent of the zygoma to the cranial border on both sides.(Grummons 1987)

2. The relation of the midsagittal reference line (to be described in the following section) to the center of the cervical vertebrae.(Grummons 1987)

3. The distance from tip of the mastoid process to the lateral border of the ramus.

b. **Minor Head rotation corrections**

1. Minor horizontal head rotatıons were corrected by tracing the radiograph with the emulsion side of the film up. The tracing was then duplicated at a one to one magnification. The two tracings were superimposed on the midsagittal reference line and averaged.(Broadbent Sr. et. al.1975) Although studies have shown mild asymmetries to exist in most normal individuals (Harvold 1951, Letzer and Kronman 1967, Sharad and Joshi 1978), he averaging negated any asymetries present in the craniofacial skeleton. Averaging did not affect the ınterpretatıon of the results of the study because transverse dimensions are not altered.

2. The Broadbent-Bolton orientator was used to aid in landmark identification and assess vertical head rotations.(**Figure 3**) Significant vertical differences in head position between the lateral and frontal

cephalometric radiographs taken at the same time were not found. The distance from the top of the film to the central ray axis of the orientator was noted for the lateral radiograph to estimate differences in head position between the initial and final time period. A template of various ear rods used on the Broadbent-Bolton cephalometer was used to orient the lateral radiographs on the central ray axis of the orientator. (**Figure 4**)

Cephalometric tracing and digitizing

Tracings of all P-A headfilms were made on .003" matte acetate with a 0.5mm lead tracing pencil. All tracings were done by the principle investigator and the initial and final P-A films used per subject were traced in one sitting to minimize error variance within individuals that may have lead to systematic error.(Houston 1983) Linear measurements were obtained using a microcomputer (AST-286) equipped with an x-y tablet (SummaSketch® Summagraphics™ Fairfield, CT.). A custom software program (Geocalc, Cleveland State University 1989), was used to measure the digitized points to the nearest hundredth of

On the C R (central ray) line, on the left side of the orientator, millimeters are marked from 70 to 100. This scale represents the ML (mid-line lateral distance) or the distance from the center of the cephalometer to the lateral film at the time of exposure.

On the C R line of the right side, millimeters are marked from 70 to 140. This scale represents the P+ (porionic + distance) or the distance from the center of the ear rods to the film at the time the frontal exposure was made.

First, attach the orientator to the x-ray illuminator with drafting tape so that the axis of the central ray (C R) is horizontal.

Now, position the frontal film on the orientator, as though viewing the head from the back with right side of the head to the right and with the mid-line center of the instrument is determined by the x-ray shadow of the nasion rest. Shift the film to the right or left until the instrument center is located at the appropriate P+ location on the metric scale of the orientator. Fix in place with drafting tape.

Then, place the complementary lateral view on the left half of the orientator, with the facial profile toward the frontal view and the center of the image of the ear rod axis registered on the central ray line (C R) at the point on the metric scale that corresponds to the M L distance at which this record was made.

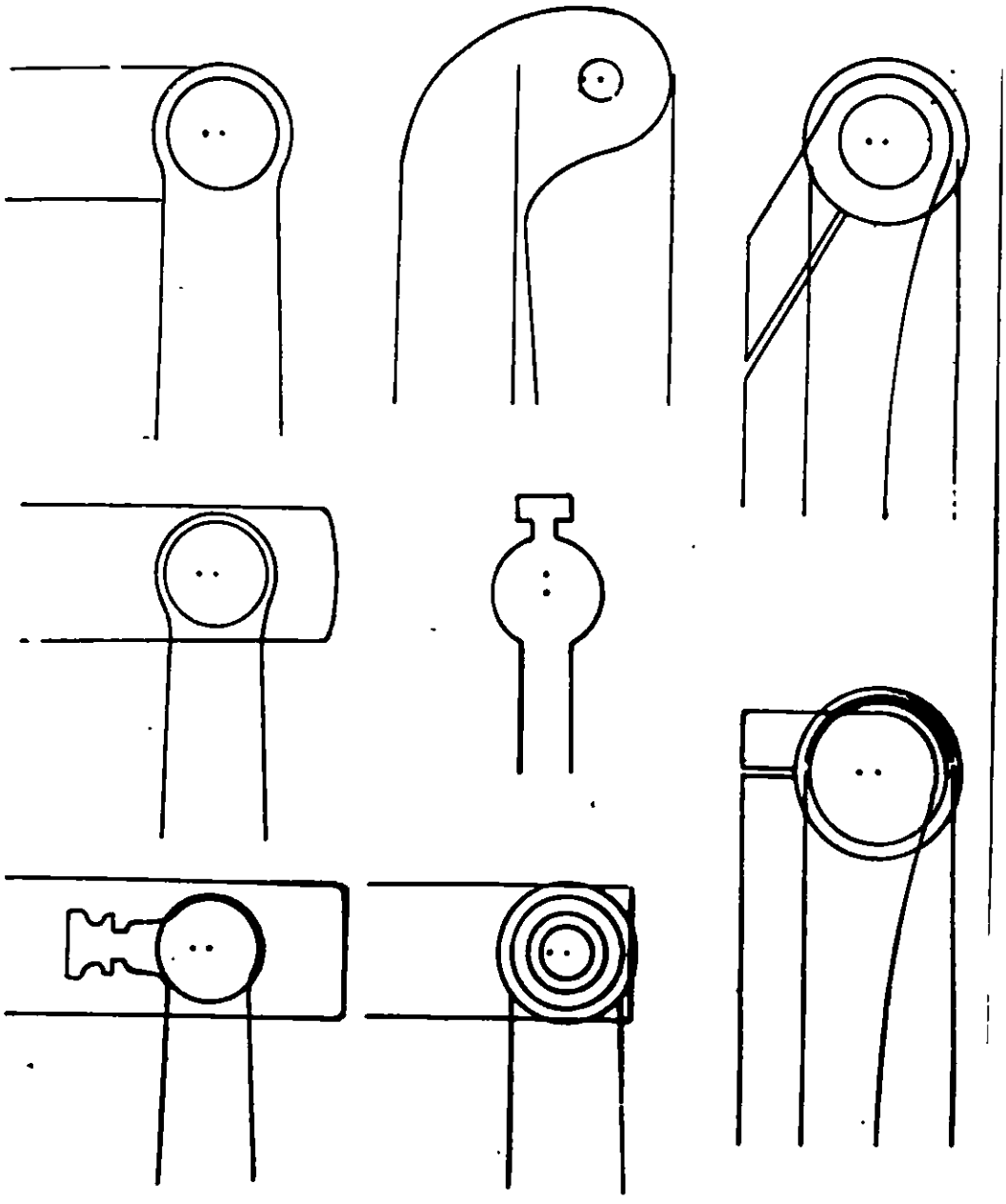
Fix in this position temporarily with drafting tape. Now, note the relation of one or two mid-line dental or anatomical landmarks, i e , menton or incisal edge of an incisor to the nearest orientator x-ray line. Follow this line to the lateral view and rotate the lateral film around its original position until its relation to the line corresponds to the frontal record Project a few anterior points which can be definitely established in both films to be certain that the film are oriented correctly

The vertical height of any point in the frontal view may be projected to the other.

Right and left landmarks, and points in the frontal view may be projected to and identified in the lateral view

Source· Bolton Study, Case Western Reserve University Cleveland, Ohio

Figure 3. Instructions on the use of the Broadbent Bolton Orientator



Source: Bolton Study, Case Western Reserve University
Cleveland, Ohio

Figure 4. Bolton Study template for historic cephalometric ear rod holders.

a millimeter. All measurements were then rounded to the nearest tenth of a millimeter.

Reference planes

Determination of the midsagittal plane:

The midsagittal plane for this study was determined by constructing a vertical plane through crista galli and ANS which was found to closely approximate the midsagittal plane of the skull.(Cheney 1961) If crista galli was undetectable, the midsagittal plane was constructed by dropping a perpendicular through the midpoint of the fr-fr (foramen rotundum) line and the midpoint of the z-z (zygomatic) plane.(Grummons 1987) The Broadbent-Bolton orientator was used to aid in the location of crista galli and ANS.

Determination of the horizontal plane

The horizontal plane was constructed perpendicular to the midsagittal plane passing through right orbitale.

Anatomic points used in the construction of the reference planes:

crista galli(cg)- the most superior point of the crista galli of the ethmoid bone

anterior nasal spine(ANS)

foramen rotundum(fr) - the midpoint of the right and left f. rotundum

Measurements

Bilateral dimensions were measured from the most lateral extent from the midsagittal plane. All measurements were made in the horizontal plane between tangents perpendicular to the appropriate landmarks.

Correction for enlargement

Correction is necessary to determine whether enlargement is due to transverse growth or due to radiographic enlargement caused by an increase in the target-film distance at time 2. Antero-posterior growth of the nose increases the distance from the midporionic axis to the frontal film. This in turn increases the object to film distance, and results in an increased magnification. Landmarks in the frontal film are located in different coronal planes and at varying distances from the anode

and film surface which makes enlargement compensation complicated in the P-A orientation. Landmarks located further anteriorly will be enlarged less than those located more posteriorly or closer to the midporionic plane or x-ray source. Thurow (1951) stated that controlling errors due to enlargement is necessary for superimpositions of serial tracings when linear distances are being compared. It is also necessary for linear ratios where the figures are from different films and for absolute linear measurements.

In this study, it was decided that antero-posterior change in the landmark of interest to the mid-porionic plane would be negligible. Behrents (1985) found minimal change in the measurement, sella to inferior zygoma, with the mean delta from initial to final period examined being 1.1mm, for sella to lateral orbit 0.7mm, for sella to ANS 1.5mm and sella to articulare 0.6mm. Enlargement correction involved correcting for the change in the film location to the mid-porionic plane. This entailed using the cephalometric radiographic enlargement tables (**Figure 5**) based on an anode-object distance of 5 feet and minimal object-film distance recorded as ML for the lateral view and P+ for the frontal view.(Bolton,Broadbent,Golden 1975) A 1mm difference in P+ value resulted in a 0.1% change in the enlargement factor for the film. Thus the error induced by variations

CEPHALOMETRIC RADIOGRAPHIC ENLARGEMENT

The Bolton Standard tracings were made from cephalograms produced by the Bolton cephalometric technique This method dictatees that the anode-object distance of 5 feet be maintained and that the object-film distance be kept to a minimum. The object-film relation in the lateral cephalogram is termed *midline-lateral film distance (ML)*. In the frontal cephalogram, it is designated as *porion-film distance (P+)*. The following chart shows the average ML abd P+ distances that were used at each chronologic age and the resultant enlargement inherent in the Bolton Standards It is important to consider this percentage of enlargement when the Standards are compared to cephalometric films from other sources.

This chart may also be used to obtain a direct reading of enlargement for a specific cephalometric radiograph inwhich the fundamental technique has been used and the ML or P+ distance is known

BOLTON STANDARDS

Radiographic enlargement*

Age	ML	% enlargement	P+	% enlargement
1	80.0	5.2	-	-
2	80.0	5 2	-	-
3	80.0	5 2	104.0	6.8
4	81 0	5.3	107.0	7.0
5	82 0	5.4	108.0	7 1
6	83.0	5 4	109.0	7 2
7	84 0	5.5	110.0	7.2
8	84.0	5 5	113.0	7 4
9	85 0	5.6	114.0	7 5
10	86.0	5.6	116 0	7.5
11	87.0	5.7	118.0	7.7
12	88.0	5.8	120.0	7.9
13	89.0	5.8	122.0	8.0
14	89 0	5.8	123.0	8 1
15	90.0	5.9	125.0	8.2
16	90.0	5.9	125.0	8 2
17	90.0	5.9	126.0	8.3
18	90.0	5.9	128.0	8 4

* The columns to the right of the chronologic ages are the ML distance of the lateral film with its percentageof enlargement. The ML and P+ recordings are made at the time that the films are exposed.

Source. Bolton Study, Case Western Reserve University Cleveland, Ohio

Figure 5. Cephalometric radiographic enlargement from radiographs produced by the Broadbent-Bolton Cephalometer

in A-P growth of the landmarks studied was considered within the limits of the cephalometric technique. Also since points would be moving closer to the film at time 2 compared to time 1 the relative enlargement at time 1 would be greater.

Data Analysis

Tracing and measurement accuracy was evaluated by retracing and remeasuring 10 randomly chosen P-A headfilms at a later time period. The principle investigator performed all tracing operations. Random error was detected by estimating the coefficients of reliability, r, and r^2, the coefficient of determination. The coefficient of determination measures the proportion of variability in one variable that can be attributed to, or explained by variation in a second variable. The coefficient of determination defines the magnitude of the association while r defines the direction, positive or negative.

Scatter plots were obtained for each variable measured. The ordinate representing the difference in millimeters between time 1 and time 2, and the abscissa represented the number of subjects ranked in ascending order based on the interval in years between time 1 and time 2. A second series of line graphs were constructed

for 5 subjects with a third series of records that was taken either before the time 1 or time 2 records of after time 2 with a minimum of 5 years between records. The abcissa represented the three time points and the ordinate represented the widths of each landmark in millimeters.

Because of variations in time intervals, means and standard deviations were not calculated. Instead a non-parametric statistical test, the Wilcoxon signed-rank test, was performed. This test was used to evaluate the negative or positive differences of the variables between time 1 and time 2. This test statistically determined whether there was a significant increase or decrease in the variable during the time interval. The Wilcoxon signed-rank test was used because assumptions that the population was normally distributed could not be made. The non-normal distributions invalidate the use of the t-tests for this study. The Wilcoxon signed-rank test assumes that the sample is random, the variable is continuous, the population symmetrically distributed about its mean and the measurement scale is at least interval. A two-sided null and alternative hypothesis was selected since change could be positive or negative. (H_0:$\mu = \mu_0$, H_A:$\mu \neq \mu_0$) A sufficently small value of T_+ or T_- will cause a rejection of H_0:$\mu = \mu_0$. The test statistic was T_+ or T_- which ever was smaller.

Due to the multiple statistical tests performed in this study, a Bonferroni correction was used. Alpha (α), type I error, set at $p<.05$, was divided by the 11 variables examined setting the p to .0045.

RESULTS

Resultant sample

The resultant sample consisted of 30 subjects, 22 males and 8 females. The majority were of European ancestry except one of Asian (Japanese) ancestry. A variation of malocclusions were present, 22 class I, 8 class II (division 1 and 2). The majority of the subjects had maxillary and mandibular first and second molars present. At time 2 (and at time 3 for some subjects), five subjects either had first or second molars missing in the maxillary and/or the mandibular arch. Four subjects had one or more molars crowned and one subject wore a partial denture. Six subjects had medical health problems ranging from diabetes, arthritis, and cancer, to thyroid disorders and hysterectomy.

The age and year records were taken for each subject at time 1, time 2 and time 3 is presented in **Figure 6.** Ages of the resultant sample ranged from 21 to 82 years. Intervals between time 1 and time 2 records ranged from a

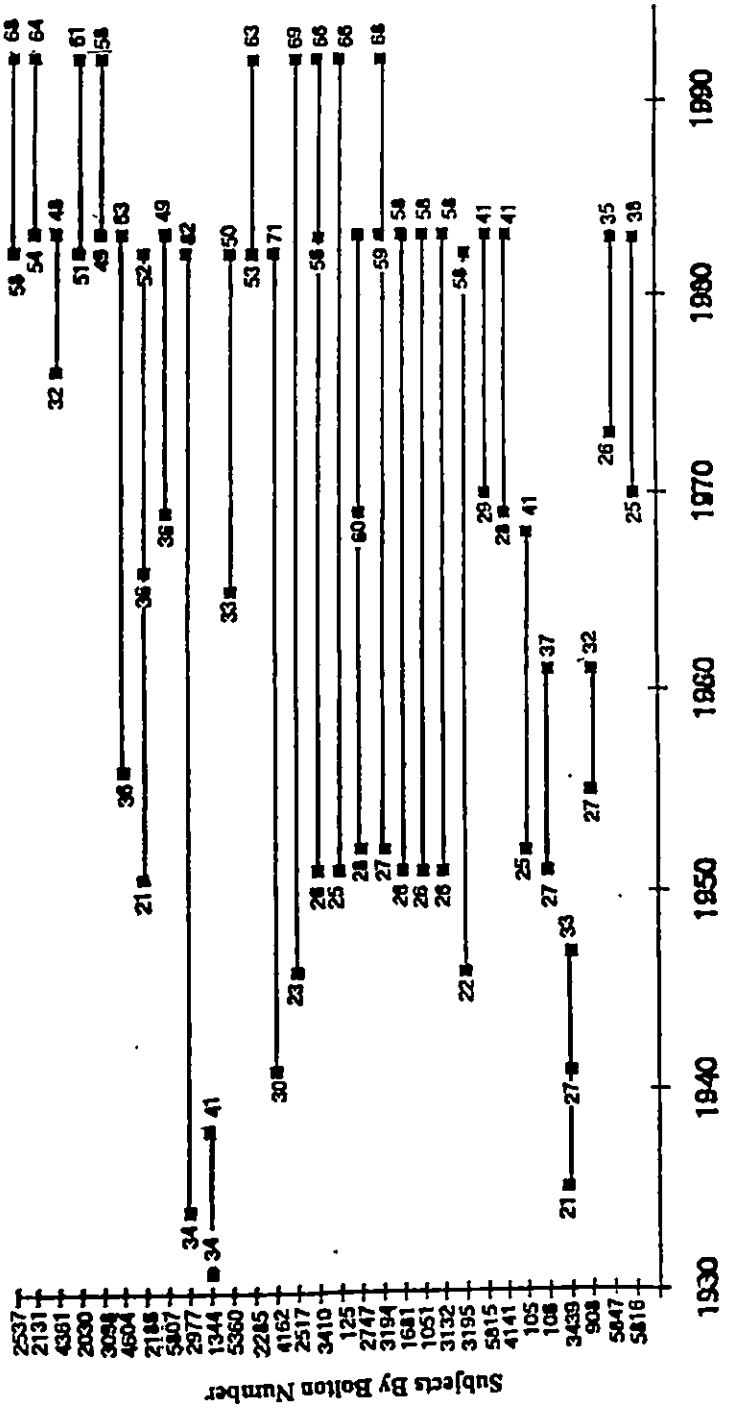


Figure 6. Age and year of records taken at T1 and T2 for each subject.

minimum of 5 years to 48 years. At time 1, 17 subjects were in the age range of 21 to 29 with records taken from 1935 to 1970. Eight subjects ranged from 30 to 36 years, with records taken from 1931 to 1976. One subject at 49 years, was recorded in 1982. Four subjects ranged from 51 to 58 years with records taken from 1982 to 1983. At time 2 (and time 3) 5 subjects ranged in age from 32 to 38 years with records taken from 1942 to 1983. Six subjects ranged in age from 41 to 49 years with records taken from 1938 to 1983. Eight subjects ranged in age from 50 to 58 years with records taken from 1982 to 1992. Nine subjects ranged in age from 60 to 69 years with records taken from 1970 to 1992. One subject at age 71 years, and one subject at 82 years, had records taken in 1982.

Error Study

The coefficients of determination, r^2, were calculated for repeated measurements of 10 randomly selected sets of P-A cephalometric records. The results of the double determination is presented in **Table 1.** Coefficients of determination were used to detect variance due to random errors and defines the magnitude of association. Results for the eleven variables show high correlation between the two measurements.

Table 1. Correlation coefficients of reliability and coefficients of determination for the double

determination of 10 randomly selected series of P-A cephalometric radiographs.

variables	r	r^2
eu2	0.995	0.99
eu	0.998	0.996
fz2	0.989	0.978
fz	0.993	0.986
go2	0.994	0.988
go	0.999	0.998
Im2	0.992	0.984
Im	0.996	0.992
lo2	0.979	0.958
lo	0.993	0.986
mas2	0.996	0.992
mas	0.995	0.99
mo2	0.927	0.859
mo	0.99	0.98
mx2	0.994	0.988
mx	0.994	0.988
na2	0.942	0.887
na	0.99	0.98
um2	0.998	0.998
um	0 985	0.97
z2	0.999	0.998
z	0.999	0.998

Data of absolute linear measurements of the variables at time 1 and time 2 for each subject can be found in **Table 2.** The differences between time 1 and time 2 of the variables for each subject are located in **Table 3. Table 4** represents absolute linear measurements of 5 subjects at time 1, time 2, and time 3. **Table 5** represents the Wilcoxon Matched-Pairs Signed Ranks Tests

Bolton#	eu-eu	eu2-eu2	z-z	z2-z2	mas-mas	mas2-mas2	fz-fz	fz2-fz2	go-go	go2-go2	lo-lo
5816	144.3	143.1	128.5	129.7	109.1	108.6	106.4	105.7	99.1	100.0	99.3
105	137.7	139.0	125.6	126.0	99.3	100.9	95.7	95.5	91.6	92.5	87.5
2186	147.5	149.7	132.8	134.4	113.6	114.5	105.8	106.3	90.6	91.4	97.5
1344	143.2	143.4	127.7	127.2	104.4	103.6	99.2	99.4	98.4	96.6	92.0
2747	148.8	149.3	132.7	133.9	117.1	117.5	102.3	103.1	104.6	105.5	88.8
5807	136.7	137.2	121.9	121.6	107.4	108.4	97.6	97.3	92.2	90.5	90.1
4141	149.9	150.7	137.7	138.4	108.8	109.7	108.5	110.9	100.9	100.9	102.1
3194	149.3	151.1	131.0	132.3	110.9	113.3	104.9	106.4	96.0	96.0	89.7
1051	147.2	148.5	133.1	134.7	110.6	110.8	100.3	102.1	97.6	99.5	94.2
908	131.7	131.8	94.7	97.0	96.8	97.0	93.9	95.9	91.4	90.6	86.0
3098	145.5	147.7	128.6	129.4	108.6	108.8	96.2	95.4	95.3	94.8	90.2
3132	141.1	142.3	130.3	132.0	108.5	108.7	105.6	106.1	95.9	97.6	98.7
2977	147.3	146.2	131.5	131.0	112.8	112.4	102.9	102.2	95.1	93.8	92.3
106	141.9	141.6	124.8	124.4	99.1	99.3	92.5	92.8	92.1	93.2	84.5
3410	146.5	149.2	126.9	129.3	109.1	109.4	104.3	107.7	86.2	88.6	101.4
5360	135.4	137.4	113.9	114.8	96.9	97.2	92.5	92.3	87.0	88.5	83.4
5847	147.1	147.0	129.0	129.1	111.4	112.6	98.8	98.7	104.6	105.5	89.6
5815	155.3	154.8	132.4	132.6	110.3	110.3	98.4	98.2	98.8	100.1	88.2
2537	145.3	145.0	126.7	127.0	108.0	107.9	104.1	105.0	96.9	98.4	94.0
2131	148.4	149.2	130.1	129.5	112.6	113.3	99.7	98.4	98.3	98.8	92.1
2030	139.5	141.3	116.4	117.8	103.3	103.7	100.7	101.5	82.9	81.8	90.6
4604	152.4	154.5	140.1	141.8	117.8	118.1	107.2	107.1	110.6	111.3	100.3
4162	140.5	143.7	127.2	129.3	109.2	111.9	103.6	106.6	93.9	95.7	95.9
2285	136.5	136.9	126.2	127.1	106.9	107.0	98.5	99.2	97.6	97.9	90.7
3439	142.5	142.5	125.1	125.3	99.5	98.7	99.9	99.9	88.4	88.7	91.8
4361	146.3	147.7	133.6	133.8	110.6	110.7	97.0	97.9	100.3	100.7	91.2
2517	137.5	139.4	117.1	121.8	99.2	101.4	95.2	97.7	93.9	95.1	88.7
1681	141.9	145.1	129.7	133.7	106.9	109.0	99.4	103.1	92.2	93.9	95.1
125	148.9	151.2	130.5	131.8	107.8	108.7	99.8	99.3	102.6	104.5	92.2
3195	138.4	141.0	113.9	116.0	94.3	96.5	96.2	101.0	86.0	88.0	88.7
*measurements in mm											

Table 2. Measurements of the variables at time 1 and time 2.

lo2-lo2	mo-mo	mo2-mo2	na-na	na2-na2	mx-mx	mx2-mx2	lm-lm	lm2-lm2	um-um	um2-um2
99.4	22.2	21.7	31.9	31.0	60.1	59.7	62.1	62.7	64.8	64.6
88.3	23.2	24.0	28.7	28.2	54.7	54.6	61.5	60.7	58.4	57.8
97.7	25.4	26.3	32.2	32.6	61.8	61.0	59.1	59.2	64.3	62.4
91.2	22.3	22.4	31.5	31.6	63.1	64.4	66.7	65.5	65.0	63.6
93.3	20.0	18.2	31.2	31.8	58.4	58.6	60.2	61.0	59.6	61.7
91.3	18.2	20.1	33.0	32.9	60.9	61.1	59.4	58.6	59.9	60.5
104.4	25.9	26.7	34.4	35.3	62.5	63.2	61.8	59.8	62.8	62.6
91.0	23.0	22.6	27.3	26.6	62.2	63.0	55.0	55.6	60.5	63.6
96.1	23.8	22.5	31.9	32.6	58.2	56.5	57.9	58.3	59.0	58.4
85.8	24.9	24.6	31.7	31.8	56.3	55.9	57.7	56.7	58.1	57.3
90.1	21.7	21.5	30.0	30.4	57.2	56.9	62.7	63.5	59.4	58.5
98.2	24.0	25.8	33.7	35.0	64.9	65.7	59.5	60.6	64.5	65.9
96.0	23.3	23.2	34.6	36.0	62.4	62.1	60.6	58.0	60.0	59.4
85.4	21.7	21.1	31.5	31.4	56.9	57.8	66.2	65.6	57.1	58.4
102.9	24.7	26.6	33.8	34.2	57.4	58.2	60.4	60.5	59.2	60.0
84.2	17.5	17.6	38.1	39.1	53.8	54.8	54.9	55.9	55.3	58.0
90.2	22.0	21.0	32.7	33.0	59.0	59.2	59.0	57.7	59.0	59.1
89.6	23.1	22.4	33.9	33.8	60.5	61.5	57.1	56.9	58.9	59.5
95.3	23.8	23.6	30.5	29.4	64.0	63.5	58.5	59.0	64.4	64.5
92.4	23.7	23.5	29.4	30.1	63.3	63.3	63.3	64.2	65.7	66.3
91.4	20.5	20.4	32.3	31.9	50.6	50.5	45.6	48.4	51.8	51.3
102.1	24.5	25.0	36.3	36.6	65.3	64.2	64.8	65.2	63.0	62.4
99.6	24.3	25.0	34.9	35.1	63.4	61.7	59.4	57.3	61.6	60.4
90.7	20.9	20.9	37.1	37.1	64.3	62.6	52.4	51.4	55.2	56.1
88.4	22.6	22.3	30.1	30.2	60.1	59.2	52.6	52.4	57.9	57.8
89.9	21.3	19.9	32.3	32.6	56.2	56.7	63.9	63.7	59.8	59.3
89.8	21.5	20.9	32.3	32.0	57.3	57.4	59.4	58.8	60.8	60.9
95.9	20.6	21.2	31.5	32.1	59.5	61.8	59.0	60.1	61.8	62.8
91.3	25.2	24.9	31.8	34.0	58.2	58.9	62.0	59.9	60.1	59.4
89.0	21.0	21.3	28.7	28.9	50.3	52.9	58.3	59.2	50.9	54.7

Table 2. Measurements of the variables at time 1 and time 2.

range*	sex	Bolton-age**	eu1-eu2	z1-z2	mas1-mas2	tz1-tz2	go1-go2	lo1-lo2	mo1-mo2	na1-na2	mx1-mx2	lm1-lm2	um1-um2
5	m	0908-27/32	0.1	2.2	0.2	2.0	-0.8	-0.2	-0.3	0.1	-0.4	-1.0	-0.8
6	m	3439-27/33	-0.1	0.2	-0.9	-0.1	0.9	0.9	0.2	-0.3	-2.6	-0.2	-0.1
7	m	1344-34/41	0.2	-0.6	-0.8	0.2	-1.8	-0.8	0.1	0.1	1.4	-1.3	-1.5
9	m	3098-49/58	2.2	0.8	0.2	-0.8	-0.5	-0.1	-0.3	0.4	-0.2	0.8	-0.9
9	m	5847-26/35	-0.1	-0.1	1.2	-0.1	1.0	0.6	-1.0	0.2	0.2	-1.3	0.1
10	f	0108-27/37	-0.3	-0.4	0.2	0.2	1.1	0.9	-0.6	0.0	0.9	-0.5	1.4
10	m	2285-53/63	0.4	0.9	0.1	0.7	0.3	0.1	0.0	0.0	-1.7	-1.0	0.9
10	f	2030-51/61	1.7	1.4	0.4	-0.9	-1.1	0.0	0.6	-0.3	0.4	1.7	-0.5
10	m	2131-54/64	0.8	-0.6	0.7	1.6	0.4	0.3	-0.2	0.7	0.0	0.8	0.6
10	f	2537-58/68	-0.3	0.3	0.1	1.0	1.5	1.2	-0.2	-1.1	-0.5	0.5	0.1
12	m	5815-29/41	-0.5	0.2	0.0	-0.2	1.3	1.5	-0.7	-0.1	1.0	-0.2	0.8
13	m	5807-36/49	0.5	-0.3	1.0	-0.2	-1.7	1.2	1.9	-0.1	0.1	-0.8	0.8
13	m	4141-28/41	0.8	0.7	0.9	2.4	-0.1	2.3	-0.8	0.9	0.7	-2.0	-0.2
13	m	5816-25/38	-1.2	1.2	-0.5	-0.8	0.8	0.1	0.5	-0.9	-0.4	0.6	-0.2
16	m	2186-36/52	2.1	1.6	1.2	0.5	0.8	-0.1	0.2	-0.4	-0.8	0.1	-1.9
16	m	4361-32/48	1.4	0.2	0.1	0.9	0.4	1.0	-0.6	-0.3	0.5	-0.2	-0.8
16	f	0105-25/41	1.3	0.3	1.8	-0.2	0.8	0.8	0.8	-0.5	-0.1	-0.8	-0.6
17	m	5360-33/50	2.0	0.9	0.2	-0.1	1.4	0.8	0.1	1.0	0.9	1.0	2.8
26	m	4804-36/62	2.1	1.7	0.3	0.1	0.8	1.9	0.5	0.3	-1.0	0.4	-0.6
32	m	3132-26/58	1.3	1.7	0.1	0.5	1.7	-0.5	1.8	1.3	0.8	1.1	1.4
32	m	1051-26/58	1.2	1.6	0.2	1.8	1.9	1.8	-1.3	0.7	-1.7	0.4	-0.6
32	m	1681-26/58	3.3	4.0	2.1	2.1	1.6	0.8	0.0	0.5	2.3	1.0	1.0
32	m	3184-27/59	1.8	1.3	2.4	1.5	0.0	1.3	-0.4	-0.7	0.8	0.6	3.1
32	m	2747-28/60	0.4	1.2	0.4	0.8	0.8	4.5	-1.8	0.6	0.2	0.7	2.1
32	m	0125-25/66	2.3	1.3	0.9	-0.5	2.0	-0.9	-0.3	2.2	0.7	-2.1	-0.7
36	f	3195-22/58	2.6	2.1	2.2	4.8	2.1	0.3	0.3	0.2	2.6	0.9	3.8
40	m	3410-26/66	2.8	2.5	0.3	3.5	2.4	1.6	1.9	0.4	0.8	0.1	0.7
41	f	4162-30/71	3.2	2.1	2.6	3.0	1.9	3.7	0.8	0.1	-1.7	-2.1	-1.2
46	f	2517-23/69	1.9	4.7	2.2	3.4	1.2	-1.1	0.1	1.6	0.1	-0.8	0.2
48	f	2977-34/82	-1.1	-0.5	-0.4	-0.7	-1.3	3.7	-0.1	1.4	-0.3	-2.7	-0.8
*range between T1 and T2 in years													
**age at time1/time2 in years													
***differences in mm													

Table 3. Differences in the widths between time 1 and time 2 of the variables.

ages in yrs	eu-eu	eu2-eu2	eu3-eu3	z-z	z2-z2	z3-z3	mas-mas	mas-mas2	mas-mas3	fz-fz	fz2-fz2	fz3-fz3	go-go
21-36-52	148.9	147.5	149.7	131.9	132.8	134 4	113.5	113.6	114.5	104.7	105.8	106.3	90.2
27-59-68	149 3	151.1	151.2	131.0	132.3	130.7	110.9	113.3	113.4	104.9	106.4	106.9	96.0
28-60-69	148.8	149.5	151.8	132.7	133.9	134.6	117.1	117.5	117.5	102.3	103.1	104.4	104.6
26-56-66	146.5	149.6	149.2	126.9	128.7	129.3	107.3	109.1	109.4	104.3	107.2	107.7	86.2
21-27-33	140.7	142.5	142.3	123.7	125.1	125.3	98.1	99.5	98.7	99.5	99.9	99.9	88.3
*measurements in mm.													

Table 4. Measurements of the widths of each variable at time 1, time 2 and time 3 for 5 subjects.

go-go2	go3-go3	lo-lo	lo2-lo2	lo3-lo3	mo-mo	mo2-mo2	mo3-mo3	na-na	na2-na2	na3-na3	mx-mx	mx2-mx2	mx3-mx3
90 6	91.4	94 6	97.5	97 7	25 0	25.4	26 3	32 8	32 2	32 6	63 4	61 8	61.0
96 0	95.9	89.7	91 0	90 8	23 0	22 6	22 9	27 3	26 6	27 4	62.2	63 0	60.9
105.5	106.2	88 8	93.3	94 3	20.0	18.2	18.7	31.2	31 8	32.4	58.4	58 6	58.2
90.4	88.6	101.4	103.1	102.9	24 7	26.5	26.6	33.8	34 1	34.2	57 4	57.7	58.2
89.6	86.7	89.3	90.8	91.7	21 6	22.6	22.4	30.7	30 4	30.1	60 6	61.5	59.5

Table 4. Measurements of the widths of each variable at time 1, time 2 and time 3 for 5 subjects.

lm-lm	lm2-lm2	lm3-lm3	um-um	um2-um2	um3-um3
59 5	59.1	59.2	63.0	64.3	62 4
55 0	55.6	54 9	60 5	63.6	60.6
60.2	61 0	59.8	59.6	61.7	60.0
60.4	60.6	60.5	59.2	60.7	60.0
52.6	52.6	52.4	58.1	57.9	57.8

Table 4. Measurements of the widths of each variable at time 1, time 2 and time 3 for 5 subjects.

for the difference between time 1 and time 2 for each variable.

Table 5. Wilcoxon Matched-Pairs Signed-Ranks Tests for the difference between time 1 and time 2 for each variable.

	T+, x1<x2	T-, x1>x2	ties, x1=x2	Z	2-tailed P*
c1-c2	24	6	0	-3.7743	0.0002
z1-z2	25	5	0	-3.8977	0.0001
mas1-mas2	25	5	0	-3.3218	0.0009
fz1-fz2	19	11	0	-2.571	0.0101
go1-go2	22	7	1	-2.6705	0.0076
lo1-lo2	23	7	0	-2.9824	0.0029
mo1-mo2	17	12	1	-0.1081	0.9139
na1-na2	21	9	0	-2.098	0.0359
mx1-mx2	17	13	0	-0.7507	0.4528
lm1-lm2	15	15	0	-0.5245	0.5999
um1-um2	15	15	0	-0.6993	0.4844

*p<.0045

Figures 7 through 18 represent scatterplots of differences between time 1 and time 2 of each of the 11 variables. The abcissa represents the interval in years between time 1 and time 2 and the ordinate represents the change in millimeters.

In order to assure that changes found were within the limits of the cephalometric technique, it was decided to evaluate the data derived from those subjects whose measurements exhibited change greater than 1mm in either direction.

Figure 7 represents the scatterplot for eu1-eu2 and the scatterplot for mas1-mas2 is in **Figure 8.** The abcissa is a yearly interval between time 1 and time 2 in ascending order, and the ordinate is change measured in millimeters. For the variables, eu and mas, the Wilcoxon Matched-Pairs Signed Ranks Test was significant for change greater than zero between time(T) 1 to time(T) 2. For the variables eu1-eu2 and mas1-mas2, the subjects showing change greater than 1mm were those that had greater than 9 year intervals between records at T1 and T2. More changes greater than 1mm were found in cranial width as compared to mastoid width. There were no changes significantly greater than -1mm for either variables. For eu1-eu2, the range of differences lies from -1.2mm to 3.2mm. 14 subjects fall within 1 and -1.2mm, and 16 subjects show increases greater than 1mm. 5 out of 8 females and 11 out of 22 males showed change greater than 1mm. For mas1-mas2, the range of values lies from -0.9mm to 2.6mm. 9 subjects had values greater than 1mm and 2 subjects have values that lie between 1 and -1mm. 4 out of 8 females and 5 out of 22 males showed change greater

than 1mm. The smallest interval between T1 and T2 was associated with the least amount of change while the greatest change was seen at wider intervals between T1 and T2.

Figure 9, **Figure 10**, and **Figure 11** represent plots for fz, lo, mo respectively. Lateral orbit,(lo) showed statistical significance for change greater than zero between T1 and T2 ($p=.0029$, $p<.0045$). Variable fz, frontozygomatic, showed no statistical significance between T1 and T2 ($p=.0101$, $p<.0045$). Mo, medial orbit ($p=.9139$ $p<.0045$), showed no statistical significance for change between T1 and T2.

For lateral orbital width, the range of values lie from -0.6mm to 4.7mm. 12 subjects had values greater than 1mm and 18 subjects had values lying within 1 and -1mm. No subjects showed change greater than -1mm. 3 out of 8 females and 9 out of 22 males showed changes greater than 1mm.

For variable fz, the range of values lie from -0.9mm to 4.8mm. 10 subjects had values greater than 1mm. 20 subjects had values lying between -1 and 1mm and no subject had values greater than -1mm. 3 out of 8 females and 7 out of 22 males showed changes greater than 1mm. For lo and fz, the smallest interval between T1 and T2 exhibited the least amount of change while greatest

magnitude of change was seen at wider intervals between T1 and T2.

For the variable mo, the range of values lie from -1.8mm to 1.9mm. 3 subjects had values greater than 1mm and 2 subjects had values greater than -1mm. 25 subjects had values that lie between -1 and 1mm. There were 3 males who showed changes greater than 1mm and 2 who showed changes greater than -1mm. None of the females exhibited changes greater than 1mm or -1mm.

Figure 12, Figure 13 and **Figure 14** represent plots for z, na and mx respectively. Zygion, z, showed statistical significance for change between T1 and T2, ($p=.0001$, $p<.0045$). The range of values lie from -0.6mm to 4.7mm. 15 subjects had values greater than 1mm and 15 subjects had values lying within 1 and -1mm. No subjects showed change greater than -1mm. 4 out of 8 females and 11 out of 22 males showed changes greater than 1mm. In general, the smallest interval between T1 and T2 exhibited the least amount of change while greatest change was seen at wider intervals between T1 and T2.

Variables na, nasal width, and mx, maxillary arch width, were not statistically significant for change in either direction between T1 and T2. The range of values for na were from -1.1 to 2.2mm. 4 subjects had values greater than 1mm and 26 subjects had values from -1.1 to

1mm. 2 out of 8 females and 2 out of 22 males had values greater than 1mm.

For mx, the range of values were from -2.6mm to 2.6 mm. 3 subjects had values greater than 1mm, 4 subjects had values greater than -1mm and 23 subjects had values that lie between -1mm and 1mm. 1 female and 2 males had values greater than 1mm and 3 males and 1 female had values greater than -1mm. The variables na and mx showed no obvious trend in changes from T1 to T2 throughout the age intervals with the majority clustered between +1 and -1mm.

Figure 15, Figure 16 and **Figure 17** represent plots for go, um and 1m respectively. None of the variables were statistically significant for change between T1 and T2. For gonion width, the range of values lie from -1.8 to 2.4mm. 12 subjects had values greater than 1mm and 4 subjects had values greater than -1mm. 14 subjects had values lying between -1 and 1mm. Five out of 8 females and 7 out of 22 males showed changes greater than 1mm. Changes greater than -1mm were also seen in 2 males and 2 females.

For the variable lower molar, 1m, the range of values were from -2.7 to 1.7mm. 2 subjects had values greater than 1mm and 6 subjects had values greater than -1mm. 22 subjects had values lying between -1mm and 1mm.

1 male and 1 female had values greater than 1mm and 4 males and 2 females had values greater than -1mm.

For the variable upper molar, um, the range of values lie between -1.9 and 3.8mm. 6 subjects had values greater than 1mm and 3 subjects had values greater than -1mm. 21 subjects had values lying between 1 and -1mm. 4 males and 2 females had values greater than 1mm and 2 males and 1 female had values greater than -1mm.

The aim of the second part of the study was to examine if any oscillations in the growth pattern occurred in each variable from time 1 to time 2 by selecting a third time point either before time 1, in between time 1 and time 2, or after time 3. A subsample of five male subjects had a third series of records that satisfied the selection criteria of the study. The range of ages at time 1 were 21 to 28 years, ages at time 2 ranged from 27 to 60 years, and ages at time 3 ranged from 33 to 52 years. Medical health problems consisted of diabetes and arthritis in subject 2, and arthritis, cancer and diabetes in subject 4. For subject 1, the second molars were followed through the three time periods, for subject 2 the first molars were followed with crowns present on the maxillary first and second molars at time 2. The first molars were followed in subject 3 with crowns present on the maxillary first and second molars at time 2 and 3 and maxillary and

mandibular removable partial denture at time 2. Subject 4 had his second molars followed through the three time periods, and subject 5 had his second molars followed with the first maxillary molars lost at time 3.

Table 4 represents the absolute measurements for time 1, time 2, and time 3 for each of the eleven variables for the 5 subjects. **Figures** 17 through 27 represent line graphs of the 5 subjects for each variable at time 1, time 2, and time 3. The abcissa represents time 1, 2 and 3 for each subject but each time point does not represent the same age for each of the 5 subjects. The ordinate represents the measurements of the widths of the variables in millimeters.

For the variable eu (**Figure 18**) and mas (**Figure 19**), all subjects showed increase from time 1 to time 3. Increases were seen for both variables from T1 to T2. The amount of change from time 1 to time 2 in general, was greater than that seen from time 2 to time 3. Subject 1 experienced a decrease (1.4mm) at time 2 for cranial width. No trauma was reported but reports of appendicitis and hernia were noted but not the onset. For T2 to T3, both variables showed a plateau except for subjects 1 and 3 for cranial width who showed increases of 2.2mm and 2.3 mm respectively.

It is also interesting to note that subject 1 was one of two subjects with T1 at 21 years. The variability

can be seen when compared to subject 5 who was also 21 years at T1. Subject 5 showed an increase from T1 to T2 and plateaued to T3 while subject 1 decreased at T2 and increased at T3 to 0.8mm greater than the value at T1.

Variables fz (**Figure 20**), lo (**Figure 21**) and mo (**Figure 22**), continued increase was noted from T1 to T3 for fz and lo however variability was noted in medial orbital width. From T1 to T2, fz and lo showed an increase with a plateau from T2 to T3 except for subject 3 who showed greater increase from T2 to T3 in variable fz. Variable mo showed variability from T1 to T2 but no change from T2 to T3 except subject 1 who increased 0.9mm to T3. From T1 to T3 subject 3 showed a decrease of -1.8mm and subject 4 showed an increase of 1.8mm. Subject 4 reported a history of cancer, diabetes, arthritis, skin tumors, and inguinal hernias while subject 3 had no medical ailments. Both subjects were similar in age at the three time points.

For variable z (**Figure 23**) from T1 to T2, all subjects showed gradual increase and from T2 to T3, most showed a plateau, except subject 1 who increased 1.6mm and subject 2 who decreased 1.6mm. Subject 2 had crowns placed at T2 and the amount of increase from T1 to T2 equaled the decrease seen from T2 to T3. Variable na (**Figure 24**) showed no change from T1 to T2 and T2 to T3. For mx (**Figure 25**), no change was seen from T1 to T2

except subject 1 who showed a decrease of -1.6mm to T2. Time 2 to time 3 showed relatively little change except subject 2 and 5 decreasing 2.1mm and 2.0mm respectively. Subject 5 was noted to have had a loss of maxillary first molars at T3.

For variable, go (**Figure 26**), no change was seen from T1 to T2 except subject 4 who showed an increase of 4.2mm. From T2 to T3, no change was seen except for subject 4 who decreased from T2 to T3 -1.8mm. For variable um (**Figure 27**), a general trend of increase from T1 to T2 was seen. Subject 2 and 3 showed an increase 3.1mm and 2.1mm respectively and both had crowns placed at T2. A decrease from T2 to T3 was seen in this variable for most subjects to approximately the same value as T2. The variable 1m (**Figure 27**) for T1 to T2 showed no change as well as from T2 to T3.

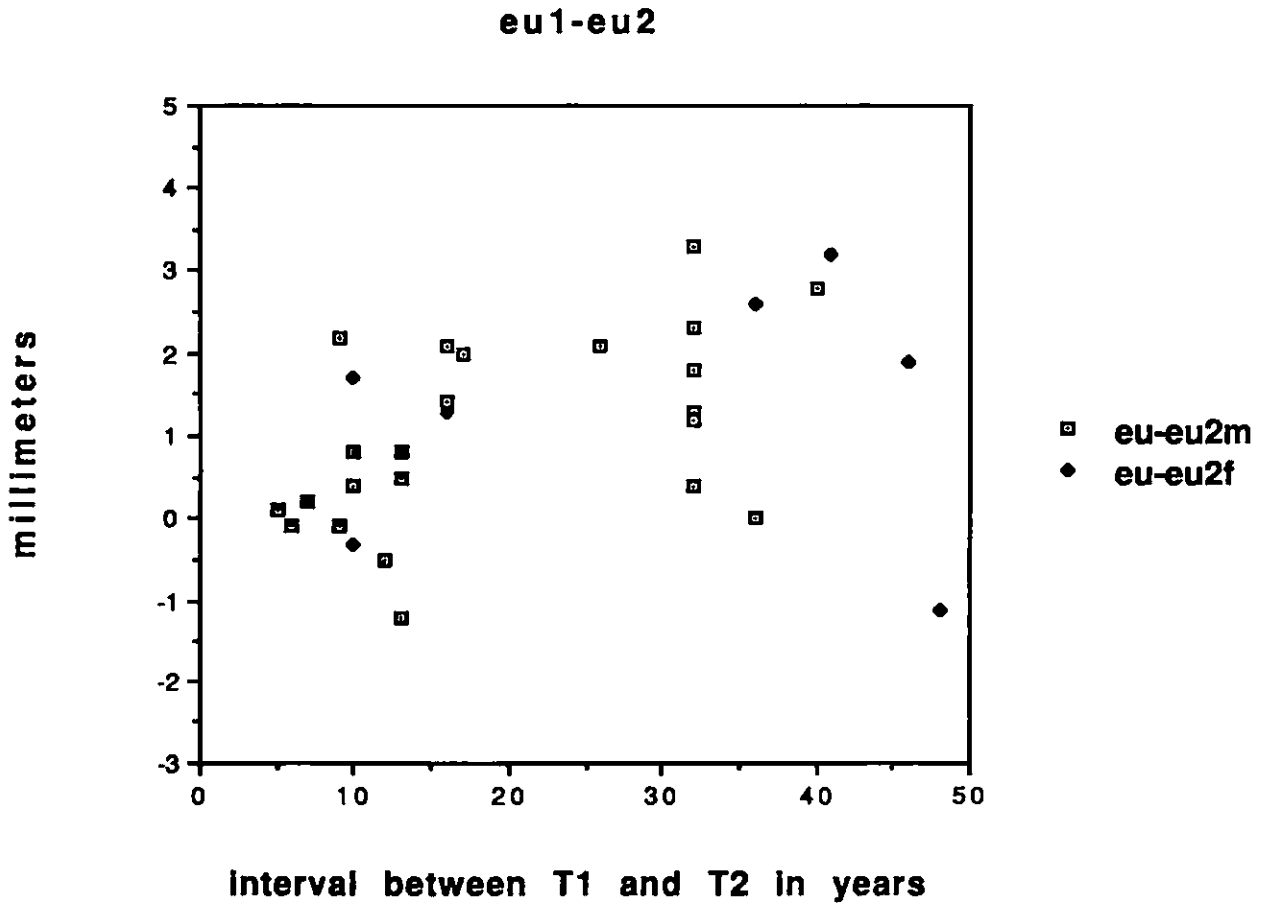


Figure 7.
Scatterplot of the difference between T1 and T2 for variable eu for each subject.

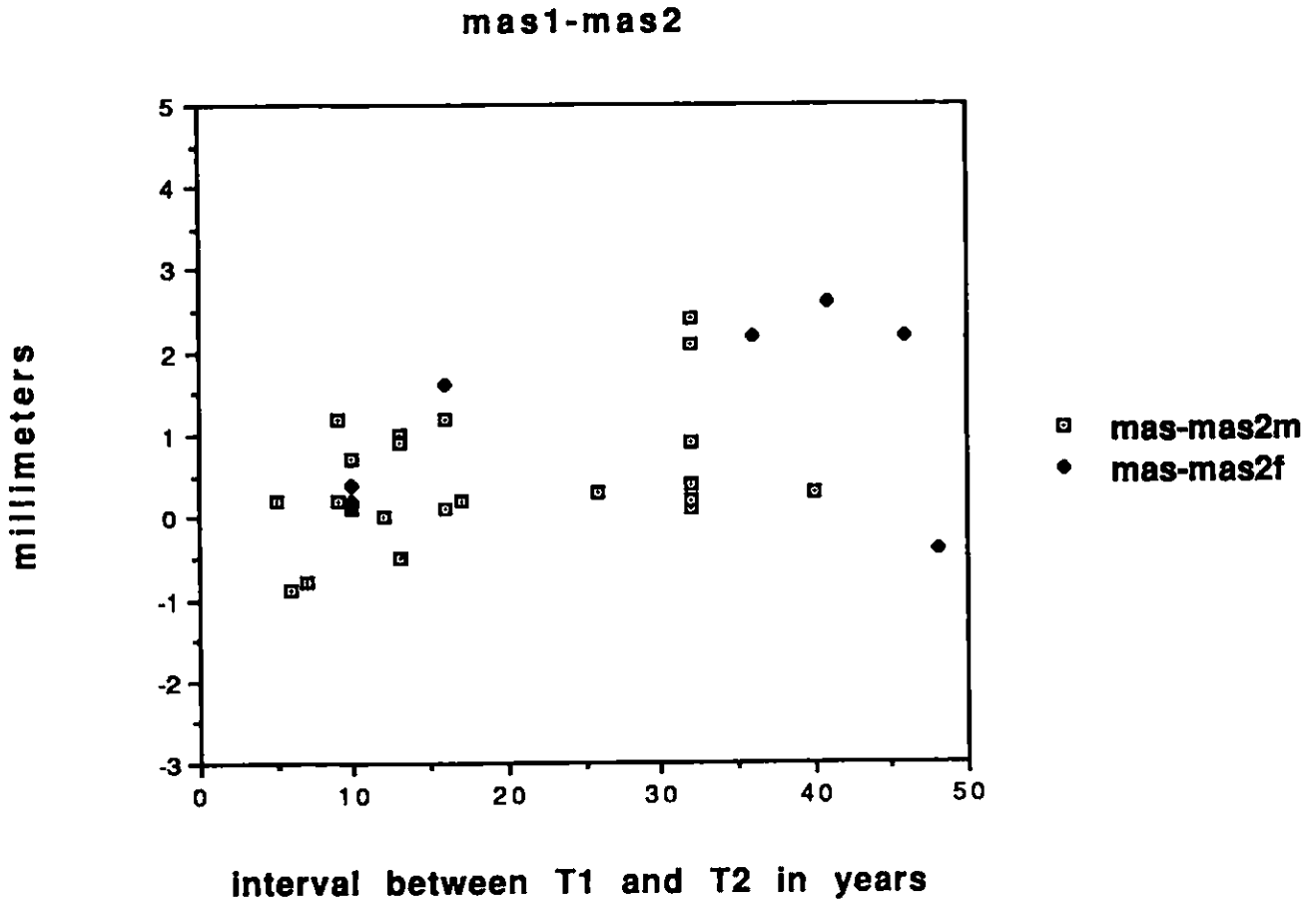


Figure 8.
Scatterplot of the difference between T1 and T2 for variable mas for each subject.

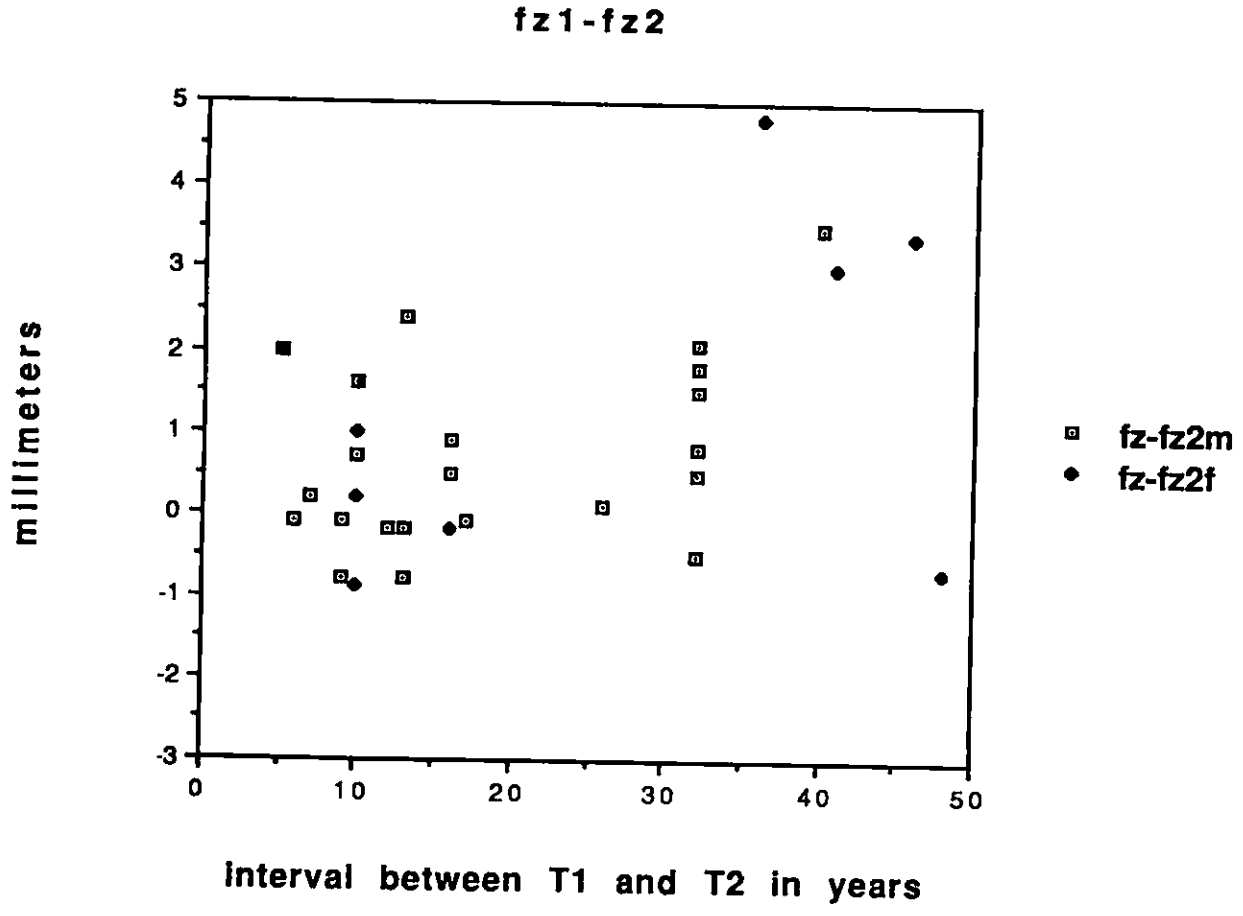


Figure 9.
Scatterplot of the difference between T1 and T2 for variable fz for each subject.

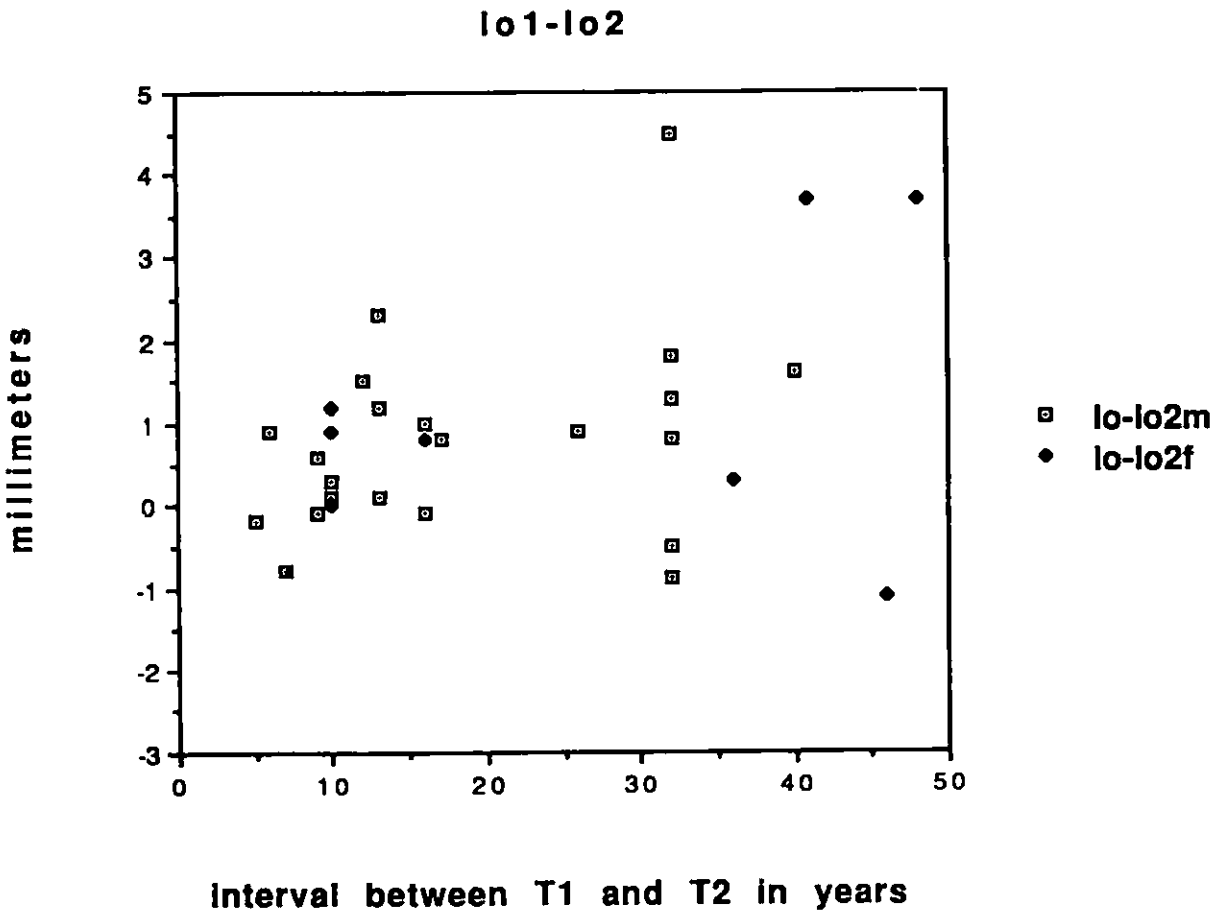


Figure 10.
Scatterplot of the difference between T1 and T2 for variable lo for each subject.

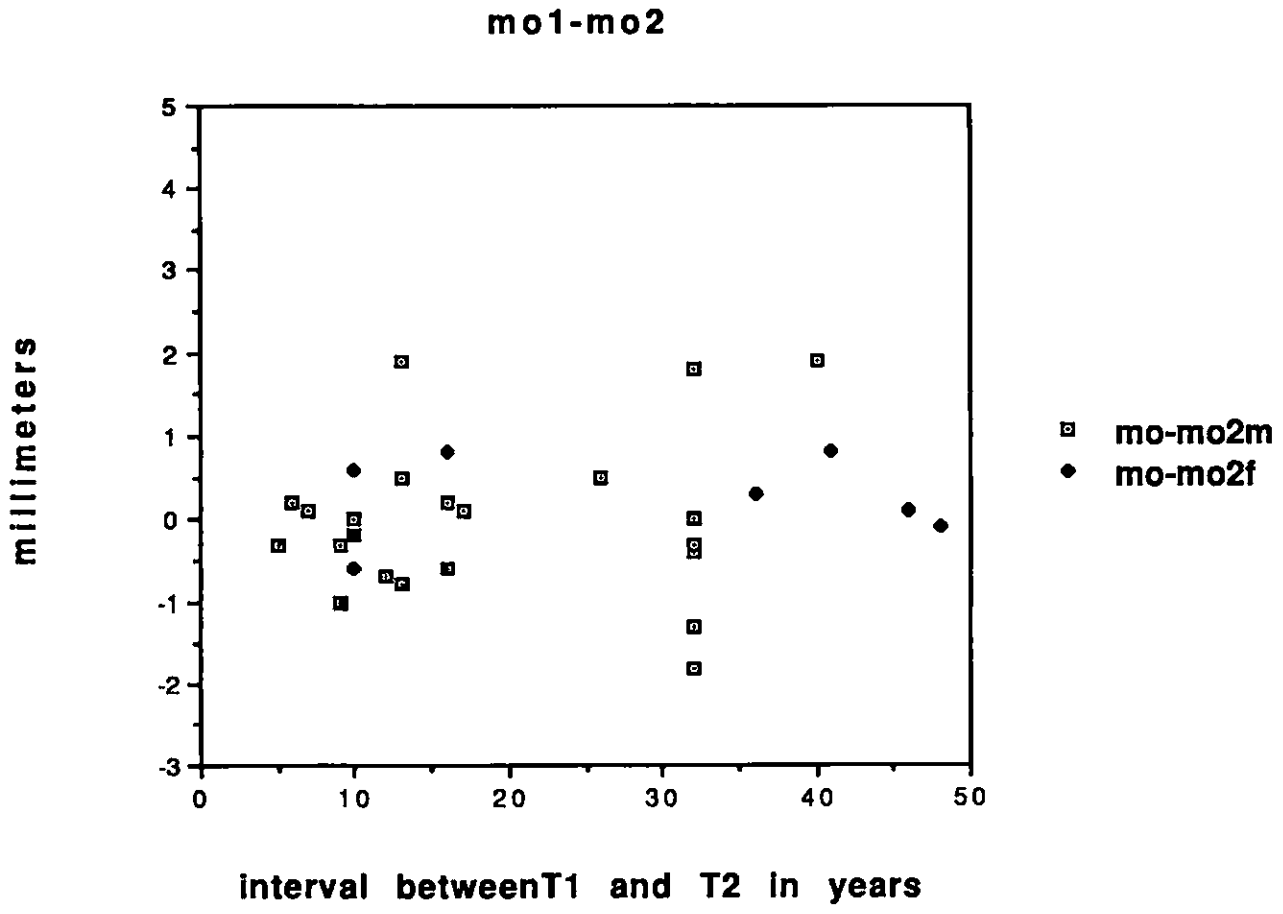


Figure 11.
Scatterplot of the difference between T1 and T2 for variable mo for each subject.

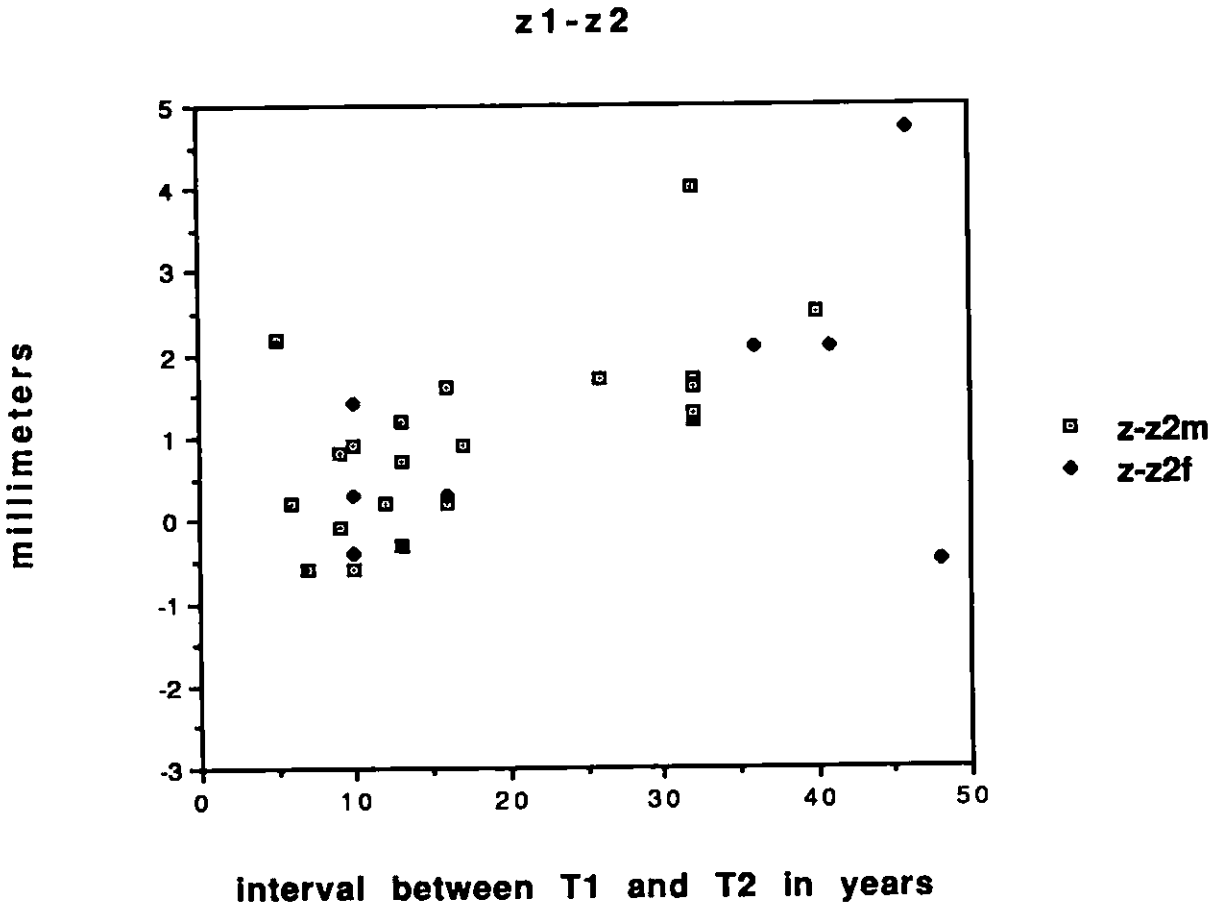


Figure 12.
Scatterplot of the difference between T1 and T2 for variable z for each subject.

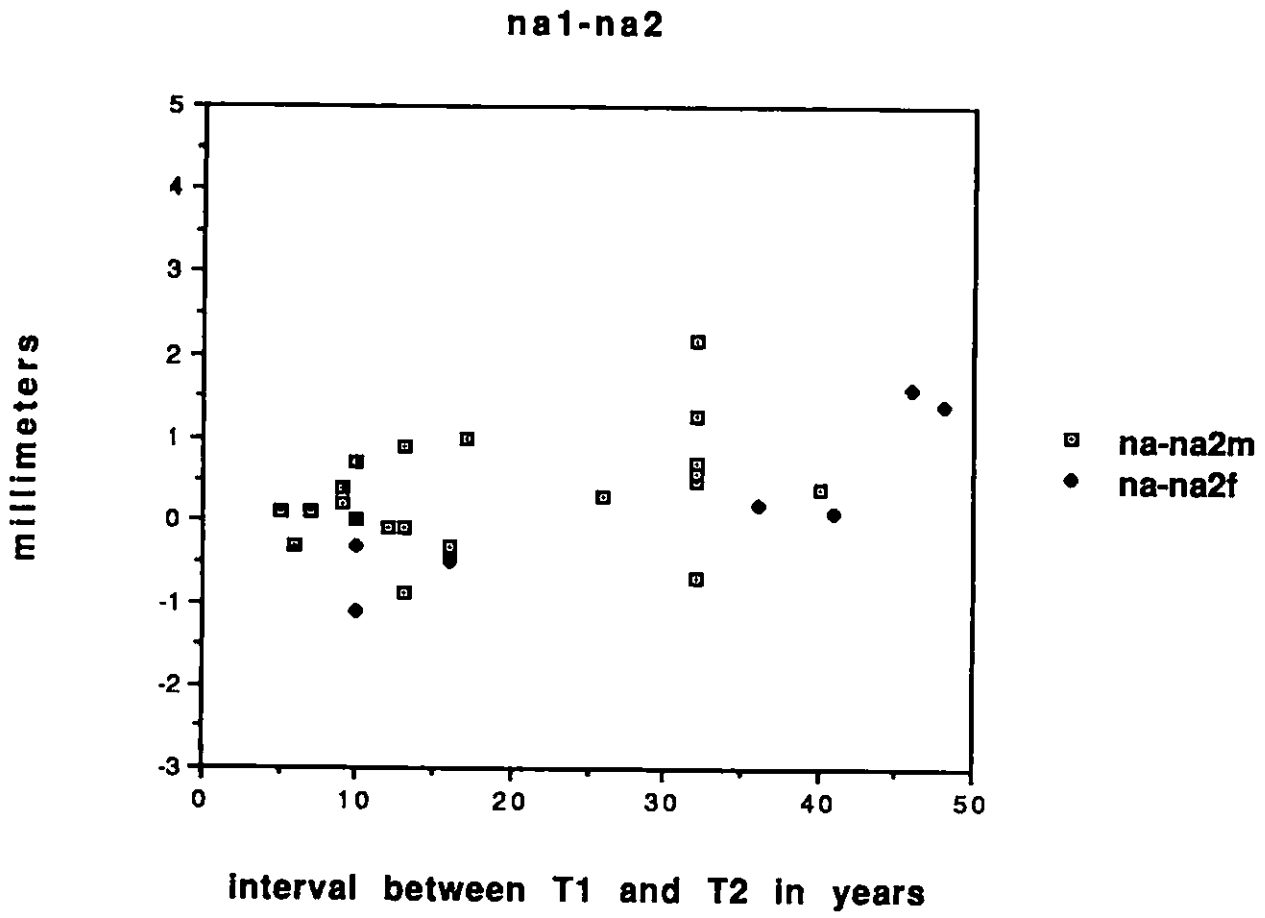


Figure 13.
Scatterplot of the difference between T1 and T2 for variable na for each subject.

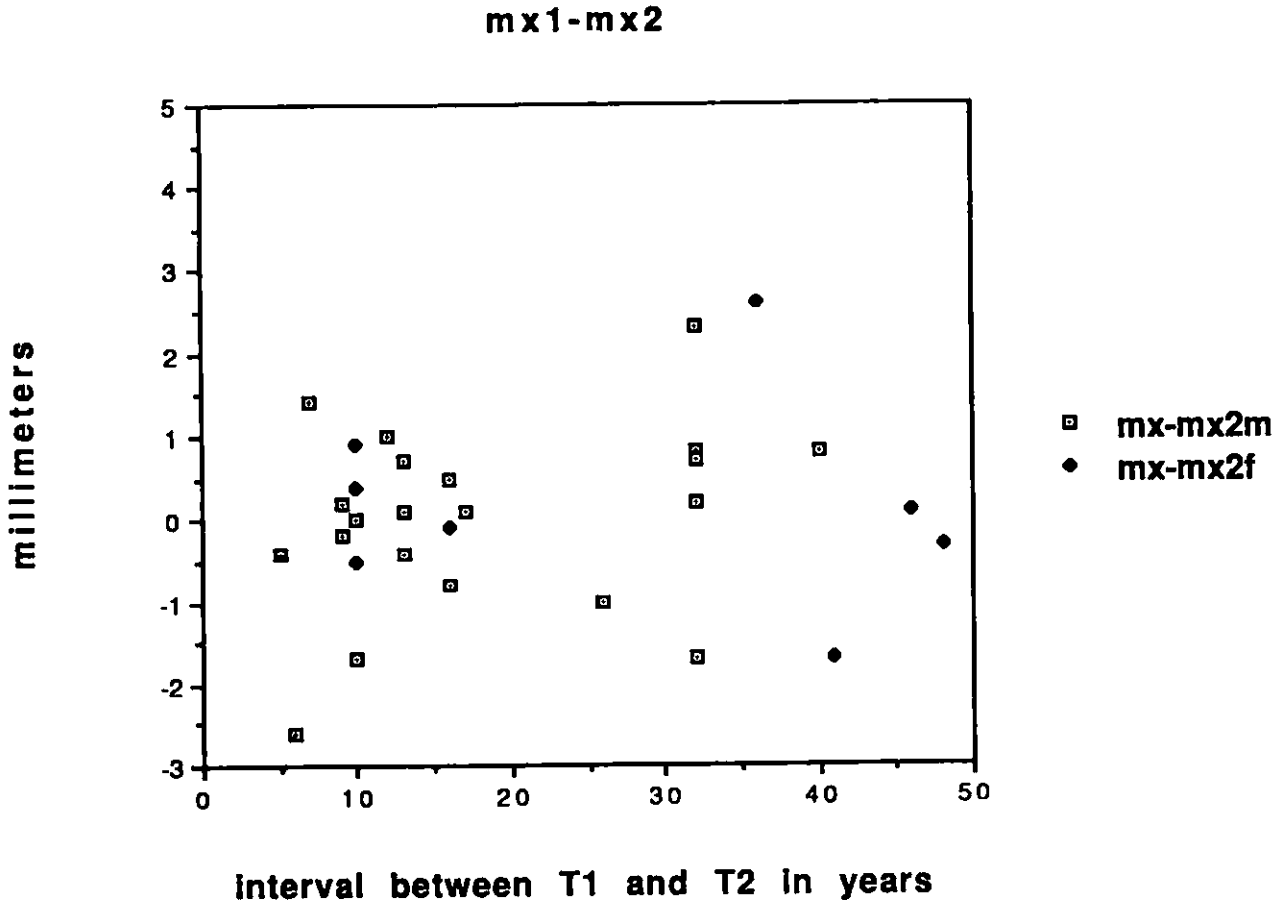


Figure 14.
Scatterplot of the difference between T1 and T2 for variable mx for each subject.

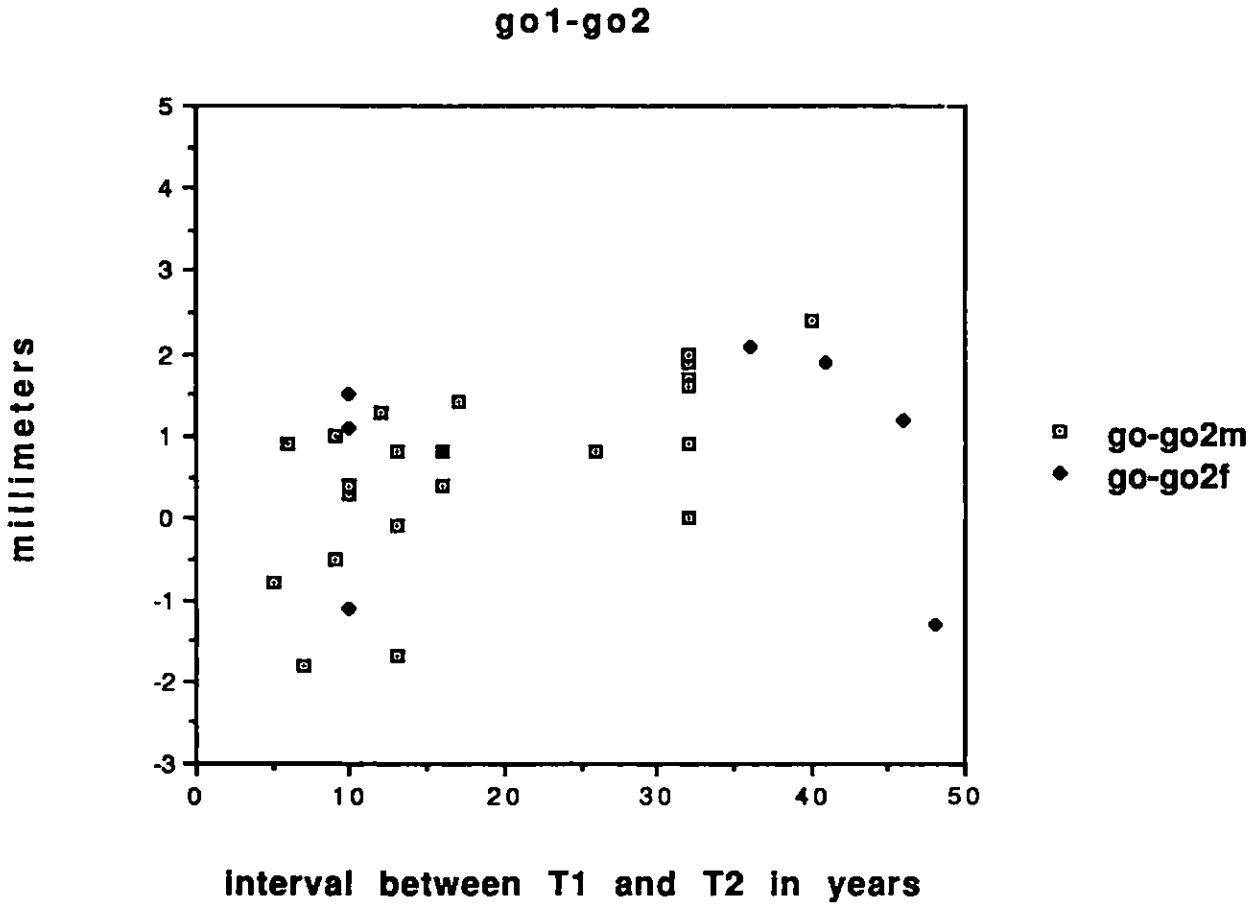


Figure 15.
Scatterplot of the difference between T1 and T2 for variable go for each subject.

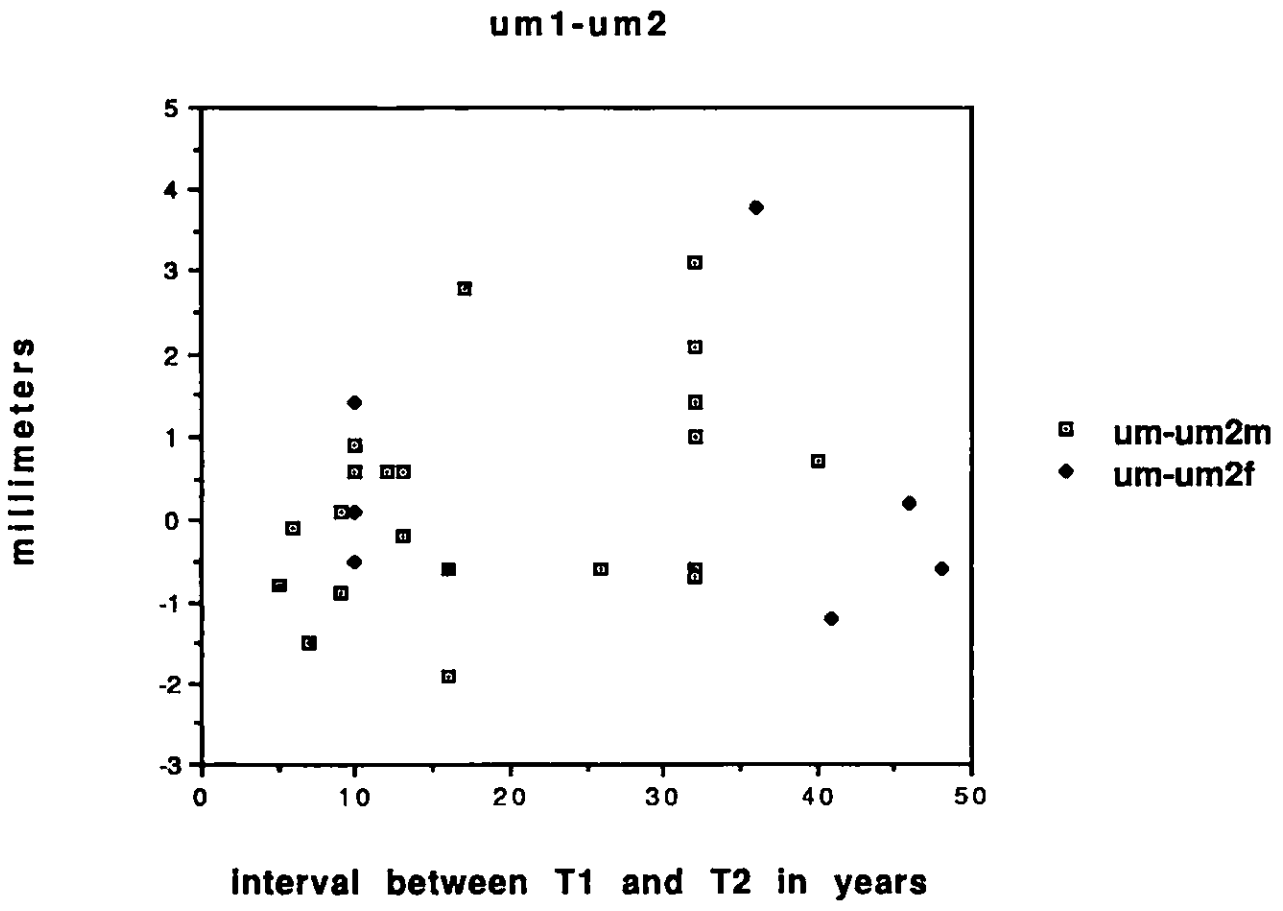


Figure 16.
Scatterplot of the difference between T1 and T2 for variable um for each subject.

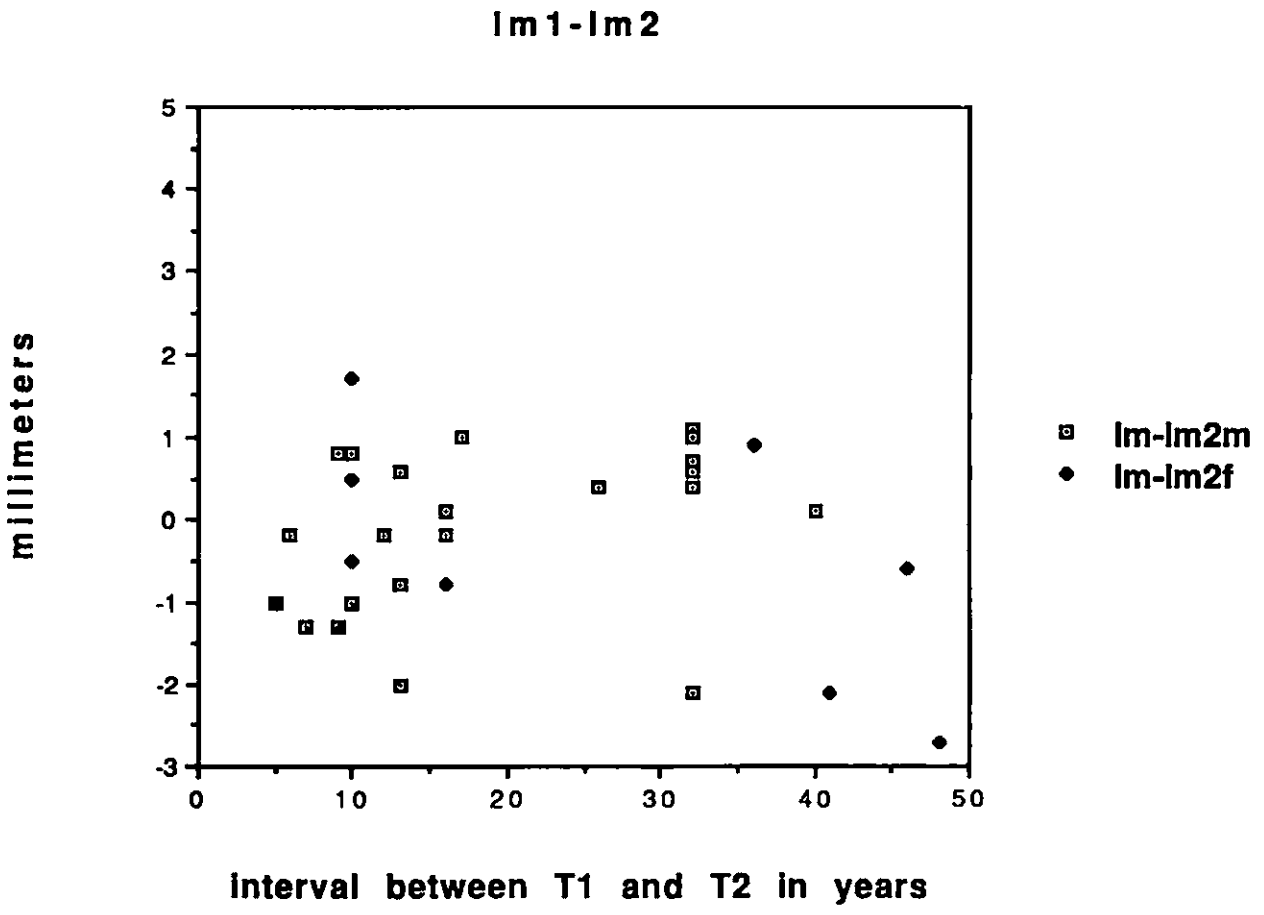


Figure 17.
Scatterplot of the difference between T1 and T2 for variable lm for each subject.

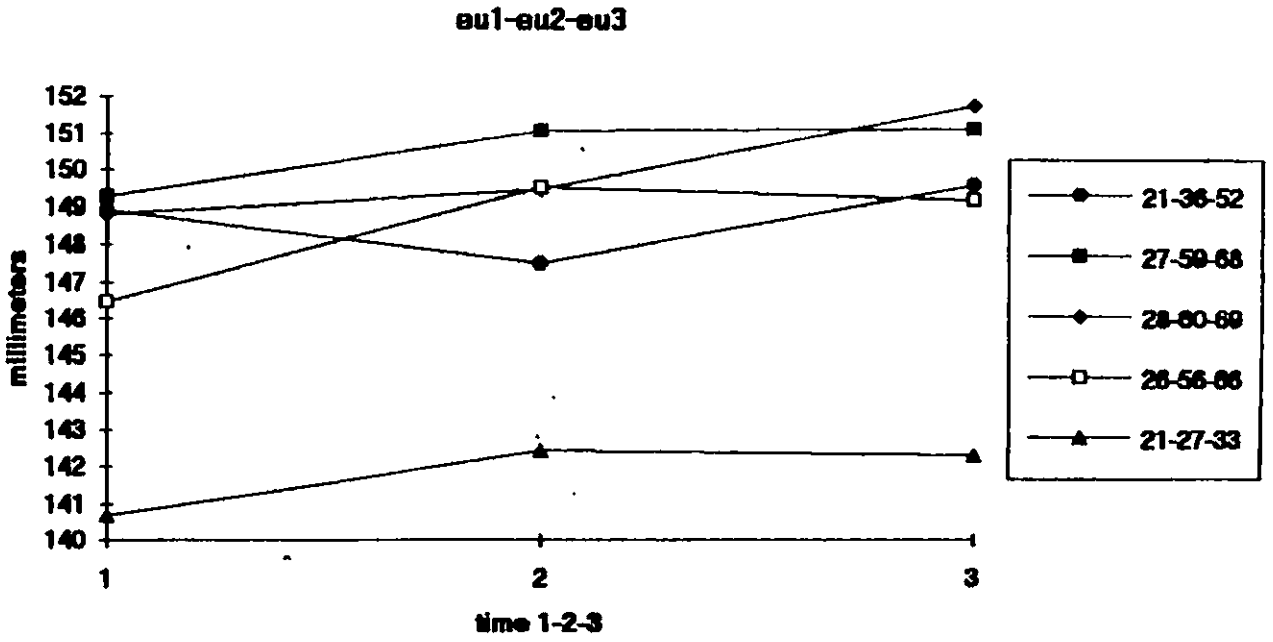


Figure 18. Plot of eu1-eu2-eu3 for 5 subjects.

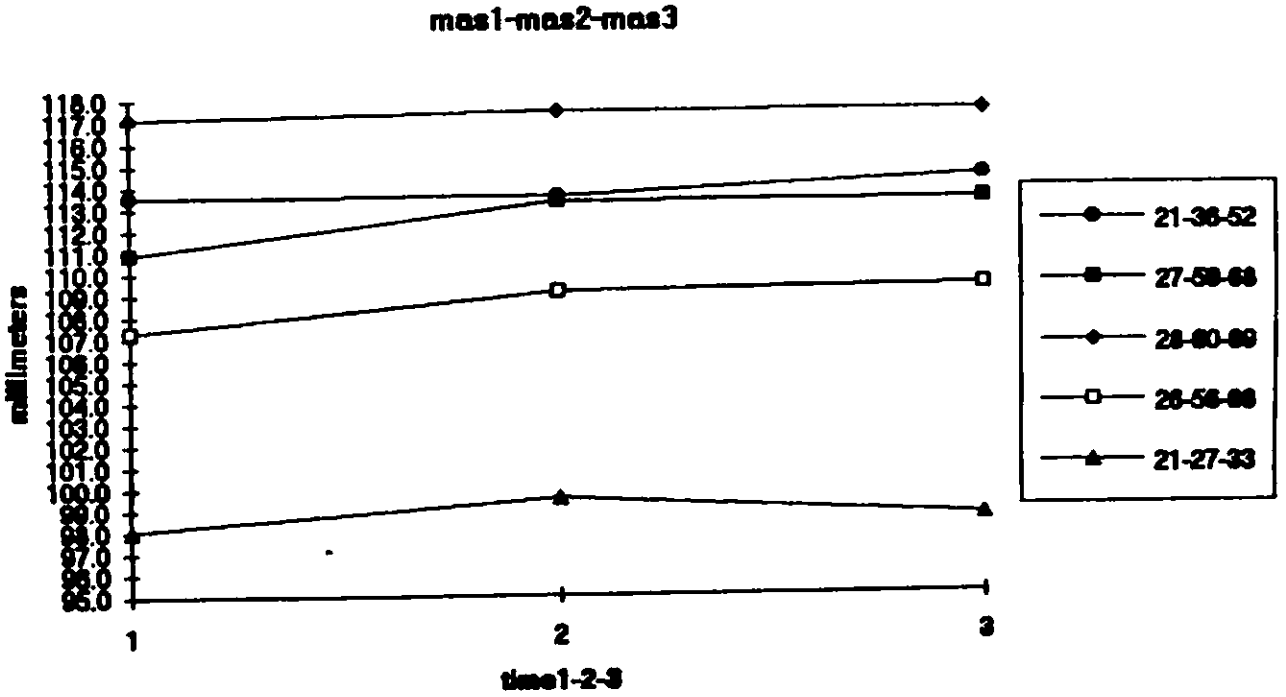


Figure 19. Plot of mas1-mas2-mas3 for 5 subjects.

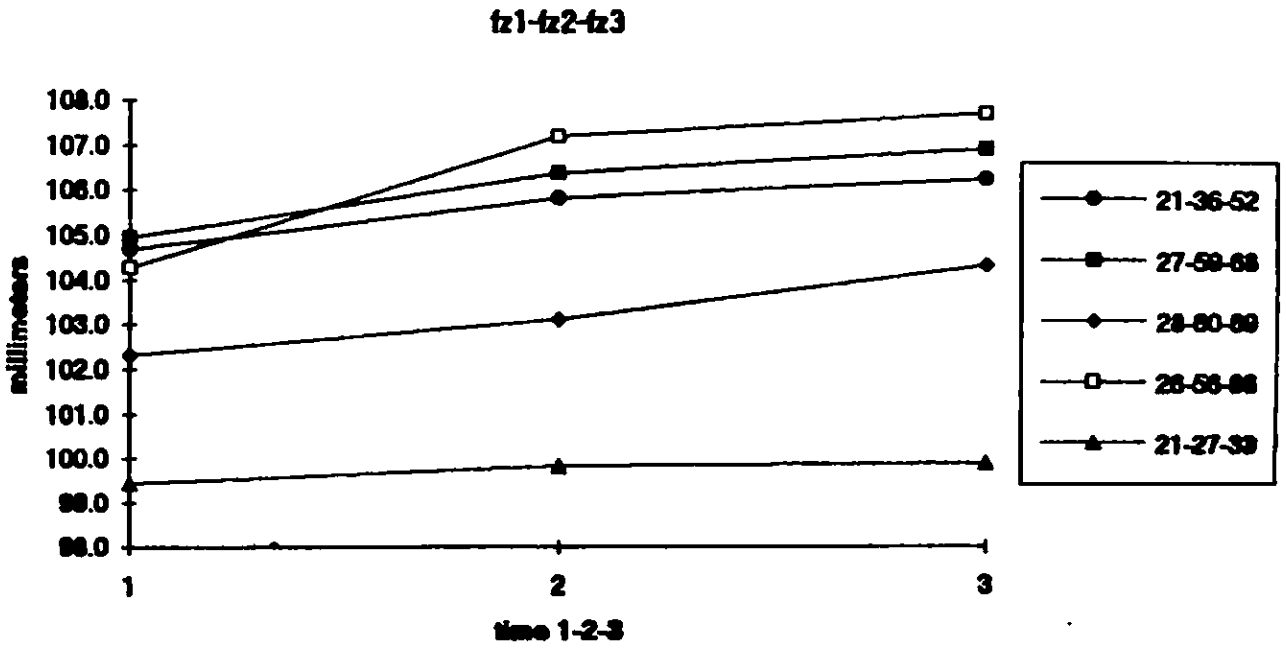


Figure 20. Plot of fz1-fz2-fz3 for 5 subjects.

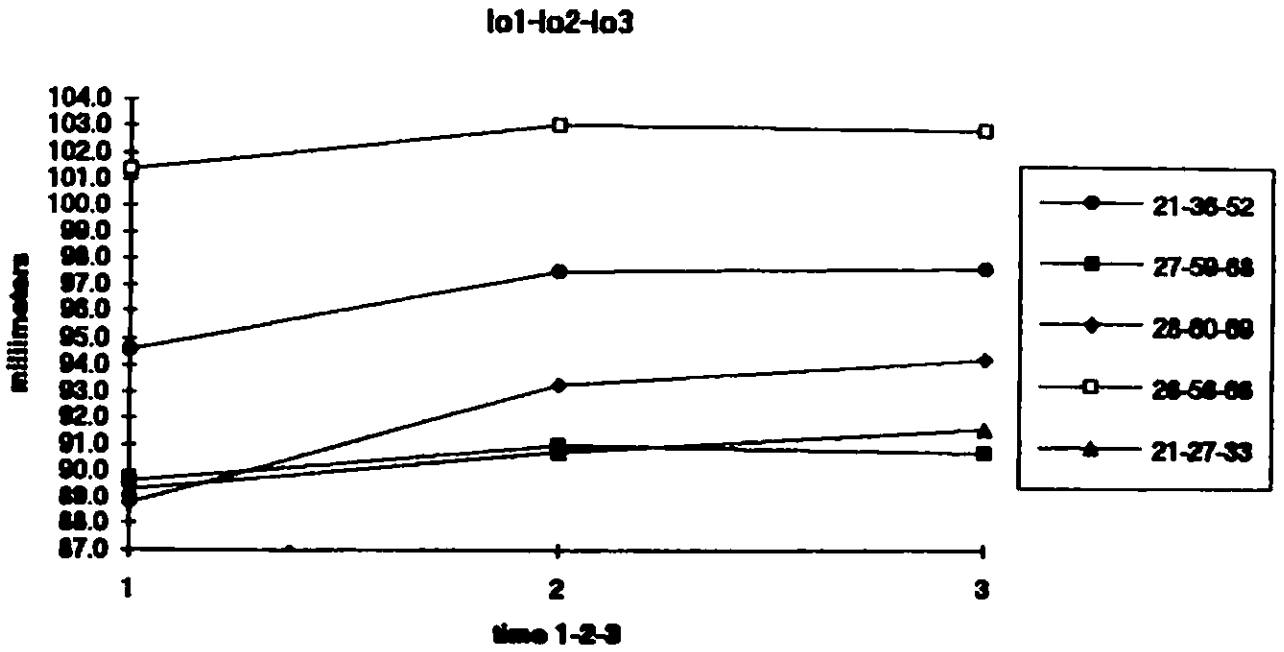


Figure 21. Plot of lo1-lo2-lo3 for 5 subjects.

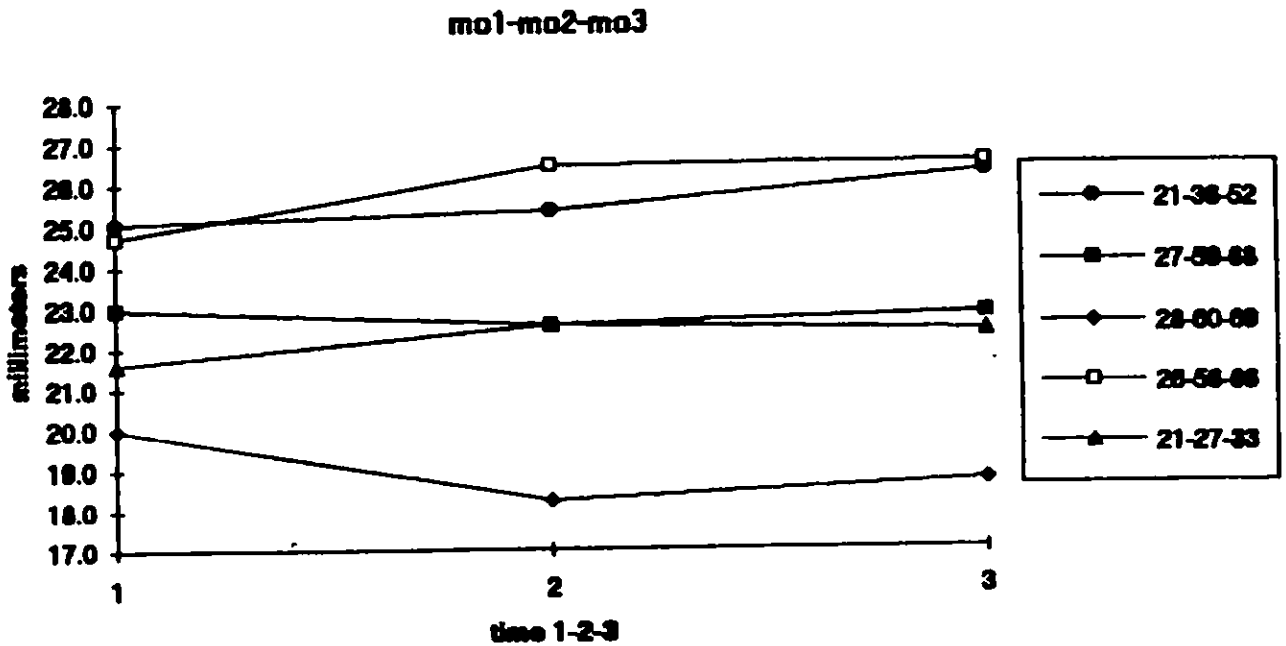


Figure 22. Plot of mo1-mo2-mo3 for 5 subjects.

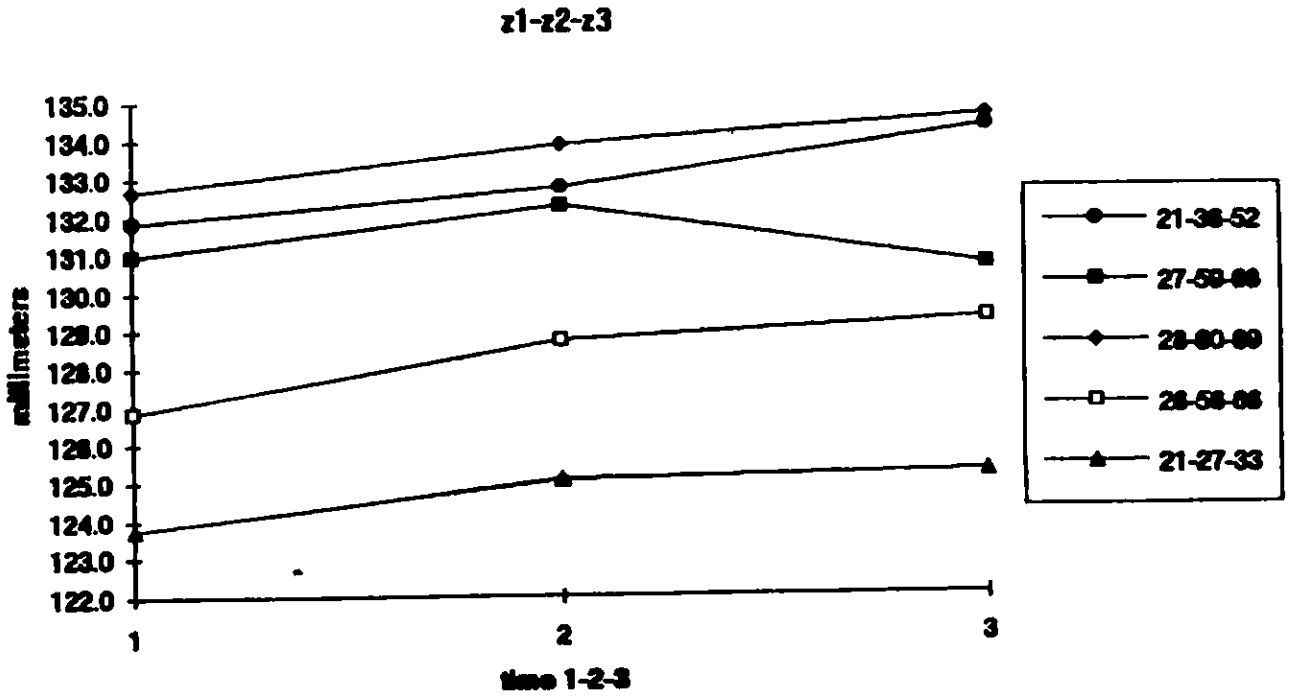


Figure 23. Plot of z1-z2-z3 for 5 subjects.

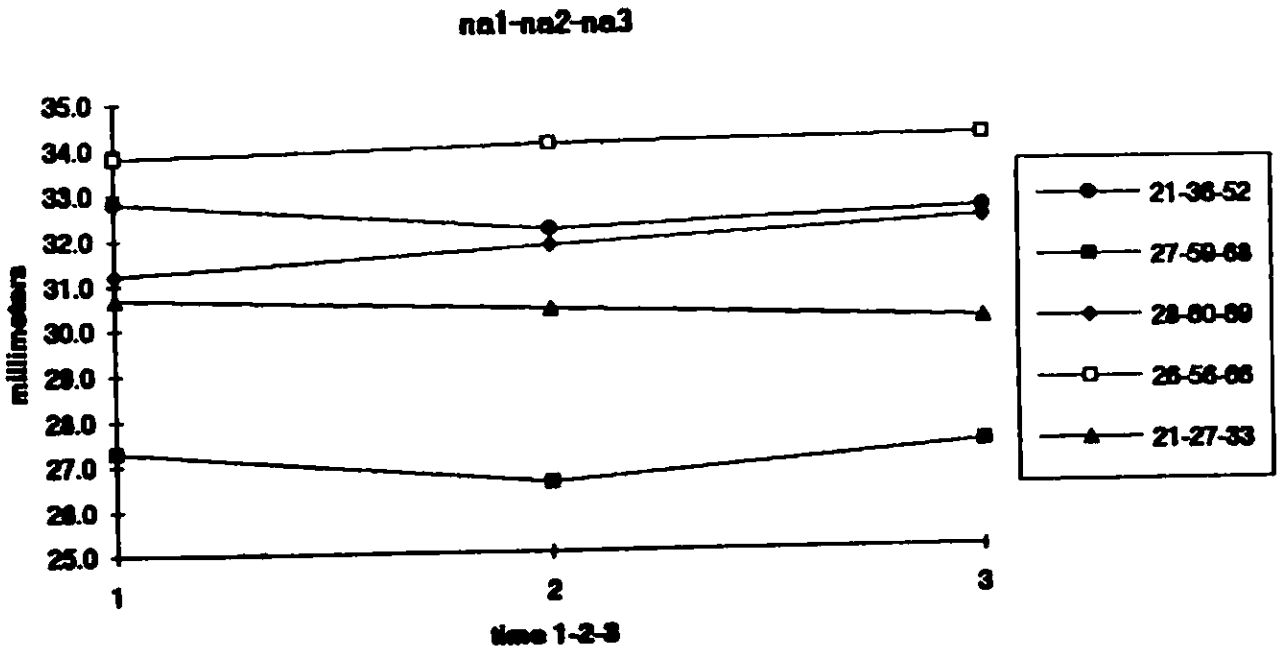


Figure 24. Plot of na1-na2-na2 for 5 subjects.

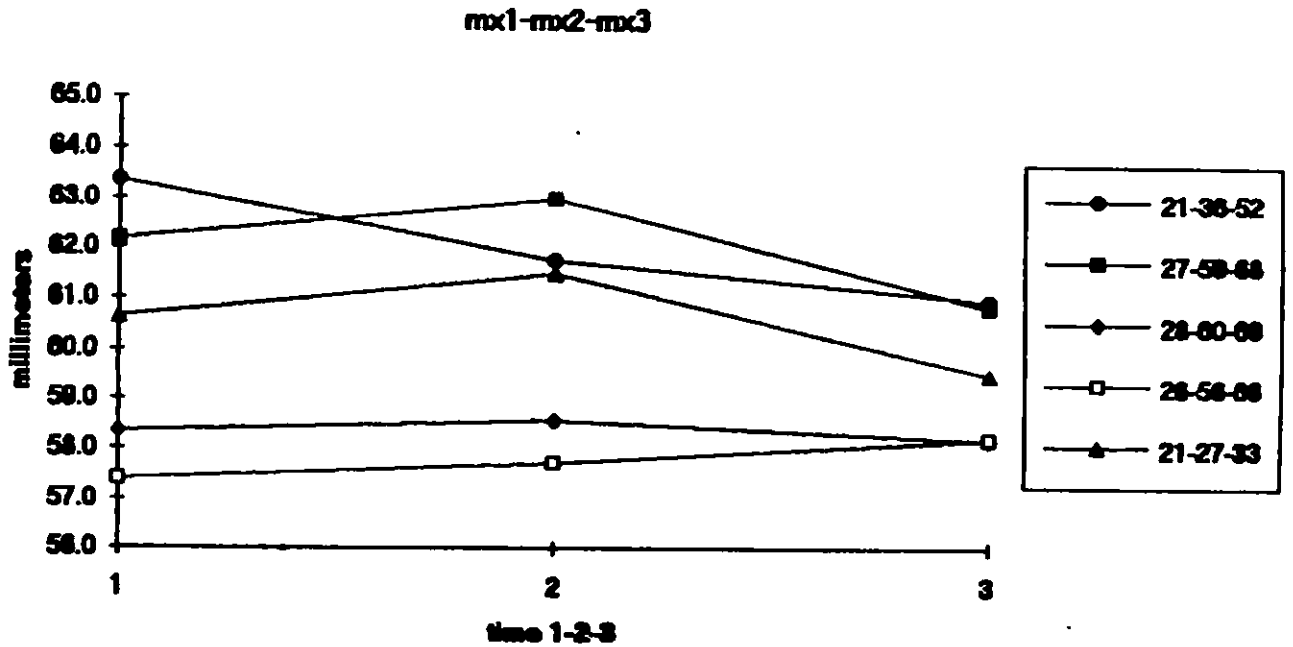


Figure 25. Plot of mx1-mx2-mx3 for 5 subjects.

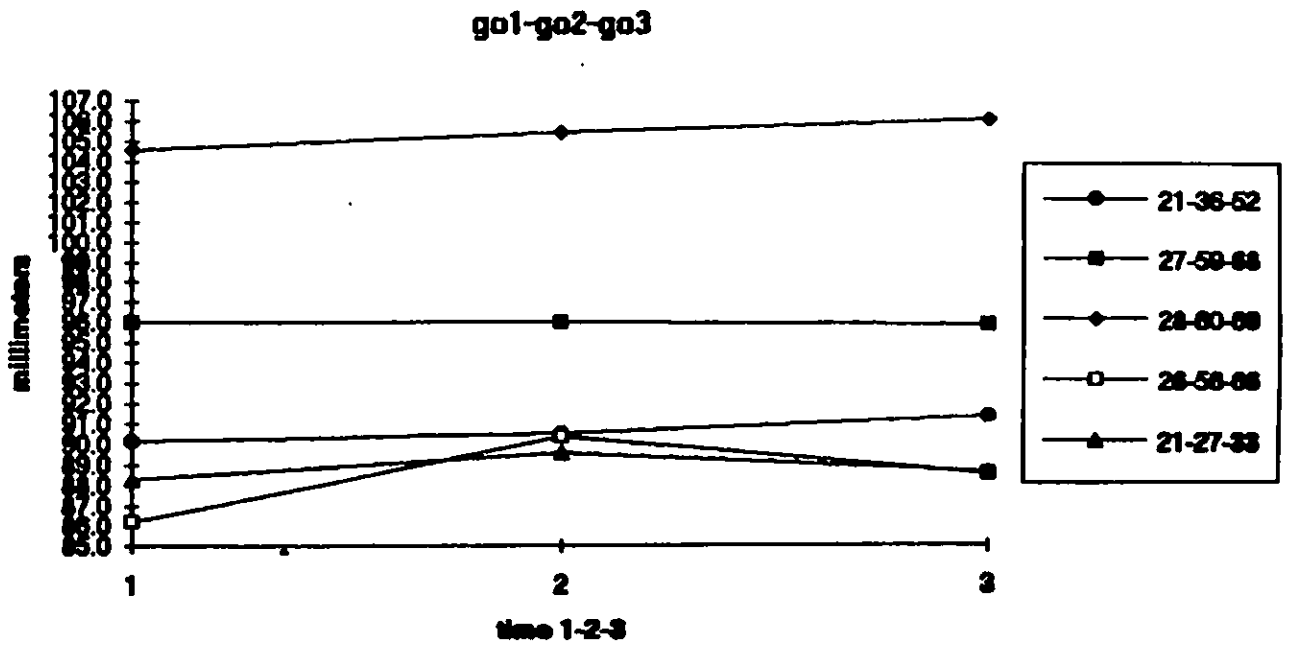


Figure 26. Plot of go1-go2-go3 for 5 subjects.

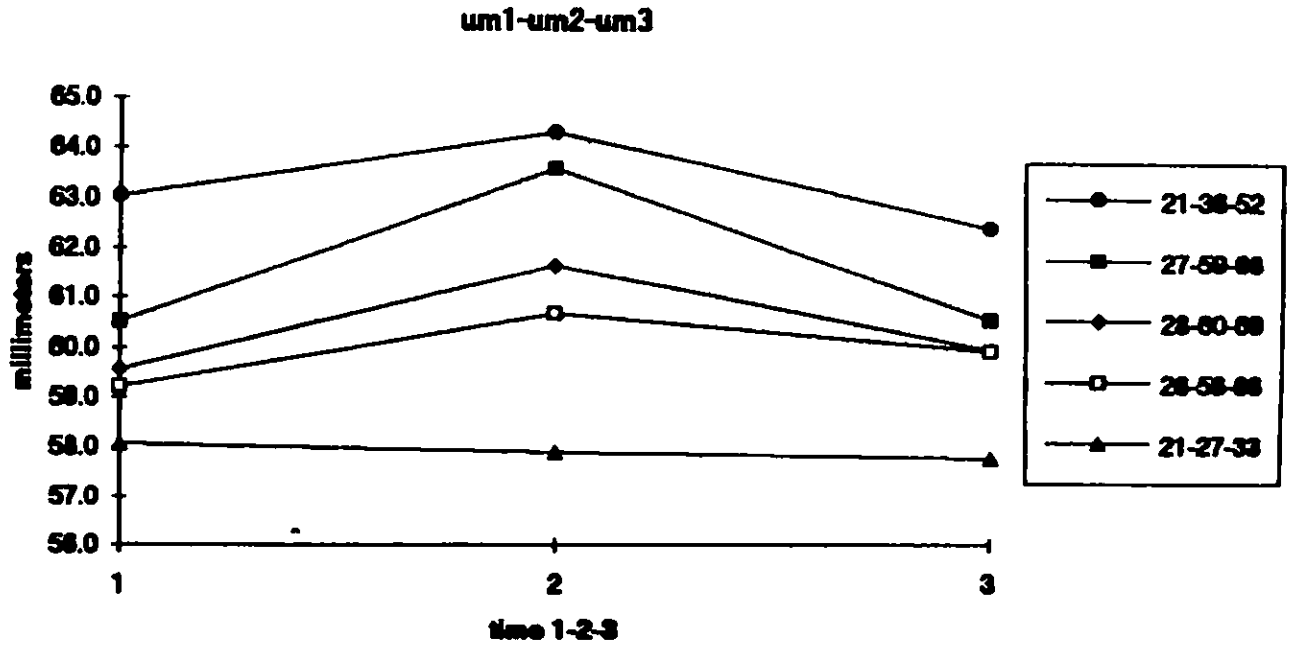


Figure 27. Plot of um1-um2-um3 for 5 subjects.

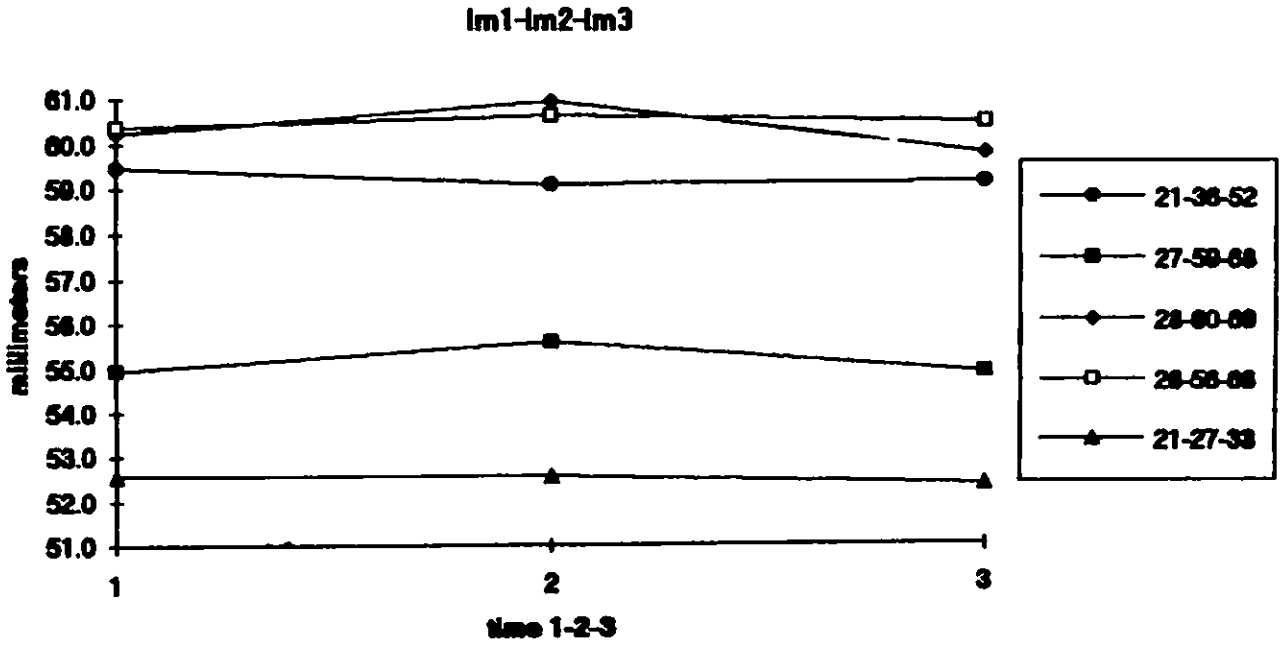


Figure 28. Plot of lm1-lm2-lm3 for 5 subjects.

DISCUSSION

Subjects included in this study were orthodontically untreated to avoid variance due to possible relapse. Six subjects reported medical problems ranging from diabetes, arthritis, thyroid disorder, and one female underwent a hysterectomy. Six out of eight females were post-menopausal at the time of the study. These situations affect bone density and quality. The time of onset was not always indicated but may have an importance in the dimensions measured.

Although the selected subjects were originally from generally economically advantaged families, with access to medical and dental care, education and good nutrition, the advantages they had as children are today generally accessible for the majority of the population.(Behrents 1985)

Longitudinal data was utilized as opposed to cross-sectional data to avoid the confounding effects of secular trends. Cross-sectional studies are limited to describing changes based on age differences between groups and can only infer that these changes correspond

to age changes in individuals. Longitudinal studies have the advantage of revealing age changes but do have limitations such as small sample size and variability in the ages at the time of initial and final films and the results may not be generalizable to other populations.

Measurements made at time 1 range from the 1930's to the 80's. The influence of the depression in the thirties and the post-war period and beyond on nutrition, health care and socio-economic conditions are factors associated with secular changes documented in height.(Meredith 1963) The difference in nutrition and health care during these periods may have influenced the dimensions measured. Secular changes have been documented in the morphology of the skull between present day Swedish men and skulls of Swedish men who had died in 1810.(Ingerval et. al. 1972) Changes were noted in the width of the head, maxilla, gonion, mastoid, lateral orbit, and width at the first molars. Width dimensions were larger for molar width and gonial width in the skulls which the author explained was due to greater chewing force in the earlier centuries. Secularization was chiefly due to genetic drift and increased hybridization of Swedes. When comparing three subjects matched closely for range of interval between T1 and T2 and age (B5815 with T1 records taken in the 70's, B0105 with T1 records taken in the 50's, and B3439 with T1 records taken in the 30's) width dimensions were

larger for B5815 in gonion and lateral orbit. Although maxillary width was also larger, B3439 had lost maxillary first molars which may affect the maxillary width dimension. No clear trend was seen in the other variables. It is not possible to determine whether these changes were affected by the social and economic environment of the time or due to genetics and individual variation.

Two subjects (B2186, B3439) were selected at 21 years at time 1 for the second part of the study. Late skeletal maturation influences were not obvious from the data compared to the rest of the subjects.

The different starting and final ages and irregular time intervals among the subjects produced unbalanced data prohibiting statistical evaluation of the entire sample as a whole using conventional statistical package programs. It was decided to use a non-parametric statistical test (Wilcoxon-Matched-Pairs Signed Ranks Test) to best evaluate the data based on the direction of change greater or less than zero. The only valid statements that can be made from this data is the statistical significance for change greater or less than zero,or no change, but not the magnitude of change. A pure longitudinal study with uniform starting ages and records at regular intervals is considered ideal for growth studies.(Lewis and Roche 1988) Despite the

problems inherent in evaluating longitudinal data, it still provides useful and valid information on age changes in an individual.

The correlation coefficients for the variables were all fairly high.

Error studies are necessary in cephalometrics due to the number of possible sources of random errors. Although patient positioning in the cephalometer were done by different ınvestigators in the three previous studies, the technique of using the Broadbent-Bolton Cephalometer minimized variations in positioning of the patient. A standardized source to ear rod distance of 5 feet in the frontal and 5 feet from the source to midsagittal plane was adhered to. Variations in film densities and sharpness were present among the radiographs evaluated. Films taken during the original Bolton Study used slow film and high definition screens which gave better definition than the fast films and rare-earth intensifying screens used in Behrents' study (1985) and the Update 2000 which reduced patient exposure to radiation but gave poorer film definition. The limited experience of the principle investigator in identifying landmarks in the P-A orientation was also a factor to the variability found. The method of averaging the P-A radiographic tracings to remove effects of minor horizontal head rotation also incorporated error to the

study, adding an additional tracing procedure. The use of a digitizer could also have contributed to the variance but probably to a minor degree.

Correction for magnification was done for all measurements. This is particularly important for this study to separate radiographic enlargement from actual biologic effects. Landmarks in the P-A headfilm are located in different coronal planes and at varying distances from the anode and film surface. Some variables, gonion and mastoid, are located posterior to the transporionic axis and would be enlarged to a greater extent than the variables located further anterior to the transporionic axis; lateral orbit, medial orbit, pyriform aperture, upper molar, lower molar, zygomatic arch, and frontozygomatic suture. Cranial width is located very close or in line with the transporionic axis and is probably well corrected for magnification. The antero-posterior change of some of the landmarks examined based on Behrents' results (1985) were found to be minimal. Since differences were examined between T1 and T2 and not absolute measurements, the effect of the location of the landmark with respect to the transporionic axis is minimal and adequate correction for enlargement was made using P+ values for the dimensions.

Examination of the results revealed an increase in some of the variables in the transverse dimension with

age. Four variables showed statistical significance for change. These were cranial width, mastoid width, lateral orbital width, and zygomatic width. No statistical significance for change was found in gonial width, maxillary arch width, lower molar width and upper molar width, medial orbital width, frontozygomatic suture width and nasal width.

Changes were described based on differences greater than 1mm in either direction to assure incremental change was greater than the limits of cephalometric technique. (Baumrind 1971)

Past craniometric studies (Todd 1924, Ruff 1980, Bartlett et. al. 1992) have indicated transverse craniofacial dimensional increase in adults. Longitudinal and cross-sectional somatometric studies showed facial width to increase up to the fifth and sixth decades and cranial width increases were variable ranging from the third to the sixth decades. (Hrdlicka 1928, Buchi 1950, Hooten and Dupertius 1951, Lasker 1952, Susanne 1977) Lateral cephalometric studies on the aging craniofacial complex have shown conflicting evidence for change. (Kendrick and Risinger 1967, Isreal 1968, 1973, 1977, Behrents 1985, Tallgren 1974). No longitudinal P-A cephalometric studies currently exist in the literature. The results of this study are the first to examine transverse changes in the adult craniofacial complex.

Further examination of the four statistically significant variables reveals the following:

1) Cranial widths among this sample showed increased change with age with the majority showing change greater than 1mm in the fifth and sixth decades. Craniometric and somatometric studies have also shown increase in cranial width up to the fifth and sixth decades.(Hrdlicka 1938, Hooten and Dupertius 1951, Lasker 1952, Susanne 1977, Ruff 1980). The cranial landmark has shown variability among the subjects with the widest width occurring either on the temporal or parietal bone. Those with greatest width at the parietal bone which is located more posterior to the transporionic axis than the temporal bone would be enlarged more but since differences were examined and not the absolute measurement the location of the landmark examined with respect to the transporionic axis minimally contributes to the variability seen in the data.

Among the 14 subjects showing change greater than 1mm, 4 subjects noted medical illnesses ranging from arthritis, diabetes, thyroid disorder, and one female underwent a hysterectomy, time of onset was not noted and no indication of Pagets disease was noted. Insulin dependent and maturity onset diabetes have shown evidence of osteoporosis with impaired calcium regulation.(Revell 1986) Hypothyroidism in adults results in depressed

cellular activity in bone and hyperthyroid individuals commonly have osteoporosis as a result with a negative mineral balance and loss of calcium from increased bone resorption and decreased intestinal absorption. (Revell 1986) Three females showing change greater than 1mm were post-menopausal. Upon menopause, there is an estrogen deficiency which deprives osteoblasts of a stimulation to the formation of bone matrix around which calcium is deposited to form new bone tissue. Estrogen exerts an anticatabolic effect on skeletal tissue and thus prevents excess bone resorption resulting in osteoporosis and decreased bone density.(Liss 1987) With osteoporosis, there is increased endosteal bone resorption with normal or increased periosteal bone formation.(Revell 1986) Although these subjects exhibited increased cranial width with age, the effect of their medical status can not be determined.

Temporalis muscle function and its influence on the cranium may be a factor to the increased changes seen. Although genetics serves as the major determinant of adult facial bone morphology, environmental factors exert effects on facial bone structure. During growth, the overall size of the skull is probably determined by intrinsic factors such as growth of the brain, ear capsule, nasal capsule and orbital contents. The functional forces of mastication play a significant part

in molding specific regions of the skull. (Moss and Rankow 1968) Washburn (1948) and Whitely et. al. (1966) found physical impulses affecting bone development either originating in muscle or at least directly related to muscle function. The posterior temporalis muscle originates on the inferior temporal line and bones of the temporal fossa including parts of the parietal, squama of the temporal bones, and greater wing of the sphenoid and inserts on the coronoid process and anterior border of the ramus.(Enlow 1990) Upon contraction it pulls its origins in an anterior, inferior and lateral direction while the anterior temporalis exerts forces that draw the parietofrontal aspect of the vault inferiorly and laterally.(Enlow 1990)

Local biomechanical loading of bone from muscle contraction generates alterations in the bioelectric environment producing a piezoelectric response which causes osseous structural responses through activation of osteoblasts and osteoclasts. Upon net deformation of a bone, selective adaptative apposition or resorption occur which models a given bone such that its ultimate configuration will not undergo net unidirectional deformation with function.(O'Ryan and Epker 1982) Electric fields are positive with concave deformation or negative with convex deformation corresponding with bone deposition or resorption respectively. It is not known

whether bioelectric activity is the natural signal that is the actual primary triggering mechanism for skeletal growth and remodeling.(Enlow et. al. 1977)

Mechanochemical changes have been hypothesized as also being a biologic signal for stress-induced skeletal remodeling. In this hypothesis, bone remodeling cells respond to an altered extracellular calcium activity in their local environment, either building up bone to redistribute an increased stress or removing surplus bone during reduced stress. The signal in this hypothesis originates in osseous tissue and not from signals emanating from soft-tissue.(Enlow et. al. 1977)

Mechanical forces can also act as first messengers as well as some systemic hormones such as parathyroid hormone and drugs, and facilitate bone remodeling by activating adenyl cyclase that transforms ATP to cAMP. Cyclic AMP in turn activates and controls the rate of synthesis of other cellular enzymes that are involved selectively with bone deposition and resorption. Osteoblasts secrete components of the bone matrix and osteoclasts produce, store and secrete enzymes and acids for breakdown of organic and inorganic components of bone.(Enlow et al 1977)

Other causes of increased cranial width with age may possibly be related to bite force of the individual and diet. A correlation between bite force and facial

morphology has been shown by Rinqvist (1973) and Ingerval et. al. (1978). Other views suggest that forces generated at the occlusal surface are directed into and absorbed by the food bolus being masticated and tooth-periodontal membrane-alveolus complex.(Oyen in Enlow 1990) The influence of the form of diet on changes in morphology and dimension of the craniofacial skeleton has been examined on rats. Rats raised on hard diet had wider transverse dimension of the maxilla and anterior cranial head width and larger muscle mass.(Whitely et. al. 1966) Scott (1961) found well-developed zygomatic arches, gonial angle, coronoid process in Eskimos due to their diet. Diet histories were not collected as part of the records for the Bolton Study until Update 2000. Diet effects on the cranial width changes could not be assessed.

Tooth loss was not a factor in cranial width changes since the majority of subjects maintained first and second molars through records at time 2. It was found that muscle function with aging in subjects with complete or partially compromised dentitions did not have significant alterations in masticatory function although the number of chewing strokes increased with age for preparation for swallowing with complete or partially compromised dentition.(Feldman et. al. 1990) Of those subjects with molar loss or crowns placed (B3195, 3194,

2747, 2131, 2030) no obvious trend toward cranial width gain was seen. B2747 who wore an upper and lower removable partial denture and had maxillary first and second molar crowns placed at time 2 showed no gain in cranial width with age.

It may be possible that general bony apposition takes place in the adult cranium. Adult bone surface apposition was found in the second metacarpal by Garn et. al. (1967). He found bone apposition was not restricted to weight bearing nor flexion stress bones and was a general occurrence in humans and was not population specific nor sex-specific. Adult bone deposition was also found in the ribs (Epker and Frost 1966) and humerous (Pfeiffer 1980) and skull in the sagittal dimension (Isreal 1968). This may be occurring in the cranium in the transverse dimension.

Isreal (1968) found increase in cortical thickness in the adult cranium from lateral cephalometric radiographs with surface deposition and inner table resorption until 70 years with the reverse occurring after 70 years. It would be interesting to examine cortical thickness changes in the transverse dimension and the pattern of inner or outer cranial bone remodeling.

2)Mastoid process width exhibited increasing change with age. Measurements were made at the midpoint of the most

lowest point of the mastoid process. Larger increases were seen in the subjects with larger intervals between time 1 and time 2 records. Three females exhibiting large magnitude of increased change were notable for chronic medical illness ranging from thyroid disorder, arthritis, and diabetes. These systemic disorders are known to cause disturbances in all body systems including bone. Mastoiditis was not noted in the records for any of the subjects. Factors that may contribute to enlargement of the mastoid width may involve its association with the sternocleidomastoid muscle which plays a role in neck balance and rotation of the head. The mastoid process is the site of insertion for the sternocleidomastoid muscle with its origin attached to the clavicle. The contraction of this muscle may produce lateral changes seen in this sample.

3) Zygomatic arch width in this sample showed increased dimension with age with the majority of changes greater than 1mm in the fifth and sixth decades. Somatometric and cranial studies have shown increases in this landmark in the fifth and sixth decades.(Buchi 1950, Hooten and Dupertius 1951, Baer 1956, Susanne 1977, Ruff 1980) Measurement was made at the greatest width of the zygomatic arch. Measured change may be associated with the biomechanical loading due to masseter muscle function. The zygomatic process of the maxilla and

inferior border of the zygomatic arch serves as the site of origin of the masseter muscle.(Enlow 1990) Spatially it is lateral, anterior and superior to its insertion at the lateral aspect of the angle of the mandible. Its spatial arrangement puts forces on the origin in a medial, posterior, and inferior direction increasing the vertical length of the arch as well as its lateral development. Four subjects noted for diabetes, arthritis, thyroid disorder and hysterectomy exhibited increases in zygomatic width greater than 1mm. These effects towards zygomatic width increase is not known. The majority of changes and greater magnitude of changes occurred as age at T2 increased indicating a possible age related change in zygomatic arch width. One subject, B2977, with the largest interval, 48 years, did not show dimensional change. It is not known if the width prior to T2 was at a plateau or showed increase or decrease due to the unavailability of an additional record. Those noted for tooth loss and crowns showed increased zygomatic width along with those with no tooth loss and crowns. The availability of sutural involvement in maxillary growth was found by Bjork and Skeiller (1977) to cease by 17 years in males and 15 years in females although Kokich (1974) found patency in the frontozygomatic suture up to the age of 95 years.

4)Lateral orbital widths in this sample showed change with increasing age. Since the eye is nearly complete at 90% by 7 years of age (Morin 1960) it is unlikely that the increased width is related to the eye. Enlow (1990) speculates that forces generated by masticatory function affects the superior and lateral orbital margins which may also explain increased lateral orbital dimension with age. The lateral orbital rim which is situated above the key ridge and below the supraorbital frontal bone considered as buttresses of the craniofacial complex provide support and biomechanical stress resistance balancing the physical properties of the skull against the forces acting within it.(Enlow 1990) Kashima (1965) examined stress distributions in the facial skeleton from masticatory forces measured by wire strain gauge and found stress concentration occurring at the lateral region of the orbit and zygomatic bone from masseter muscle action.

Two subjects showing change greater than 1mm were noted for thyroid disorder and arthritis (B4162) and skin cancer (B2977). The affects of these medical problems on lateral orbital width increase could not be determined. Those with tooth loss and/or crowns (B3194, 3195, 2747, 2030, 2131) showed no increase in lateral orbital width.

Seven other variables were measured which were found to be statistically nonsignificant.

1)Gonial width- Regarding gonion which represented the widest point of the angle of the mandible one might expect to see changes because of its association as the insertion for the superficial portion of the masseter muscle. The masseter and medial pterygoid act synergistically to elevate and close the mandible during normal masseter function.(Sicher 1980) Concave deformation of the gonial angle exhibits bone apposition proportionate to the magnitude of deformation caused by masticatory function. Rinqqvist(1973) found molar bite force values less in class II long face individuals compared to class II short face individuals. In long face types, masticatory muscle activity was found to be less than short face types and there was less masseteric than medial pterygoid muscle activity during maximal bite. Short face types demonstrated masseter muscle predominance compared to medial pterygoid msucle.(Epker and O'Ryan 1982) Variability in the data may be a result of force and force vector of the masseter and medial pterygoid muscle in long and short face types. The lack of statistical significance may be a result of a larger proportion of normal face type versus long or short face types.

Changes in gonion greater than 1mm occurred for the majority at T2 in the fifth and sixth decades in both males and females. Three subjects (B0125, B3195, B4162)

exhibiting increases were noted for medical problems ranging from arthritis, thyroid disorder, diabetes, and one female underwent a hysterectomy. Subjects with loss of a molar, crowns, or removable denture (B3194, B2747, B2030, B2131) showed no change greater than 1mm in either direction. One subject (B3195) showed an increase of 2mm, was noted for the loss of one maxillary second molar and one mandibular first molar, and a crown placed on an upper first molar. Individual variation in responses to altered muscle function in the gonial region may explain the variability. Two male subjects, T2 in the 40's, showing change greater than -1mm (B5807, B1344), were followed over a 7 year and 13 year interval respectively. No medical illness nor tooth loss and prosthodontic work was noted. This mild decrease in bony dimension may be attributable to decreased muscle mass or function changing the bone-soft tissue equilibrium. Muscle mass and strength and fiber number is known to decrease with aging (Hyatt et. al. 1990) and it is possible that this is occurring in these subjects although the majority of subjects in the 50's and 60's at T2 showed increased width with age.

2)Nasal width- The nasal width was measured as the widest width of the pyriform aperture. The majority of subjects 26 out of 30 showed no changes greater than 1mm in either direction indicating stability in this region with age.

Anthropometric reports of increased nose breadth (Hrdlicka 1938) is most likely due to soft tissue increase than bony width increase based on these results.

3)Frontozygomatic width- The frontozygomatic width was measured at the right and left frontozygomatic sutures. The frontozygomatic suture interposes between the frontal process of the zygomatic bone and the zygomatic process of the frontal bone reflecting the changes occurring in both these regions. Kokich (1976) found this suture open in cadavers up to 95 years of age. He attributed this to transmission of tensile forces from the masseter muscle. It is possible in the subjects showing change that changes in this suture may be associated with patency of this suture.

4)Medial orbit- Medial orbit width was measured at the most concave aspect of the medial orbital rim and tended to correspond to the superior half of the orbital rim. The superior portion of the medial orbital wall is associated with the more stable nasal bridge. The majority of the subjects, 24 out of 30, showed no change greater than 1mm in either direction. The breadth of the nasal bridge in the region just below the frontonasal suture does not markedly increase from early childhood to adulthood.(Enlow 1990) The results for this variable are consistent with the stability of the medial orbital width.

5)Maxillary arch width- The maxillary arch width was measured as the most concave aspect of the maxillary arch. Krogman (1951) found transverse widths of the maxillary and mandibular arch and the width of the dental arch to be completed prior to the adolescent growth spurt and remained fairly stable post-pubertally. The results for this variable are consistent with this data. 24 out of 30 subjects showed no change greater than 1mm in either direction. The results show 2 subjects with increases of 2mm or more and 4 subjects show decreases greater than -1mm. The 2 subjects showing increase in maxillary width also showed increase in upper molar width but with varying magnitude. The maxillary base is closely related to the roots of the upper molars. The subjects showing decrease had both second and first molars present in both arches. The decreases in width dimensions found may be due to the influence of the surrounding orofacial muscles.

5)The upper molar and lower molar widths were measured at the most buccal contour of the crowns of the right and left side. There was no statistical significance for change in the molar widths. The majority of the subjects for upper molar width (21 out of 30) and for lower molar width (22 out of 30), showed no change greater than 1mm in either direction. This agrees with longitudinal dental arch width studies utilizing dental casts and radiographs

finding the molar widths to remain stable after 13 years in females and 16 years in males.(Knott 1961, Sillman 1964) For upper molar width, three subjects showing change greater than 1mm (B3195, B3194, B2747) had crowns placed at T2 in which its overcontour may explain the increased width. Those subjects showing decreased width in the upper and lower widths were not noted for tooth loss or prosthodontic work. These changes may be associated with periodontal disease and or surrounding muscle influence.

Patterns were seen among some of the variables examined. Cranial width and mastoid width both showed increased change but at a variable magnitude probably due to influences from different muscles. An increase in frontozygomatic suture width and zygomatic arch width showed a pattern of increase but with variable magnitude. Wei (1970) showed a correlation between bizygomatic width with frontozygomatic width in his adult sample of Chinese males and females. Although zygomatic arch width and frontozygomatic suture width show similar trend in changes with age, zygomatic arch width and lateral orbit width and frontozygomatic suture width and lateral orbit width did not reveal any obvious relationship from the data. The upper molar width and maxillary base width showed a pattern in direction of change and generally in magnitude. These findings are only observational and

correlation studies would be able to confirm these observations.

Behrents (1985) found the lateral orbital rim and supraorbital rim to move forward in the second decade (mean delta 0.7mm sella to lateral orbit). With forward movement of the lateral orbital rim the results of this study indicate that the wall also increases laterally. The lateral wall of the orbital rim widens by resorption on the orbital side and deposition on the cutaneous side in response to forces of masticatory muscles.(Enlow 1990) Although nasal width did not show statistical significance for change, Behrents (1985) found the frontomaxillary nasal suture to show continued anterior movement as well as the tip of the nasal bone (mean delta 1.3mm sella to tip of nasal bone). Behrents felt there was continued adaptive growth in the nasal region antero-posteriorly with age. The results of this study show stability in the width of the pyriform aperture with age.

Due to the small sample size of females in this study conclusions about sex differences in the transverse dimension of the craniofacial complex could not be statistically evaluated. Sexual dimorphic characteristics in the zygomatic prominences, external mandibular angle, and mastoid process seen in the transverse dimension are generally smaller and more rounded and delicate in form in the females and larger and prominent in the males. The

gonial angle in the males exhibits prominent lipping and in the females are rounded.(Broadbent Sr., Broadbent Jr., Golden 1975) These findings were on observation were seen in the sample examined. Behrents (1985) found major differences in the shape of the upper facial areas around the eyes in the females and males. The females demonstrating a more upright and superior orientation. Wei (1970) found significant sex differences for both medial orbit and lateral orbital widths but his sample consisted of Chinese adults and may be a racial difference. Behrents (1985) and Ingerslev and Solow (1975) found size differences between adult males and females. A larger sample of females would be indicated to examine differences between the adult males and females in the transverse dimension.

Behrents (1985) found that pregnancy may play a role in increased craniofacial dimensions in females of childbearing years. It may be possible that pregnancy effects could be detected in the transverse dimension as well. Due to the small female sample comments regarding pregnancy could not be made.

Regarding the five selected subjects followed through three time points much interindividual variation was found. In general an increase was seen with variability in increments from T1 to T2 for cranial width, zygomatic width, mastoid width, frontozygomatic

suture width, gonion width, lateral orbital width, and upper molar width. Variability was found in medial orbital width and no changes were seen for lower molar width, nasal width, and maxillary arch width. From T2 to T3, in general, no change with some variation, was seen in cranial width, zygomatic arch width, mastoid width, frontozygomatic suture width, gonion width, lateral orbit width, medial orbit width, nasal width, and lower molar width. Decreases were seen in upper molar width and maxillary arch width. The variations noted in these samples was most likely due to the effect of environment on their inherent genetic make-up. Changes noted may be influenced by health status, diet, the surrounding soft tissue and change in function due to prosthetically altered occlusion and tooth loss. Wide variation in these findings may support the idea that change in the adult craniofacial complex is an ongoing process.

Factors contributing to the changes seen are only speculative. These changes may be due to the contribution of the muscles of mastication and their action on its insertions and origins. The skeleton is a dynamic, growing structure which continually remodels its internal architecture, surface, contours, and bone mass to maintain an equilibrium between form and function.(Enlow et. al. 1977) Although the relationship between muscles and bone is the most likely explanation for change, other

changes associated with aging can also contribute to the finding. These include decreased muscle mass, hormonal changes, dietary and environmental changes. As well, systemic disease can affect bone density and quality.

This study is a pilot study in examining transverse dimensional changes in the adult craniofacial complex. Studies incorporating a larger female cohort will be beneficial in examining sex differences in the adult craniofacial complex as well as the effects pregnancy and menopause. Future studies on the examination of cortical thickness in the cranium in the P-A orientation would add to the information gathered from lateral cephalograms of increase with age. Future studies can include comparisons of edentulous and dentulous subjects on the effects of the craniofacial skeleton in the transverse dimensions as well as orthodontically treated and untreated subjects.

Limitations of the study are those inherent in evaluation of longitudinal data. These include different initial and final ages and varied intervals between records. This limited the statistical analysis of the data. Small female sample size limited the ability to assess differences between females and males. Small sample size of subjects with specific health problems such as diabetes, thyroid and other hormonal disorders which affect bone. No longitudinal transverse cephalometric studies exist for comparison. Inherent in

the study were cephalometric technique limitations to measurement.

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