A Photocephalometric technique for

determining hard and soft tissue relationships of the face.

Gary E. Chapman, D.D.S.

This paper submitted in partial fulfillment

of the requirements for a certificate in Orthodontics

The Oregon Health Sciences University

July, 1989

Acknowledgements

I would like to express my sincere thanks and appreciation to the following individuals for their assistance and inspriation during the research and preparation of this paper:

Dr. Douglas Buck for his patience, patience, patience.

Dr. Larry Doyle who has always been encouraging and accessible.

Nancy Crosby for typing this manuscript.

D'Lorah Moretz for collecting the records.

And to my fellow residents Marie, Marianne and Shufang for the stimulation, support and friendship I have been most fortunate to have shared.

INTRODUCTION

The composite arrangement of the elements of the human face has long attracted the talents of investigators in disparate fields. The artist has delighted in manipulation of elements of the facial complex to attain esthetically pleasing relationships. The interest of the medical scientist lies in consideration of those elements relevant to successful cosmetic and functional correction of facial deformity.

The orthodontic literature reflects concern with the relationships of the facial soft tissue to the etiology, diagnosis and treatment of deformities within the orofacial region. Orthodontic study has limited itself largely to consideration of the static relationship of the soft tissue to the underlying skeleton in the sagittal plane. [1-8]

Population study to yield normative values for soft tissue facial profile has been limited largely to two tactics: (1) derivation of angular values relating soft tissue landmarks to one another or to the facial skeleton and (2) recording the mean and range for linear measurements of various aspects of the soft tissue drape. Few definitive conclusions can be drawn from these studies, as angular measures without an external reference, do not distinguish between positional variability in the elements of the angular relationship. Linear measurement which is not normalized yields limited applicable information in the clinical situation. It is not surprising, therefore, to find little agreement on whether or not the soft tissues relate in any predictable fashion to the underlying skeleton. [1,4,6-9]

Study of positional change of soft tissue with orthodontic or surgical treatment has shed some light on this complex interaction. The soft

1

tissues respond to treatment with a certain degree of predictability which is not strictly definable in terms of change at only one boney landmark. (10-16)

The goal of the following study is to determine the relationships between hard and soft tissues of the face based on study of photographs and posterior-anterior cephalograms. Statistical correlation of relationships between hard and soft tissue landmarks will be ascertained.

The material chosen for study consists of standardized posterior-anterior cephalograms and oriented photographs enlarged to exactly match the cephalograms in size. This investigation is cross sectional utilizing patients from The Oregon Health Sciences University Orthodontic Department.

HARD TISSUE EVALUATION FROM THE FRONTAL VIEW

Numerous longitudinal and cross sectional studies of both non-treated and treated subjects in virtually all age groups have been reported utilizing the standardized lateral cephalometric headfilm. [17-22] These studies have added immeasurably to our knowledge of growth in both vertical and antero-posterior directions, known from anthropometric times as the two dimensions which increase the greatest amount during growth and development of the human face. [23]

Much less study has occurred, however, utilizing the frontal headfilm. Due to a lack of comparative material studied from this viewpoint, the clinical orthodontist and oral surgeon has tended to eliminate the frontal view from their cephalometric appraisal of the human face. There is virtually no other way to study, in a serial manner, the development in width of the facial skeleton. [23]

Prior the advent of roentgen rays, physical anthropologists utilized measuring instruments that either measured dead skulls directly or living skulls through the soft tissues. Inaccuracies arose from measuring skulls through varying thicknesses of soft tissue. [24]

Methods of directly obtaining data from the living head took a tremendous turn following the discovery of Roentgen rays. In 1931, Broadbent introduced the radiographic cephalometer that has become the standard research tool in analysis of the hard tissues of the head. It's initial application was as an instrument to study craniofacial growth in 1700 children in the Broadbent-Bolton Study. The properties of facial morphology were represented by points and lines in two dimensions. Numerous angles and facial dimensions were calculated to provide data on

3

a normative population study and growth standards for assessing dento-facial development similar to the method of T. Wingate Todd for assessing skeletal age from the hand and wrist film. [17,25]

At about the same time, Hofrath and Maves, the former who independently developed a similar cephalometric technique in Germany, were prescribing it for prosthetic planning and for following prosthetic procedures. [26,27]

To date, numerous standard cephalometric measurements have been described to form analysis of cranio-facial morphology. [2,20,22,28-31] All of these analyses were derived from the lateral cephalogram, since the profile view and concomitant antero-posterior and vertical growth changes were of interest to the orthodontic community at that time. As it turns out, linear and angular measurements of cephalometric landmarks in the sagittal plane gave more accurate and reproducible results for longitudinal research. [32] Frontal analysis was hampered due to difficulties in consistently orientating the patient to the head and film holders. There was also a lack of acceptable reference points and planes so that insufficient clinical data in both treated and non-treated patients resulted in an inability to establish standards for clinical use. [33]

Davis in 1918 was the first to use the posterior-anterior head film for the study of assymetry of the paranasal sinuses. [34] Broadbent in 1931 combined the use of both lateral and frontal projections for his ortho diagraphic analysis. But use of the frontal projection was limited to ...... "it's contribution to an understanding of the structures that appear in the lateral view." [25]

Potter and Meredith (1948) compared two methods of obtaining

4

biparietal and bigonial measurements on 94 white children between the ages of 4 and 5 years. One procedure called for direct measurement of the landmarks in question; the other involved a posterior-anterior cephalogram and indirect measurement made from the films. Both procedures were performed with a high degree of scientific rigor. They found that biparietal diameter was represented with more validity by direct measurement and that bigonial diameter was measured more reliably by the indirect radiographic method. [35]

Woods in 1950 studied the frontal headfilm for dimensional changes during growth. Using the technique as proposed by Wylie and Elsassar (1948), he corrected measurements made from the posterior-anterior films to obtain widths of various skeletal landmarks. [35] He showed that the corrected measurements taken from posterior-anterior exposures were essentially the same as direct measurements taken from the same dry skulls. [37]

Harvold (1954), performed two studies on assymetry in unilateral cleft palate subjects and proposed the first parameters for assymetry of the upper facial skeleton. He developed a method to give precise information about the symmetrical construction of the facial skeleton in living material. On the posterior-anterior cephalogram, the lateral parts of the zygomatico-frontal sutures were identified and a horizontal line was drawn between these two points. Another vertical line was drawn perpendicular through the root of crista galli representing the median plane. This construdted his so-called "x"-line method. In a sample of 67 normal children, he found that anterior-nasal spine was less than 1.5mm deviated from the x-line in 90% of the cases. When the distances were

5

measured on both sides from the temporal border of the zygomatic bone, and from the zygomatic-maxillary sutures on the malar processes to the x-line, the index of symmetry obtained radiographically closely corresponded to anthropologic findings. He concluded that it was, therefore, possible to register assymetries within the facial skeleton to a considerable degree of accurary with the use of posterior-anterior cephalograms. [38]

Subtelny (1955) used the laminographic technique frontally for a comparative study of normal children and unoperated cleft palate children. [39]

Mulick (1961 and 1962) studied the frontal headfilm in a triplet series longitudinally for comparative effects of age, sex and craniofacial region on asymmetry. He could not demonstrate any significant differences between identical and fraternal twin groups, which led him to believe that with the exception for hereditary syndromes, craniofacial symmetry is not controlled by heredity exclusively. In 1965, Mulick presented a paper on clinical use of the frontal headfilm and demonstrated its value in orthodontic diagnosis of the following problems: (1) midline deviations (2) occlusal plane tilt (3) facial assymetry (4) functional shift of the mandible (5) morphological typing (6) dental analyses, and (7) congenital deformity. [23]

Gerald and Silverman (1965) investigated interorbital distances with special reference to Down's Syndrome patients. Interorbital distance was determined by measurements on posterior-anterior roentgenograms of what was believed to represent the junctures of the medial angular processes of the frontal bone with the maxillary and lacrimal walls. They

6

studied the roentgenograms of children with a clinical diagnosis of Down's Syndrome and 100 roentgenograms of normal children. They found the interorbital distance of Down's children to be significantly decreased as compared to the normals, indicating orbital hypotelorism. [40]

Owen (1988) studied frontal facial changes with the Frankel Appliance using the standard posterior-anterior cephalometric view. Fifty cases (ages 5.9 to 13.8, average 9.6 $^+$ 1.54) were analyzed for changes in mandibular width as measured across the antigonial notches and changes in lower face width as compared to the middle and upper face widths. He concluded that the Frankel Appliance treatment showed a significantly greater increase in bigonial width and a related decrease in fronto facial taper than in comparable cases treated with edgewise therapy or in untreated norms. [41]

The use of standard cephalometric films has basically necessitated a two dimensional approach to diagnosing a three dimensional problem. This was recognized early on by Broadbent as he modified his original cephalometer to include a posterior-anterior projection so that a complimentary pair of films was produced. [17] Sassouni (1958 described a method of correlating information from the lateral and posterior-anterior views by horizontal orientation of the tracings side by side on graph paper. [42] Both Broadbent and Sassouni attempted to gain a three dimensional understanding of the head through the study of the two classic orthagonal views.

A third view, the basilar view, was described by Schueller (1905) and then by Merrill (1949). Berger (1964) proposed a method of orienting this basilar view to the standard lateral and posterior-anterior cephalograms

7

using the Frankfort horizontal plane as a common factor. [43]

Nahoum, et. al. (1964) described a technique of aligning the structures of these three cephalograms to one constructed plane based on drafting principles of a three dimensional projection. [44]

In order to make three dimensional analysis manageable, computer aided analysis was needed to handle the vast amounts of raw data generated by two or three views of the head in order to generate more accurate and reliable norms. [45]

Kaban, et. al. (1981) demonstrated more clearly the clinical deformity present in his cases of hemifacial microstomia utilizing his methods of three dimensional analyses. He used the two classic orthogonal views and a submental projection and derived a vertical reference plane connecting anterior nasal spine to sella turcica. [45]

Grayson (1983) presented three dimensional multiplane cephalometric approach that permits visualization of skeletal midlines at selected depths of the craniofacial complex. He localized craniofacial assymetry in the frontal and basilar views and supported his findings by determining the plane of sectioning on the lateral cephalogram with the landmarks chosen. [47]

Baumrind, et. al. (1972) introduced the concept of coplanar stereometry to cephalometrics. They deviated from the conventional orthagonal approach by producing a traditional lateral cephalogram and a second coplanar projection exposed from an "off set" perspective to enable supplementary data to be derived and correlated with the first view. By combining the pair of stereo images, a true three dimensional coordinate system of all structures could be plotted and analyzed with the aid of a computer. [48]

8

Although many refinements have been made to the techniques, machines and analyses utilized by the early cephalometric pioneers, inherent problems still persist. Problems such as penumbra, distortion, enlargement, film graininess, and secondary radiation have been investigated and improved upon, but not eliminated, by various workers.

Differential enlagement appears to be the major problem that remains. In order to deal with this, several workers have designed specialized mechanical devices. These include the "orientator" of Broadbent (1937) [17], the "compensator" of Wylie and Elasasser (1948) [36] and the "modified compensator" of Vogel (1967). [49] In general these solutions have been much too tedious to be feasible for routine usage.

SOFT TISSUE EVALUATION OF THE FACE (FRONTAL VIEW)

People seek out orthodontic care for their children or for themselves because they wish for an improvement in facial appearance, not just to have the teeth aligned so they will function better and be healthy. [50] Case (1921) was a pioneer in the awareness of facial esthetics as a primary goal of orthodontic treatment. [51] Since then, many investigators and clinicians have held esthetics as a primary goal along with function and stability. [4,5,22,50,52-55]

Assessment of facial appearance, although clearly a three dimensional problem, has been attempted in two dimensions by the majority of techniques available. Facial form may be abstracted into two planes of space: (1) frontal and (2) sagittal (profile). [6,8,52,54,56-58] There have been several analyses used for evaluating the soft tissue facial profile. The frontal view, however, has met with more inconsistencies due to the three dimensional nature of the face. In general, our perception of others is first formed by their frontal appearance. Therefore, we usually remember people's faces by their frontal image. For this reason, it is important to investigate facial proportion and relationships not only in profile, but also from the front. [60] Brodie (1946) quotes E.H. Angle, saying, "we know that while all human faces are greatly alike, ... they all differ. Lines and rules for their measurement have been sought by artists and many have been the plans for determining some basic line or principle from which to detect variations from the normal, but no line, no measurement, admits of anything nearly like universal application." Angle, Malocclusion of the Teeth, 1907. [61]

Measurement and evaluation of man's face began with anthropometry

(from Greek, anthrops, "human" and metron, "measure"). By this method, facial dimensions were obtained directly from the living person. Most of the cranial and facial measurements were performed according to classical methods of physical anthropology (Hrklicka, 1920; Martin1928; Gunther, 1933; Goycki ,1956; Martin and Saller, 1962; Weiner and Lourie, 1969). Soft tissue measurements were technique sensitive due to the amount of pressure exerted by the measuring instrument. Skill and experience were required for consistent results. [62]

Another approach to soft tissue measurement was utilized by early forensic anthropologists. Investigators such as Welcher (1883), His (1895), and Kollman (1898) are credited with being the first to establish average tissue thickness at various identifiable points over the face. Welcher obtained tissue thicknesses by inserting a thin blade vertically through the skin of cadavers at selected points until the tip encountered underlying bone and then withdrawing it. His and then Rollman used varying themes on a sewing needle technique, inserting it until bone was contacted. [63] The resulting tissue thicknesses were used for soft tissue reconstruction over dried skulls for identification purposes.

In the field of orthodontics, Milo Hellman (1920's-1940's) is generally credited for the adaptation of anthropometric methods for diagnosis and treatment planning. He made use of the Todd head spanner and anthropometric calipers. Later, Elsasser (1951) introduced the facial orthometer to measure soft tissue relationships in two planes of space: vertically and horizontally on points lying on the facial midline. This instrument was proposed as an alternative to radiographic measurement and diagnosis. [64] The orthometer, however, was doomed to limited use as radiographic orthodontic diagnosis of malocclusion became the norm.

More currently, Farkas and his co-workers could be considered the major contributors to anthropometric data regarding the soft tissues. He has applied his techniques to large samples of cases involving craniofacial anomolies [65-70] as well as normative data. [62,70] In his published book on "Anthropometry of the Head and Face in Medicine" (1981), he states that the most common sources of error are found in: (1) improper identification of landmarks, (2) inadequate use of measuring equipment, and (3) improper measuring technique. He recommended that all measurements be repeated and averages recorded. [62]

Photography overcomes many of the difficulties of measuring the face, either directly or indirectly. With direct measurement, the difficulties are the distortion induced by pressure on soft tisues, the sensitivity of some of the tissues, for instance the eyes, and the complexity of shape of the face. [71] Photographic methods had been used in anthropology to record characteristics qualitatively until 1940 when Sheldon published his work on somatotyping, using the camera as a measuring instrument in the assessment of body physique. [72]

Tanner and Weiner (1949) investigated the reliability of photographic assessment of physical parameters. They modified and standardized the technique to such an extent that certain body dimensions could be measured to a degree of accuracy equal to that obtained in anthropometry. They found the single greatest source of error in two dimensional photograpy was due to posing. Their method was deemed so accurate that the term photogrammetry was applied. [73]

Photogrammetry of the face is anthropometry adapted for quantification of surface features from standard (one-fifth, one-quarter,

one-third, half or life size) photographs. The use of standard photographic methods to produce prints of standardized views and sizes allowed photogrammetry to be scientific, accurate and documentary. [74]

Ferris (1927) [75], Jackson (1937) [76], and Weinberger (1948) [77] were among those who had developed a method of making from a negative, two positives; one in the mirror image of the other. "Each positive was cut in the midline, and both right and left halves reunited by photomontage." This was a convincing method of demonstrating the presence of facial asymmetry.

Other photogrammetric documentation of the face concentrated on the lateral profile view. [5,59,78,79] Few additions to profile evaluation via cephalometric radiography were made by this photographic view, as most concentrated on midline profile features.

Facial proportions have been evaluated using photogrammetric records without the support of direct measurements. [80-84] Most of the classic formulae concerning idealistic proportions of the face were first developed by the Egyptians; later by Polykleitos, a famous ancient Greek sculptor and then later reviewed in the Renaissance by Durer and Leonardo da Vinci.

Farkas and co-workers (1985) using "standard anthropometrical methods of measurement" reevaluated these neoclassical cannons of facial proportion using a large sample of North American caucasians. He concluded that two of the nine canons do not fit modern faces, and that revision is necessary. The modern face is longer and narrower than that of the ancients. [85]

Ainsworth, et. al. (1979) stated that the use of a proportion index

13

that comprises a few anthropometric data permitted a more complex judgement of the face and established a basis for more detailed comparison than did the analysis of single absolute measures. [86]

Nakajima and Yanagisawa (1985) in a sample of 34 Japanese subjects utilized frontal facial photographs to evaluate facial form. Landmarks were defined according to Rickett's criteria. A series of indices comprising facial, nasal, orbit and lip heights and widths were compiled and compared with the Rocky Mountain Data System of classification for malocclusion. They found a distinct ethnic difference for a sense of beauty not subscribing to Rickett's "golden ratio". a 1:1.618 facial profile relation. In a subsequent publication they describe the Japanese sense of beauty being represented by a numerical valve closer to the   2 rule of ancient Japan. [60]

Reliability studies on photogrammetry have been few. Tanner and Weiner [73] made unsubstantiated claims of reliability in their study: ...."that it seems that not only body dimensions, but many of the head and face can be obtained from our photographs".

Gavan, Washburn and Lewis (1952), on a sample of two subjects recommended that the lens-subject distance be at least 10 times the "breadth of the subject to reduce photographic error to less than one percent". They reported data specific for six measurements. [87] In conclusion, they said if selected anatomical points were premarked on the individual, many measurements could be taken as accurately on the photographs as on the individual directly.

Frasier and Pashayan 91970) reported 12 measurements from photographic prints of 50 subjects but only said they "correlated well" with anthropometric measurements. [88]

14

Realizing the lack of hard data on reliability of photogrammetry, Farkas, Bryson and Klotz applied their skills in anthropometry to this problem in 1980. [74] They compared direct measurement and indirect photographic measurement of 36 healthy, young, white Canadians. A measurement was considered reliable only if the average difference between indirect and direct measurement was no greater than 1mm or 2 degrees. The indirect method yielded 40.4 percent fewer measurements than the direct method mainly due to obscuring by hair. They found lateral prints gave more valid measurements (13 of 20 were reliable) than frontal prints (only 10 were reliable), but that measurements of the eyes, lips and mouth were most precise from the frontal view. Farkas determined five areas of error in photogrammetry: (1) errors are made measuring prints without previously indicated landmarks on the face, (2) head positioning and maintenance of head position in sequential exposures, (3) distortion caused by photographing accounted for the greatest differences between direct and indirect methods relating to the three dimensional face on a two dimensional print, (4) varying thickness of soft tissue over bony landmarks, (5) photographs were not sharp enough to allow accurate identification of some landmarks.

Farkas concludes that in spite of the shortcomings of photogrammetry, the application of standard photographs in medical assessment is of great importance. The usefulness of this technique can be increased by developing new techniques to indicate landmarks obscurred by hair. Also the number of reliable measurements will be increased if additional special views of the face are developed.

The next step in photographic analyses was the use of

stereophotogrammetry. The object of stereophotogrammetry has been concisely described by Hertzberg, Dupertuis and Emmanuel (1957). "The basic principle of stereophotogrammetry is exactly that of binocular vision. The two eyes send slightly different images of an object to the brain, where they are interpreted in terms of depth as well as of length and breadth. Similarly, if two binocular or stereophotographs of an object are juxtaposed so that the left eye sees the left photograph and the right eye sees the right photograph in proper relation, the perception of depth can be as clear as if the object were seen directly". [89] Stereo images provide a means of creating a spatial model of the object, thus the face could be measured in three dimensions. A stereometric camera is used to take overlapping photographs, from slightly different perspectives, to create a stereo pair. The images are then oriented onto a stereo plotting device. The operator sees a three dimensional optical model of the two photographs. A contour map with Cartesian coordinates (x, y, z) of a point on the face can be compiled by varying the elevation to correspond with the contour interval. [90]

The stereophotogrammetric technique was first introduced to medicine and dentistry by Mannsback in 1922. [91] Zeller (1939) published a contour map of a man's face using a 40cm. base Wilde stereo camera and an A-4 Wild autograph plotting machine. [92]

Thalmann Degan (1944) recorded serial stereo pairs of facial photographs using a stereometric camera, of a baby with Pierre Robin Syndrome and for an adult with facial assymetry. The stereophotographs were then plotted with a terrain plotter to create contour maps of the faces. [93]

16

Bjorn, Lundquist and Hjelmstrom (1954) utilized a Wild stereocamera to investigate post operative swellings by means of an automatic planemeter attached to the plotting machine. [94] Savara (1965) using a Graflex camera, recorded facial contours and claimed an accuracy of .02mm on a "kelsh" plotter. [95]

Burke and Beard (1965, 1967) used a dual purpose stereocamera and plotting machine to monitor growth changes of individuals. The subjects were carefully orientated using ear rods and the Frankfort horizontal as references. Growth changes were calculated on volumetric change of the plotted regions. [96]

In 1971, Burke investigated normal facial assymetry in children using the dual purpose stereocamera and plotting machine again. Records were collected on 24 pairs of like sexed twins of varying ages. A range of normal assymetry was calculated on the sample. Burke also looked at the reliability of this method and pointed out that posing error was eliminated in making linear measurements contained within the plot, but that any serial measurements related to an external three dimensional grid system are. Landmark identification was identified as a source of error, with the angles of mouth, and tip of nose being difficult to reliably identify. The standard deviation of linear distances in respect to repeat stereopairs of the same subject was 0.69mm, of which most (0.65mm) was related to plotting procedures. He thus concluded that better equipment was necessary. [71]

Following up in 1983, Burke, et. al., using more sophisticated equipment investigated surgical soft tissue change. By using an Apple II computer and digitizer, they were able to reduce the standard duration of

17

the x and y coordinates to about 0.20mm. Much better than the previous effort. [93]

This method was further advanced by Berkowitz and Cuzzi (1977), who used three stereometric cameras to give full coverage of the face and cranium, but the hair prevented plotting and had to be covered by a rubber cap, so that only an approximation of head shape was obtained. Expensive cameras and plotting machinery were required for this technique making it impractical. [97]

Savara, et. al. (1985) further applied the techniques of biostereometrics and state of the art computer graphics to a series of patients with craniofacial malformations. He proposed that this three dimensional technique be united with other sources such as computerized tomography, biplane cephalometry and digitized dental casts to form a composite data set. [98]

Having measured both the hard and soft tissue components of the head and face independently, other researchers have turned to identifying the relationships between the two. Using standard photographs and cephalograms, they sought to correlate their findings and come up with a composite hard to soft tissue analysis.

Eisenfield, et al (1975) [99] modified a computer program which displayed iconicaly a predicted face based on input from frontal photographs and posterior-anterior cephalograms. Included was a statistical correlation of relationships between hard and soft tissue landmarks. Their study tested the hypothesis that positional variation of elements of soft tissue face can be described from the position of a sufficient number of underlying skeletal landmarks which can be identified radiographically.

18

The data presented described only those measurementa for which significant correlation was found or measurements which helped to determine the basic makeup of the face. Other hard and soft tissue relationships were measured; but, because of small sample size (N=9) meaningful statistical information was not derived.

During this same period, Rabey (1971-1977) [100,101] formulated a "morphoanalysis" system to analyze craniofacial morphology in three planes of space. Based on his fixed relations theory, a recording machine called an analytic morphograph was developed to convert his theory into clinical practice. A sophisticated electronic pressure monitoring system was incorporated into the cephalostat that give a "zero reading" if both external acoustic meati are properly positioned, thus orienting the x and y coordinates. A third coordinator (z) is derived from a piece of lead shot affixed to the point "orbitale".

Standardized cephalograms and photographs were taken in the orthagonal frontal, lateral and basal views with grid films on 100 subjects. Subsequently, tracings were made and data fed into the computer to generate "analytic histomorphograms" which have a measure of central tendency and variation. A consideration of error is mentioned and based on "analytic validity", which meant that each step of the complex process was carried out correctly.

In the past 15 years, an increasing number of operations have been undertaken for the treatment of facial deformity as well as for esthetic concerns. The need for more accurate prediction of the surgical outcome has become very important. [102] Many studies have been undertaken to document soft tissue response to hard tissue remodeling, via surgical

19

procedures [10,14,15,16,103,104] and orthodontic treatment. (1,13,53,106)

Paulus (1979) developed what he referred to as new photographic template technique. It produces a positive-negative black and white print of the patient's face on transparent print film. Superimposition of the two transparancies (photographic and radiographic) is facilitated using lead markers placed at orbitale and pogonion. There is no doubt that this technique aids in the visualization of soft and hard tissue relationships. (107)

A new technique, photocephalometry, was introduced by Hohl, Wolford, Epker and Fonseca (1978) as an attempt to aid in the prediction of surgical outcome. They studied three patients, using metallic markers affixed to the face. Standard lateral and anterior-posterior cephalograms were exposed as well as carefully oriented photographs of the face and lateral view. The cephalograms and photographs were superimposed using the metallic markers to determine hard-soft relationships, as well as surgical results. Sources of error were said to be under investigation. To summarize: the advantages of photo cephalometric technique are two-fold: (1) a more detailed visualization of soft tissue in the frontal and lateral views; (2) a more accurate analysis of hard to soft tissue relationships. Prediction remained to be seen. [108]

Fanibunda (1981) improved upon the previous methods by incorporating a graduated scale in the form of a metallic ruler in every photograph and radiograph. This enabled the photograph to be enlarged exactly the same as the radiograph. Using a Hasselblad camera on a movable tripod, he utilized a mirror target system to align the camera for

20

each exposure. Radiographic alignment was constant. There is no mention of the method of superimposition of soft and hard tissue exposures. [102]

In 1983, Fanibunda modified his method by permanently fixing the Hasselblad to the wall, so that its point of perspective was similar to that of the x-ray tube. Superimposition of exposures was accomplished using the surrounding cephalostat and markers as indices of alignment. [109]

It was not until 1984 that a study relating to errors of projection and landmark identification in photocephalometry was published, (Phillips et al). Their article reported on quantification of the two classes of error involved in the estimation of measurements from two dimensional images of three dimensional objects as cited by Baumrind and Franz (1971). As relating to photocephalometry, they were (1) the magnification and distortion errors involved in the superimposition of the photograph and cephalometric images; (2) the location errors of the lateral and frontal photographic and cephalometric landmarks. Utilizing a set up similar to Hohl et al (1978), standardized cephalograms and photographs were taken in the natural position with a 1cm stainless steel wire plexiglass grid locked into position. The sample included 12 adult females (19-31 years). The conclusions drawn were such that the differences in the enlargement factors between the photographic and radiographic images are of such magnitude that the superimposition of the two images is not feasible for absolute quantitative comparisons of soft and hard tissue anatomy. The largest differential of magnification was (5.8%) when looking at landmarks from sella forward. [110]

SUBJECTS AND SOURCE MATERIALS

The sample is cross-sectional and comprised of patients from The Oregon Health Sciences University Orthodontic Department. Materials on 30 subjects were collected as part of the pretreatment diagnostic workup.

Seventeen females (age range 11 years, 2 months to 15 years, 10 months) and 13 males (age range 11 years, 9 months to 15 years, 4 months).

The photocephalometric apparatus is an adaptation of the standard cephalometric set up first described by Broadbent (1931). This study incorporated a modified photocephalometric apparatus after Hohl and associates. [108] Instead of using an anterior-posterior cephalogram and a movable cameras, the posterior-anterior cephalogram was used and the camera mounted on the wall so that its point of perspective was exactly the same to that of the x-ray tube head, but opposite. The use of the "split image" viewing screen of the camera facilitated this step.

Several authors [111-113] recommend that 35mm photography is adequate for photocephalometric research. But since a 2-1/4" Hasselblad ELM5OO was available, it was used due to its well known superiority. The camera was equipped with an 85mm Carl Zeiss lens and a 15 ft. electronic cable release to eliminate camera movement during exposures. Plus-x-pan film was used and the entire camera and film were protected from scatter radiation during x-ray exposure with a lead lined box.

Photography is dependent upon light for proper exposure. Many lighting systems have been described. Due to space restrictions, it was necessary to use two 2300 degree K tungston lights in 10" aluminum reflectors mounted at 30 degree angles and approximately five feet from

22

the subject. A dual light source casts soft shadows which help convey depth of field. It should be noted that all of the apparatus used was firmly fixed to either the wall or the floor and, therefore, their relationships were constant throughout the data collection process.

As the subject was seated for the cephalometric exposures, 3 or 4 lead buttons were affixed to the forehead, zygomatic and/or chin areas with petroleum jelly. The patient was then placed in the cephalostat routinely. Prior to radiographic exposure, the photographic lights were turned on to acclimate the patient to the light. The patients were asked to relax their lips, swallow and keep their teeth together in occlusion. Two cephalometric exposures were made, lateral and frontal. Then within 10 seconds, the photographic exposure was made. Little more than 15 seconds separating posterior-anterior exposure and frontal photographic exposure. The same experienced x-ray technician made all exposures in the study. After development of the photographic negatives, enlargement was accomplished using an Ilford Multigrade 500-S diffusion enlarger. The negatives were each enlarged so that the metallic markers exactly matched the images on the cephalogram, a very tedious task.

ERROR ESTIMATION

This study utilizes both radiographs and photographs, therefore, consideration of the errors involved will be important to the interpretation of the results obtained. Several types of error must be accounted for, including measurement error, landmark identification, and technical errors.

The measurement and landmark error study consisted of replicate tracings made of the frontal cephalograms on two separate occasions one week apart. For the photographs, 8" x 10" acetate was utilized to trace relevant landmarks on each occasion. The two groups of data were fed into the computer. The printouts of the distance measurement were visually inspected for gross measurement error. In this manner, the landmark location points were checked for accuracy and remeasured if a difference of greater then $\pm$1mm was detected. (See Tables IA & IB) (pp. 47, 48)

As a measure of the error variance, we selected the formula after Dahlberg:

$$\text{S.E. Measure} = \sqrt{\frac{\Sigma D^2}{2 N}}$$

Technical errors such as projectional errors which include enlargement of the image due to subject film distance, and blurring of the image caused by penumbra effect and the intensifying screens, were all minimized by utilizing the same fixed x-ray apparatus. The enlargement factor for posterior-anterior cephalograms was calculated by Tan [114] in 1986 and found to be an average of 7.8% (range 7.1% - 8.8%) for points

24

anterior to sella. Further all exposures were made by the same radiology technician. Therefore, equipment variation is minimal, but head orientation errors may have resulted in a pose not truly posterior-anterior by definition.

Photography is also fraught with technical error. Equipment choice was made based on the experience of many authors as mentioned earlier. The resultant photographs demonstrated good even lighting that facilitated landmark identification. The enlargement process to print the photographs was a very tedious task and accounted for a number of subject dropouts.

Since an attempt was made to enlarge the prints to "life size", it was felt that absolute measurement would be of benefit. Linear distances were calculated of landmarks corresponding to both hard and soft tissues to determine if relationships exist. It is recognized that angular measures are a more reliable form of measure as compared to linear measures, because they remain constant regardless of enlargement factors. But, for the frontal view, few angles exist to compare hard and soft tissues.

LANDMARKS AND MEASUREMENT PROCEDURES

An outline of the relevant parts of the facial skeleton was traced on an 8" x 10" inch acetate tracing paper afixed to the radiograph. The following landmarks* were then identified on the film and recorded with a small pencil mark.

(1) center of orbit (co) (R&L)

(2) inner canthus (ic) (R&L)

(3) outer canthus (oc) (R&L)

(4) menton (me)

(5) gonion (go) (R&L)

(6) alare (ar) (R&L)

(7) subalare (sa)

(8) maxillary tuberosity (mtp) (R&L)

(9) distal aspect of central incisors (mc) (R&L)

Each lead marker was traced and utlilized to align the tracing to the photograph. Relevant soft tissue landmarks** were then traced onto the same sheet of acetate.

(1) pupil (P) R&L

(2) inner canthus (IC) R&L

(3) outer canthus (OC) R&L

(4) chelion (CH) R&L

(5) subalare (SA) R&L

(6) subnasale (SN)

(7) menton (ME)

(8) gonion (G0)

(9) alare (AR) R&L

One reference line, the H-line, was drawn connecting the centers of the pupils. All linear measurements were made either parallel or perpendicular to this line and recorded manually. All measurements were checked a second time for gross measurement error.

See Diagram 1 for landmark location on schematic cephalometric tracing.

*   See Appendix A for definition of hard tissue landmarks. (pg. 58)

**   See Appendix B for definitions of soft tissue landmarks. (pg. 59)

STATISTICAL ANALYSIS OF DATA

The following were computed from raw data on thirty subjects:

(1)   Means and standard deviations for hard and soft tissue linear
      measurements. (See Tables II A & B) (Pg. 49)

(2)   Pearson's linear correlation co-efficient (r) was computed for 11
      pairs of hard and soft tissue measurements, after checking scatter
      plots to determine linearity and homoscedasticity. (Table III) (pg. 50)

(3)   Linear regression was calculated with hard tissue measurements as
      the independent variable and soft tissue as the dependent variable in
      those instances were the coefficient of correlation was
      significant, $r \gtrsim 0.7$. (See Figures 3-7)

(4)   The Null Hypothesis is stated as:

      Ho: $r = o$ for hard tissue and soft tissue dimensions.
      Hi: $r = o$ for hard and soft tissue dimensions.

The Z-statistic was used to determine if r was statistically significant
with an å of 0.05, due to the sample size being >30.

Ten linear hard tissue dimensions were computed as shown on the list below. (See Table IIA) (pg. 49)

(1)	Total Face Height	(tfh)	H-line-me
(2)	Upper Face Height	(ufh)	H-line - sa
(3)	Lower Face Height	(lfh)	sa - me
(4)	Upper Face Width	(ufw)	oc - oc
(5)	Lower Face Width	(lfw)	go - go
(6)	Orbital Width	(ow)	ic - oc
(7)	Hard Tissue Pupil Width	(hp)	co - co
(8)	Maxillary Width	(mw)	mtp - mtp
(9)	Incisor Width	(iw)	mc - mc
(10)	Nasal Width	(nw)	ar - ar

Ten linear soft tissue dimensions were computed as shown on the list below. (See Table IIB) (pg. 49)

(1)	Total Face Height	(TFH)	H-line - ME
(2)	Upper Face Height	(UFH)	H-line - SN
(3)	Lower Face Height	(LFH)	SN - ME
(4)	Upper Face Width	(UFW)	OC - OC
(5)	Lower Face Width	(LFW)	GO - GO
(6)	Palpebral Width	(PW)	IC - OC (R)
(7)	Pupil Width	(W)	P - P
(8)	Lip Length	(LL)	CH - CH
(9)	Nasal Base Width	(NBW)	SA - SA
(10)	Nasal Width Outer	(NW)	A - A

RESULTS

Three tables were compiled from the data obtained in this study:

Tables IA and IB present the calculated measurement errors on the twenty facial dimensions based on cephalometric and photographic data. The findings reflect that the sources of errors of measurement were fairly equal for both cephalometric and photographic data. All of the cephalometric measures were within $^\circ$ 0.5mm margin of error allowed. In the same regard, the percentage of error was well below 2% in all cases.

One measurement in the photogrammetric data was unsatisfactory in regard to error. This was nasal base width (NBW) with a standard error of the measure of 0.36mm (within the $\pm$ 0.5mm limits) and a percentage error of 2.6%. It is felt that this discrepancy exists due to the small magnitude of the dimension in question and the difficulty in accurately identifying the landmarks subnasale.

Tables IIA and IIB present the means and standard deviations for the twenty cephalometric and photogrammetric dimensions. It should be noted that variability for each measure in hard and soft tissues was quite similar. (ie: tfh S.D.: 6.80, TFH S.D.: 6.74)

Table III lists the correlation coefficient between hard tissue and their corresponding soft tissue dimensions. The r-values demonstrated a wide range of values (á = .183 - .909). There were no negative values for r as one might expect. Four dimensions demonstrated high r values. These were:

(1)	Hard tissue pupil width to pupil width	r = .909
(2)	Total face height (hard) to Total face height (soft)	r = .839
(3)	Upper face width (hard) to Upper face width (soft)	r = .843
(4)	Lower face height (hard) to Lower face height (soft)	r = .754

In addition, one dimension demonstrated a moderate r value for soft and hard tissue, this was lower face width hard and soft (r = .609)

Generally, those hard and soft tissue dimensions demonstrating moderate and higher r values tested by way of the Z-statistic to be significantly different from zero at the 0.05 probability level.

31

Figures 3 through 7 illustrate the linear regression plots on those dimensions where $r \geq .6$. The independent variables used were hard tissue dimensions where the dependent variables were of soft tissue measures. By knowing a hard tissue dimension, one could predict the soft tissue dimension within the standard error of the estimate.

DISCUSSION

Photocephalometry is a method that incorporates the use of standardized photographs with the cephalometric radiographs usually taken in the examination of the orthognathic surgery or orthodontic patient. Facial photographs are a standard exam procedure for these types of patients; however, photocephalometry represents an additional step in that the standardized photographs are enlarged to allow for direct comparison with the radiograph. This technique could be utilized for assessment of facial deformities, not only to select the appropriate treatment modalities, but also to compare the degree of soft tissue movement produced after alteration of the bony contours by a known amount.

This study utilized a photocephalometric apparatus that was modified after Hohl and associates. [108] The modifications made included changing the perspective of the source of x-rays and permanently mounting all apparatus. This modification was made to reduce the differential magnification of the hard and soft tissues in their respective formats. According to data published by Phillips et al [110], the apparatus as used by Hohl and associates was subject to as much as 9% enlargement differential between cephalometric and photographic data. Utilizing the Phillips study as a guide, the current study was designed to keep the enlargement differential down to approximately 5.5%, however, this was not tested.

The frontal analysis, based on photographic data, appears to suffer from the same types of errors as other analyses. In the present sample, where the selected soft tissue anatomical points were not pre-identified by marks on the subjects' faces prior to photography, the uncertainty on the observer's part to locate some of those points resulted in some inconsistency in measurement. Although the observer is not sure if pre-marking the landmarks would have made much difference. Some soft tissue landmarks (ie: GO) were located using the hard tissue as a reference, by way of overlaying the hard tissue tracing onto the photograph.

Previous studies on similar subjects utilizing photography as an anthropometric tool have all recommended landmark identification prior to photography to facilitate accurate measurement. [73,74,87] In these studies, photography was used as a supplement, rather than as a full partner in data collection. Anthropologists have

33

refrained from using the photographic record in the past because the accuracy of the format has been doubted. Measurement must be restricted to those dimensions that run parallel to the photographic negative, otherwise mismeasurement results in those instances where the landmarks lie in the plane perpendicular to the photographic emulsion. Also, the rendition of a clear image is dependent upon a number of variables such as lens-subject distance, lighting, a constant principle plane of focus, posing, and film idiosyncrasies.

In the photographic technique employed for this study, the number of variables listed above were kept as constant as possible. The areas of greatest variation include posing and lighting. The cephalometer minimized posing error, but rotation about the ear rods is possible. In regard to lighting, the set up remained the same throughout data collecting. The observer noted that those subjects with fair skin could have been photographed with less light and those with darker skin could have benefitted from more light. Therefore, ideally, each subject should have been tested with a light meter prior to exposure.

The process of matching the photographic print to the radiograph using the metallic markers was, as mentioned earlier, a difficult task. Many prints were made of each subject until the exact enlargement was accomplished. In several cases, exact enlargement was not accomplished as superimposition of the markers was never achieved. The enlargement process would have been much easier if the subjects' faces had filled the photographic frame more. Due to limitation of equipment choices, an 85mm focal length lens was used when a better choice would have been a 150mm focal length lens. This would have reduced the lens-film distance in the enlarging process from 6-1/2 feet to about 3 feet. As was noted earlier, this step accounted for several subject dropouts and should be modified as detailed here.

It was the objective of this study to determine if significant correlation exists between corresonding hard and soft tissue landmarks in the frontal view to be of use in surgical and orthodontic prediction. Conclusions of this nature are dependent upon the landmarks chosen and their relative reliability in location. Many of the popular lateral cephalometric landmarks are not available on the frontal view due to obscuring from overlapping structures. For instance, the most likely landmark for defining the

upper limit for face height would have been Nasion; this landmark, however, is neither distinguishable in frontal radiographs or facial photographs. The alternate selected, a line drawn through the center of the pupils seems to have sufficed nicely, both in terms of easy location and reliability. Remaining landmarks were chosen with regard to proximity of hard and soft tissues and their ease of location. In addition, an understanding of individual morphologic variations affecting the determination of certain landmarks is of primary importance for cross-sectional studies. Any shortcomings in this respect would be reflected in the results of this study.

Consideration of reliability and repeatability of measurements to be compared must also be dealt with. Strangely enough, despite and perhaps due to the plethera and variety of measurements made of the living, there are very few reports of their reliability. This is one of the reasons for the long continued difficulty in gaining agreement as which measurements are preferable. The only study found was that by Phillips et al on 12 subjects. They reported an absolute mean error of less than or equal to 2mm for 57% of their frontal landmarks. In comparison, it would appear that the mean errors depicted in Table IB were well within those limits.

The results of this study appear to corroborate the earlier investigation by Eisenfeld et al . [99] For instance, they found a correlation coefficient for soft tissue pupil width and hard tissue pupil width of $r = 0.93$. (current study $r = 0.91$) Other correlations were found to be similar. A comparison of dimensional was not possible as they divided all measurements by total face height, thus, their data was presented in a ratio format.

Of the 11 correlations determined, 5 were greater than $r = 0.6$. It was felt that some predictive value may exist, therefore, regression analysis was performed and the plots presented in Figs. 3 - 7.

As the sample was fairly homogeneous in nature, the author feels that a followup study of these same subjects may shed some light on maturational changes and their effect on the dimensions of the tissues involved.

35

SUMMARY AND CONCLUSIONS

A method called photocephalometry was used to determine if significant correlation exists between selected hard and soft tissue landmarks of the face. The measurements were made from posterior-anterior cephalograms and oriented photographs taken at about the same time of 30 subjects in a cross-sectional sample.

Significant correlations ($p = .05$) were found between the following landmarks.

(1)	hard tissue pupils - soft tissue pupils	$r = .909$
(2)	upper face width (hard)- upper face width (soft)	$r = .843$
(3)	total face height (hard) - total face height (soft)	$r = .839$
(4)	lower face height (hard) - lower face height (soft)	$r = .734$
(5)	lower face width (hard) - lower face width (soft)	$r = .609$
(6)	upper face height (hard) - upper face height (soft)	$r = .436$
(7)	maxillary width - lip length	$r = .417$

In the context of surgical and orthodontic prediction, only those correlations > 0.7 may be useful. However, subtle changes in frontal soft tissues can be compared before and following surgery or orthodontic treatment and for serial growth study.

BIBLIOGRAPHY

1) Hambleton RS: Soft tissue covering of the skeletal face as related to orthodontic problems. Amer J Orthod, 50:405-420, 1964.

2) Downs WB: Variations in facial relationship: Their significance in treatment and prognosis. Amer J Orthod, 34:812-840, 1948.

3) Downs WB: Analysis of the dentfacial profile. Angle Orthod, 26: 191-212, 1956.

4) Subtelney JD: A longitudinal study of soft tissue facial structures and their profile characteristics, defined in relation to underlying skeletal structures. Amer J Orthod, 45:481-507, 1959.

5) Peck H, Peck S: A concept of facial esthetics. Angle Orthod, 40:284-317, 1970.

6) Burstone CJ: The integumental profile. Amer J Orthod, 44:1-25, 1958.

7) Burstone CJ: Lip posture and its significance to treatment planning. Am J Orthod, 45:262-284, 1957.

8) Burstone CJ: Integumental contour and extension patterns. Am J Orthod, 29:93-104, 1959.

9) Poultan DR: Facial esthetics and angles. Angle Orthod, 27:133-137, 1957.

10) Bell W, Dam III JJ: Correction of dentofacial deformities by surgery in the anterior part of the jaws. A study of stability and soft tissue changes. Am J Orthod, 64:162-187, 1974.

11) Bloom LA: Perioral changes in ortho treatment. Am J Orthod, 47:371-379, 1961.

12) Rudee LA: Proportional profile changes concurrent with orthodontic therapy. Am J Orthod, 50: 421-434, 1964.

13) Garner LD: Soft tissue changes concurrent with orthodontic tooth movement. Am J Orthod, 66:367-377, 1974.

14) Lines PA, Steinhauser EW: Soft tissue changes in relationship to movement of hard structures in orthognathic surgery. A preliminary report. J Oral Surg, 32:891-896, 1982.

15) McDonnel, McNiel: Advancement genioplasty: A retrospective cephalometric analysis of osseous and soft tissue changes. J Oral Surg, 35:640, 1977.

16) Radney L, Jacobs J: Soft tissue changes associated with surgical total maxillary intrusion. Am J Orthod, 80:191-212, 1981.

17) Bradbent BH: The face of the normal child. Angle Orthod, 7:183-208, 1937.

18) Lande MJ: Growth behavior of the human boney facial profile as revealed by serial cepahlometric roentgenology. Angle Orthod, 22:78, 1952.

19) Brodie AG: Late growth changes in the human face. Angle Orthod, 23:146, 1952.

20) Wylie WL: The assessment of anterior-posterior dysplasia. Angle Orthod, 17:97-109, 1947.

21) Ricketts RM: Planning tretment on the basis of the facial pattern and an estimate of its growth. Angle Orthod, 27:14-37, 1957.

22) Riedel RA: An analysis of dentofacial relationships. Am J Orthod, 43:103-119, 1957.

23) Mulick JF: Clinical use of the frontal headfilm. Angle Orthod, 35:299-304, 1965.

24) Hrdlicka A: Practical Anthropometry. The Wister Institute of Anatomy and Biology, Philadelphia, 1939.

25) Broadbent BH; A new x-ray technique and its application to orthodontia. Angle Orthod, 1:45-66, 1931.

26) Brodie AG: Growth pattern of the human head from the third month to the eighth year. Am J Anat, 68:209-262, 1941.

27) Maves TW: Radiology of the temperomandibular articulation with correct registration of vertical dimension for reconstruction. J Am Dent Assoc and Dental Cosmos, 25:585, 1938.

28) Sassouni V: Roentgenographic cephalometric analysis of cephalofaciodental relationships. Am J Orthod, 41:734-764, 1955.

29) Steiner CC: Cephalometrics in clinical practice. Angle Orthod, 29:8-29, 1959.

30) Tweed C: The diagnostic facial triangle in the control of treatment objectivity. Am J Orthod, 55:651-667, 1969.

31) Holdaway R: Changes in the relationships of points A and B. Am J Orthod, 42:176-193, 1956.

32) Moore AW: Cephalometrics as a diagnostic tool. Am Dent Assoc, 82:775-781, 1971.

33) Ricketts RM: Perspectives in the clinical application of cephalometrics - the first 50 years. Angle Orthod, 41:115-150, 1981.

34) Davis WB: Anatomy of the nasal accessory sinuses in infancy of childhood. Ann Otol Rhin Laryn, 27:940, 1918.

35) Potter JW, Meredith HV: A comparison of two methods of obtaining bi-parietal and bi-gonal measurements. J Dent Res, 27:459-466 1948.

36) Wylie WL, Elasser, WA: Undistorted vertical projection of the head from lateral and posterior-anterior roentgenograms. Am J Roentgenology, 60:414-417, 1948.

37) Woods G: Changes in width dimensions between certain teeth and facial points during human growth. Am J Orthod, 36:676-700, 1950.

38) Harvold E: Cleft lip and palate. Am J Orthod, 40:493-506, 1954.

39) Subtelny JD: Width of the nasopharynx and related anatomic structures in normal and unoperated cleft palate children. Am J Orthod, 41:889-909, 1955.

40) Gerald & Silverman: Normal and Abnormal Interorbital Distances With Special Reference to Mongolism. Am J Roentgen, 95:154-161, 1965.

41) Owen AH: Frontal facial changes with the Frankel Appliance. Angle Orthod, 58:257-286, 1988.

42) Sassouni V: Archial analysis in 3-dimensions. Am J Orthod, 44:443-463, 1958.

43) Berger H: Progress with basilar view cephalograms. Trans Eur Orthod, 40:159-164, 1964.

44) Nahoum HI, Fiasconaro J, Disalvo NA: The vertico-submental roentgenogram in cephalometrics. J Am Dent Assoc, 69: 132-150, 1964.

45) Savara BS: The role of computers in dentofacial research and the development of diagnostic aids. Am J Orthod, 61:231-244, 1972.

46) Kaban LB, Mulliken JB, Murray JE: Three dimensional approach to analysis and treatment of hemifacial microstomia. Cleft Pal J, 18:90-97, 1981.

47) Grayson BH, McCarthy JG, Bookstein F: Analysis of craniofacial asymmetry by multiplane cephalometry. Am J Orthod, 84:217-224, 1983.

48)   Baumrind S, Moffitt FH, Curry S: Three dimensional x-ray
        stereometry from paired co-planar images - a progress report.
        Am J Orthod, 84:292-312, 1983.

49)   Vogel CJ: Correction of frontal dimensions from head x-rays.
        Angle Orthod, 37:1-8, 1967.

50)   Jacobson, A: Psychological aspects of dentofacial esthetics and
        orthognathic surgery. Angle Orthod, 54:18-35, 1984.

51)   Case C: A practical treatise on the techniques and principles of
        Dental Orthopedia and prosthetic correction of cleft palate.
        2nd Edition, C.S. Case Company, Chicago, 1921.

52)   Holdaway R: A soft tissue cephalometric analysis and its use in
        orthodontic treatment planning, Part I. Am J Orthod, 84:1-28, 1983.

53)   Riedel RA: Esthetics and its relation to orthodontic therapy.
        Angle Orthod, 20:168-178, 1950.

54)   Cox NH, VanderLinden FP: Facial Harmony. Am J Orthod,
        60:175-183, 1971.

55)   Foster E: Profile preferences among diversified groups. Angle
        Orthod, 43:34-40, 1973.

56)   Negar M: A quantitative method for evaluation of the soft tissue
        facial profile. Am J Orthod, 45:738-751, 1959.

57)   Legan H, Benstone C: Soft tissue cephalometric analysis for
        orthognathic surgery. J Oral Surg, 38:744-751, 1980.

58)   Salzmann JA (Editor): Roentgenographic cephalometrics -
        Proceddings of the 2nd workshop conducted by the special
        committee of the American Association of Orthodontics.
        J.B. Lippincott Co., 1961.

59)   Subtelny JD: The soft tissue profile, growth and treatment changes.
        Angle Orthod, 31:105-122, 1961.

60) Nakajima E, Yanagisawa M: The Japanese sense of beauty and facial proportions. Quint Int, 16:553-557, 1985.

61) Brodie AG: Facial patterns - a theme on variation. Angle Orthod, 16:75-87, 1946.

62) Farkas LG: <u>Anthropometry of the head and face in medicine.</u> Elswier, North and Holland, Inc., 1981.

63) Stewart TD: <u>Essentials of Forensic Anthropology.</u> Chap. 14 - Reconstruction of facial soft parts. Pgs. 255-274, Charles C. Thomas, Publisher, 1979.

64) Elsasser W: Studies of dento-facial morphology. Angle Orthod, 21:163-171, 1951.

65) Farkas LG, Munro IR, Kolar JC: Abnormal measurements and disproportions in the face of Down's Syndrome patients: preliminary report of an anthropometric study. Plast Recon Surg, 75:159-167, 1985.

66) Farkas LG, Ross RB, James JS: Anthropometry of the face in lateral facial dysplasia - the bilateral form. Cleft Pal J, 14:41-51, 1977.

67) Farkas LG, Lindsey WK: Ear morphology in cleft lip and palate anomoly. Arch Oto-Rhino-Laryng, 206:57-68, 1973.

68) Farkas LG, Lindsey WK: Morphology of the orbital region in adults following cleft lip repair in childhood. Am J Phys Anthrop, 37:65-75, 1972.

69) Farkas LG, Lindsey WK: Morphology of adult face following repair of bilateral cleft lip and palate in childhood. Plast Recon Surg, 47:25-32, 1971.

70) Farkas LG, et. al.: Anthropometric proportions in the upper lip - lower lip – chin area of the lower face in young white adults. Am J Orthod, 86:52-60, 1984.

71) Burke PH: Stereophotogrammetric measurement of normal facial assymetry in children. Hum Biol, 43:536-548, 1971.

72) Sheldon WH, Stevens SS, Tucker WB: <u>The varieties of the human physique.</u> Harper and Bros., New York, 1940.

73) Tanner JM, Weiner JS: The reliability of the photogrammetric method of anthropommetry. Am J Phys Anthrop, 7:145-186, 1949.

74) Farkas LG, Bryson W, Klotz J: Is photogrammetry of the face reliable. Plas Recon Surg, 66:346-355, 1980.

75) Ferris HC: Original photographic studies of orthodontic cases. Int J Orthod, 13:627-632, 1927.

76) Jackson AF: Facts, fictions and fallacies in orthodontia. Am J Orthod, 23:1073-1095, 1937.

77) Weinberger BW: An introduction to the history of dentistry in America. Vol II, pg. 349, C.V. Mosby Co., St. Louis, 1948.

78) Stoner MM: A photometric analysis of the facial profile: A method of assessing facial change induced by orthodontic treatment. Amer J Orthod, 41:453-469, 1955.

79) Sushner NI: A photographic study of the soft tissue profile of the negro population. Am J Orthod, 72:373-385, 1977.

80) Broadbent TR, Mathew VL: Artistic relationship in surface anatomy of the face: application to reconstructive surgery. Plast Recon Surg, 20:1-17, 1957.

81) Belinfante LS: Total treatment planning for esthetic problems of the face: a team approach. J Oral Surg, 37:178, 1979.

82) Patterson CN, Powell DG: Facial analysis in patient evaluation for physiologic and cosmetic surgery. Laryngoscope, 84:1004, 1974.

83) Seghers MJ, Longacre JJ, Destefano, GA: The golden proportion and beauty. Plast Recon Surg, 34:382, 1964.

84) Gonzales-Ulloa M: Quantitative principles in cosmetic surgery of the face (profiloplasty). Plast Recon Surg, 29:186, 1962.

85) Farkas LG, Hreczko T, Kolar J, Munro I: Vertical and horizontal proportions of the face in young adult North American caucasions: revision of neoclassical canons. Plast Recon Surg, 75:328, 1985.

86) Ainsworth, et.al: Numerical evaluation of facial pattern in children with isolated pulmonary stenosis. Arch Dis Child, 54:662, 1979.

87) Gavan JA, Washburn SL, Lewis PH: Photography: an anthropometric tool. Am J Phys Anthrop, 10:331-351, 1952.

88) Frasier F, Pashayan H: Relation of face shape to susceptibility to congenital cleft lip. A preliminary report. J Med Genet, 7:112, 1970.

89) Hertzberg HTE, Duperituis CW, Emmanuel I: Stereophotogrammetry as an anthropometric tool. Photogrammetric Eng, 23:942-947, 1957.

90) Cuzzi Je, Herron RE, Bender MJ: Symposium on close-range photogrammetry. Sponsored by Am Soc of Photogrammetry, pp. 79-84, 1971.

91) Mannsbach M: Die Stereophotogrammetrie als Hiffsmittel in der Orthodontie. Deutsche Ztshi Zahn Orthopadie, 14:105, 1922.

92) Zeller M: Textbook of Stereophotogrammetry, (translated by E.A. Miskin), H.K. Lewis and Co., Ltd., London, 1952.

93) Burke PH, BanksPA, Beard LFH, Tee J, Hughs C: Stereo photographic measurement of change in facial soft tissue morphology following surgery. Brit J Ortho, 21:237-245, 1983.

94) Bjorn H, Lundquist C, Hjelmstrom P: A photogrammetric method of measuring the volume of facial swellings. J Dent Res, 33:295-308, 1954.

95)   Savara BS: Applications of photogrammetry for quantitative study
        of tooth and face morphology. Am J Phys Anthrop, 23:427-434,1965.

96)   Burke PH, Beard LFH: Stereophotogrammetry of the face. Am J
        Orthod, 53:769-782, 1967.

97)   Berkowitz S, Cuzzi J: Biostereometric analysis of surgically
        corrected abnormal faces. Am J Orthod, 72:526–538, 1977.

98)   Savara BS, et. al.: Biostereometrics and computergraphics for
        patients with craniofacial malformations: diagnosis and treatment
        planning. Plast Recon Surg, 75:495-501, 1985.

99)   Eisenfield J, Mishelevich DJ, Dann JJ, Bell WH: Soft-hard tissue
        correlation and computer drawings for the frontal view. Angle
        Orthod, (4)45:267-271, 1975.

100)   Raby GP: Current Principles of Morphanalysis and their implications
        in oral surgical practice. Brit J Oral Surg, 15:97-109, 1977.

101)   Raby GP: Morphanalysis of Craniofacial Dysharmony. Brit J Oral
        Surg, 15:110-120, 1977.

102)   Fanibunda KB: Facial photoradiography: practical considerations.
        J Audiovisual Media in Med, 4:95-98, 1981.

103)   Schendel S, et. al.: Superior repositioning of the maxilla, stability
        and soft tissue osseous relations. Am J Orthod, 70:663-674, 1976.

104)   Hunt NP, Rudge SJ: Facial profile and orthognathic surgery.
        Brit J Orthod, 11:126-136, 1984.

105)   Fromm B, Lundberg S: The soft tissue facial profile before and after
        surgical correction of mandibular protrusion. Acta Orthod Scand,
        28:158-177, 1972.

106)   Lines PA, Lines RR, Lines CA: Profile metrica and facial esthetics.
        Am J Orthod, 73:648-657, 1978.

107) Paulus PJ: Photographic templates (the positive-negative technique). Amer J Orthod, (1)76:67-69

108) Hohl TH, Wolford LM, Epkir BN, Fonseca RN: Craniofacial Osteotomies: A Photocephalometric Technique For The Prediction and Evaluation of Tissue Changes. Angle Orthod, 48:114-125, 1978.

109) Fanibunda KB: Photoradiography of facial structures. Brit J Oral Surg, 21:246-258, 1983.

110) Phillips C, Greer J, Vig P, Matteson S: Photocephalometry: Errors of projection and landmark location. Am J Orthod, (3)86:233-243, 1984.

111) Davidson TM: Photography in facial plastic and reconstructive surgery. J Biol Photog, 47:59, 1979.

112) Dickason WL, Hanna PC: Pitfalls of comparative photography in plastic and reconstructive surgery. Plast Recon Surg, 58:166, 1976.

113) Morello DC, Converse JM, Allen D: Making uniform photographic records in plastic surgery. Plast Recon Surg, 59:366, 1977.

114) Tan V: A preliminary investigation into possible correlation between frontal cephalometric and photographic indices. Certificate thesis, The Oregon Health Sciences University, 1986.

TABLE IA

Computation results for measurement errors expressed as standard error of the measure and percentage error.

I.   Cephalometric Data

	Facial Dimension	S.E. Meas. (mm)*	Percentage Error**
(1)	Total Facial Height (tfh)	.31	0.3%
(2)	Upper Facial Height (ufh)	.50	1.29%
(3)	Lower Facial Height (lfh)	.31	0.5%
(4)	Upper Facial Width (ufw)	.48	0.5%
(5)	Lower Facial Width (lfw)	.24	0.3%
(6)	Orbital Width (ow)	.18	0.5%
(7)	Hard Pupils (hp)	.34	0.6%
(8)	Maxillary Width (mw)	.25	0.5%
(9)	Incisor Width (iw)	.23	1.3%
(10)	Nasal Width (nw)	.31	1.1%

*   S.E. Meas. = Standard error of the measure calculated by the formula

$$\sqrt{\frac{\Sigma D^2}{2N}}$$

Where:

D = Difference between replicate measurements
N = Number of scores

**   Percentage error expressed as the ratio of S.E. Meas. to the mean value for the first measurements in the standard error calculation.

TABLE IB

I. Photographic Data

	Facial Dimension	S.E. Meas. (mm)*	Percentage Error**
(1)	Total Facial Height (TFH)	.33	0.3%
(2)	Upper Facial Height (UFH)	.48	1.1%
(3)	Lower Facial Height (LFH)	.38	0.6%
(4)	Upper Facial Width (UFW)	.44	0.5%
(5)	Lower Facial Width (LFW)	.48	0.4%
(6)	Palpebral Width (PW)	.27	0.9%
(7)	Pupil Width (W)	.11	0.2%
(8)	Lip Length (LL)	.43	1.0%
(9)	Nasal Base Width (NBW)	.38	2.6%
(10)	Nasal Width (NW)	.36	1.0%

* S.E. Meas. = Standard error of the measure calculated by the formula.

$$\sqrt{\frac{\sum D^2}{2N}}$$

Where:

D = Difference between replicate measurements
N = The number of scores.

** Percentage error expressed as the ratio of S.E. Meas. to the mean value for the first measurements in the error calculation.

48

TABLE IIA

Hard Tissues

		Mean	Standard Deviation
(1)	tfh	102.7	6.80
(2)	ufh	38.58	2.76
(3)	lfh	63.50	6.56
(4)	ufw	92.98	5.94
(5)	lfw	95.17	6.77
(6)	ow	34.43	1.87
(7)	hp	58.0	3.07
(8)	mw	55.53	6.69
(9)	iw	17.45	1.67
(10)	nw	27.78	2.63

TABLE IIB

Soft Tissue

		Mean	Standard Deviation
(1)	TFH	108.52	6.74
(2)	UFH	43.90	3.51
(3)	LFH	64.55	5.34
(4)	UFW	90.08	4.50
(5)	LFW	107.32	8.17
(6)	PW	28.93	2.10
(7)	W (pup)	59.37	3.27
(8)	LL	43.23	4.43
(9)	NBW	14.08	1.98
(10)	NW	35.52	2.95

TABLE III

LINEAR CORRELATION BETWEEN CORRESPONDING
CEPHALOMETRIC AND PHOTOGRAPHIC LINEAR MEASUREMENTS

Cephalometric vs. Photographic Measure	Pearson's r	Z Value*	å = .05
(1) Total Face Height (tfh, TFH)	.839	4.52	Reject Ho
(2) Upper Face Height (ufh, UFH)	.436	2.35	Reject Ho
(3) Lower Face Height (lfh, LFH)	.734	3.95	Reject Ho
(4) Upper Face Width (ufw, UFW)	.843	4.54	Reject Ho
(5) Lower Face Width (lfw, LFW)	.609	3.24	Reject Ho
(6) Orbital Width, Palpebral Width (ow, PW)	.329	1.77	Accept Ho**
(7) Hard Tissue Pupil Width, Pupil Width (co,W)	.909	4.90	Reject Ho
(8) Maxillary Width, Lip Length (mw,LL)	.417	2.25	Reject Ho
(9) Maxillary Incisor Width, Lip Length (iw,LL)	.183	.99	Accept Ho**
(10) Lower Face Width, Lip Length (flw, LL)	.343	1.85	Accept Ho**
(11) Skeletal Nasal Width, Nasal Width (nw,NW)	.198	1.06	Accept Ho**

* Z-statistic used due to N>30.

** Accept Null Hypothesis: Correlation is not significantly different from zero.

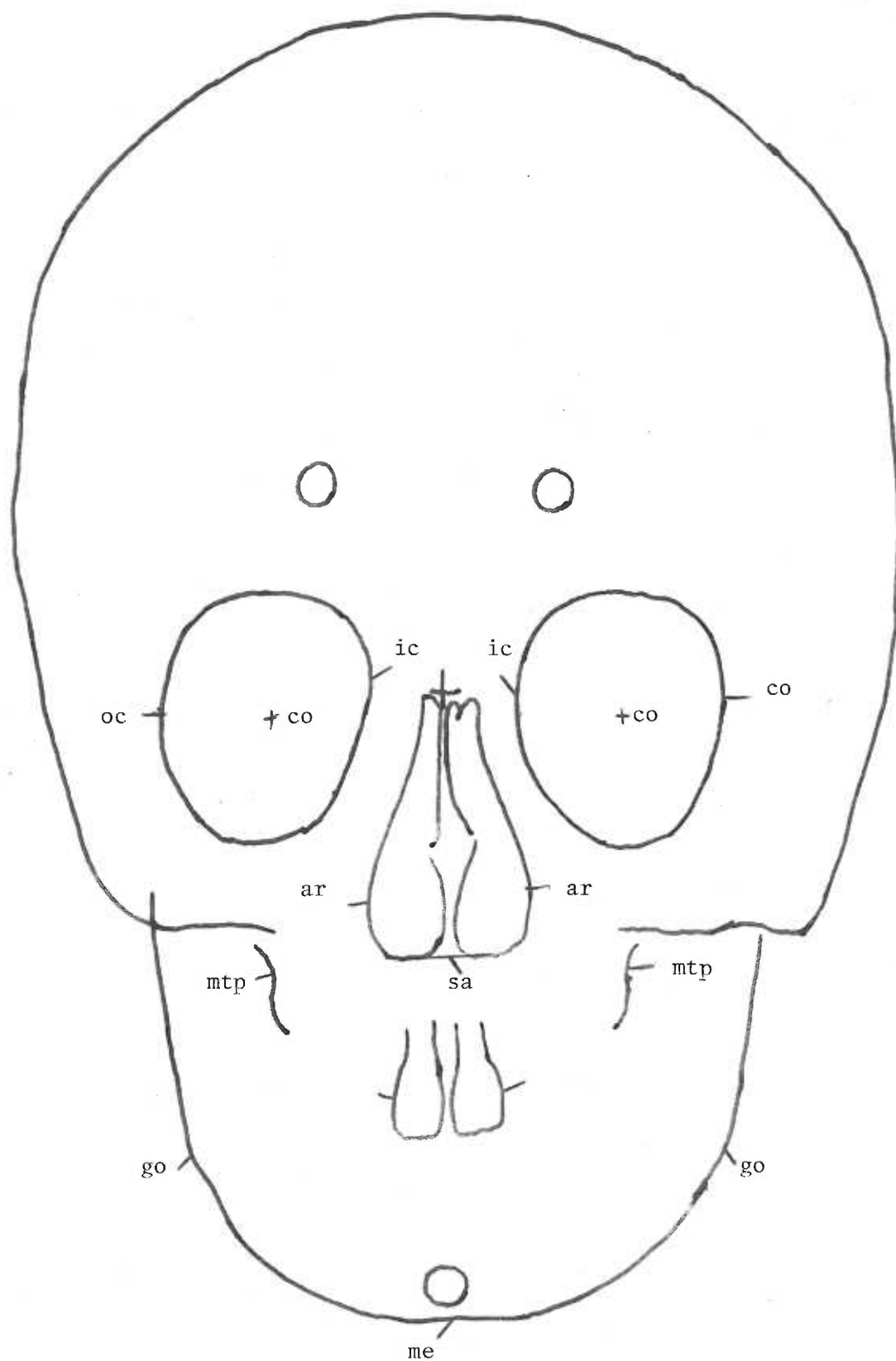FIGURE 1

Landmark Location On Frontal Cephalogram

51

Figure 3

Linear regression analysis for hard tissue total face height (tfh) as the independent variable and soft tissue total face height (TFH) as the dependent variable.
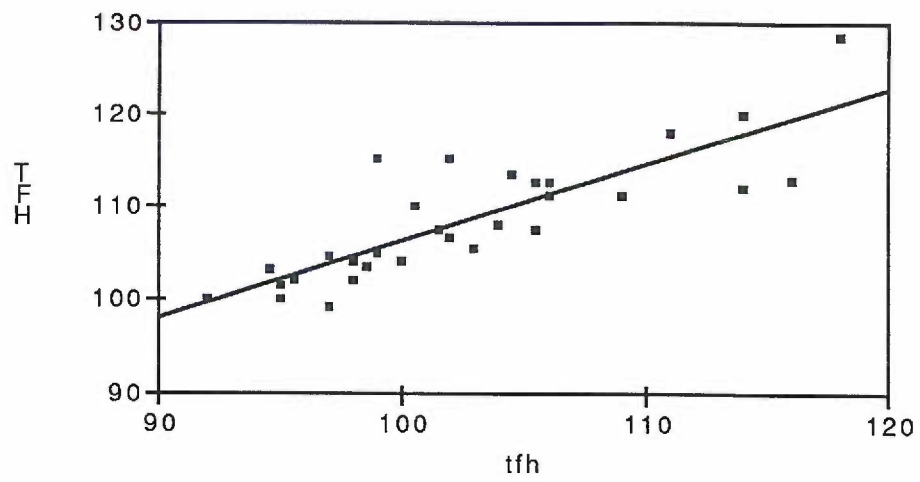
Figure 4

Linear regression analysis for hard tissue lower face height (lfh) as the independent variable and soft tissue lower face height (LFH) as the dependent variable.
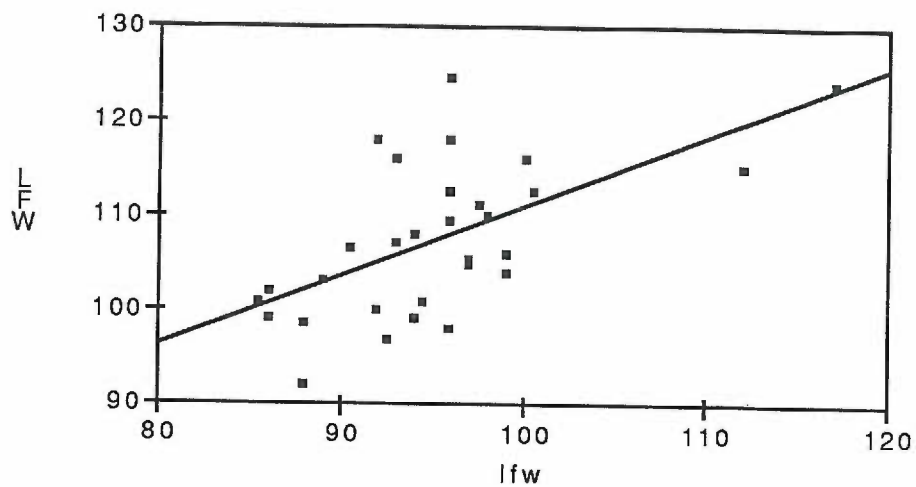
Figure 5

Linear regression analysis for hard tissue upper face width (ufw) as the independent variable and soft tissue upper face width (UFW) as the dependent variable.
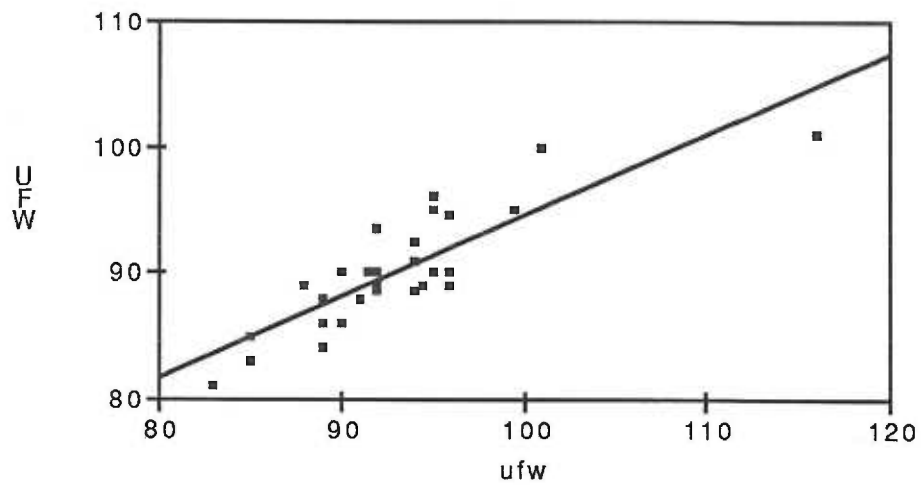
Figure 6

Linear regression analysis for hard tissue lower facial width (lfw) as the independent variable and soft tissue lower facial width (LFW) as the dependent variable.
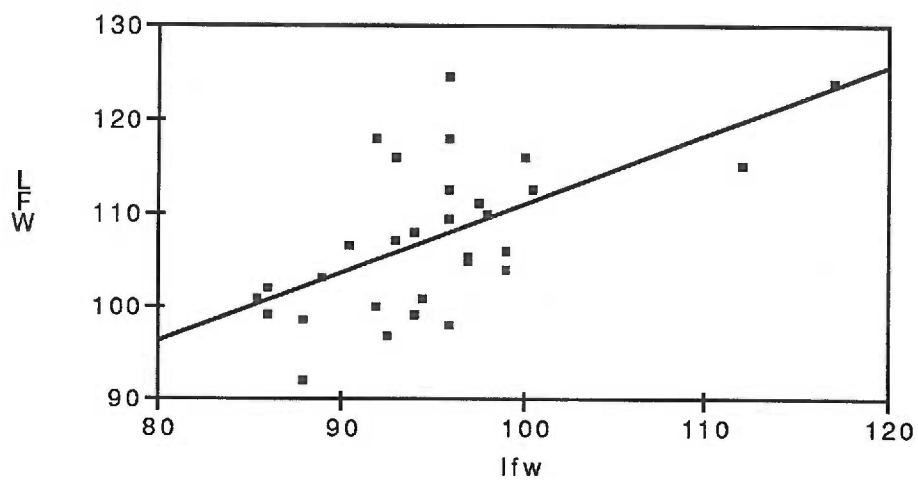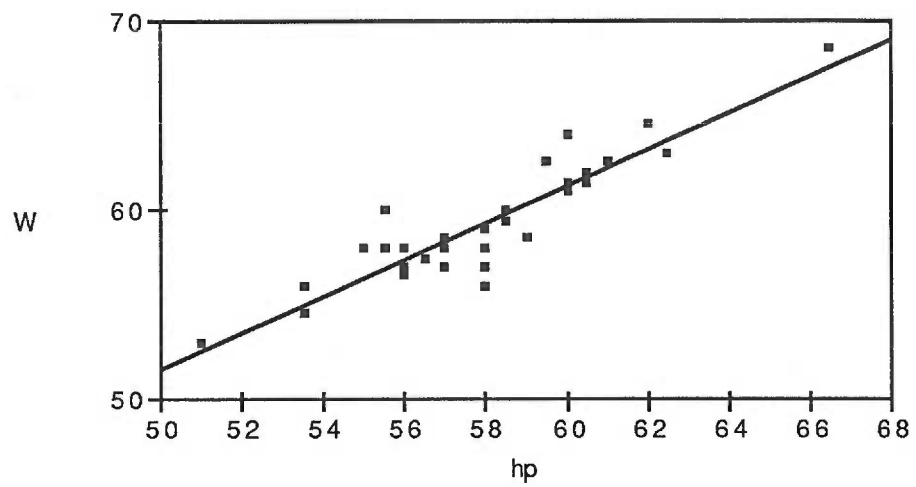
Figure 7

Linear regression analysis for hard tissue pupil (hp) dimension as the independent variable and soft tissue pupil (W) as the dependent variable.

APPENDIX A

Hard Tissue Landmarks

(1)   center of orbit (co) - geometric center of each orbit (R&L).

(2)   inner canthus (ic) - most medial point of the orbital rim (R&L).

(3)   outer canthus (oc) - most lateral point of the orbital rim (R&L).

(4)   menton (me) - a constructed point projected from the midline to the inferior border of the mandible.

(5)   gonion (go) - lowest, posterior and most lateral point of the angle of the mandible. Obtained by bisecting the angle formed by tangents to the lower and posterior borders of the mandible (R&L).

(6)   alare (ar) - most lateral point on the outline of the pyriform aperature (R & L).

(7)   subalare (sa) - most inferior point of the pyriform aperature (R or L).

(8)   maxillary tuberosity point (mtp) - the point of deepest concavity of the maxillary tuberosity.

(9)   distal aspect of maxillary central incisor (mc) - the most lateral point on the distal aspect of the maxillary central incisor (R&L).

APPENDIX B

Soft Tissue Landmarks

(1) pupil (P) - center of the pupil of the eye (R&L).

(2) inner canthus (IC) - inner commissure of the eye (R&L).

(3) outer canthus (OC) - outer commissure of the eye (R&L).

(4) chelion (CA) - commisure of the lips (R&L).

(5) subalare (SA) - point at the lower limit of each alar base where the alar base disappears into the skin of the upper lip (R&L).

(6) subnasale (SN) - midpoint of the columella base at the apex of the angle where the lower border of the nasal septum meets the surface of the upper lip.

(7) menton (ME) - a constructed point projected from the midline to the inferior border
of the chin.

(8) gonion (GO) - most lateral point on the mandibular angle, close to the boney gonion.

(9) alare (AR) - most lateral point on the soft tissue contour of the lateral cartilagenous wall of the nares.