A PRELIMINARY INVESTIGATION INTO POSSIBLE CORRELATION BETWEEN FRONTAL CEPHALOMETRIC AND PHOTOGRAPHIC FACIAL INDICES.

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INTRODUCTION

Facial photographs have been used extensively as a method of record taking and case documentation particularly among orthodontists and maxillofacial surgeons. Facial photographs in the field of Forensic Science are being used as an aid to identification. Attempts have been made to fit tracings or photographs of skulls to painted or photographic portraits of the deceased. "The dead skull is, in a sense, the matrix of the living head; it is bony core of the fleshy head and face of life."[1]

Most of the literature on identification through likenesses deals with the authentication of skeletal remains of historic personages by means of one or more existing portraits and/or the evaluation of the likeness achieved in the portraits as judged from the skull.[2] In the absence of objects of known size in antemortem photographs, others have combined the use of anatomic landmarks and anthropometric measurements of the facial skeleton with so-called established values for thicknesses of soft tissues to estimate a magnification factor, thus obtaining a superimposition by best fit.[3,4]

The feasibility of radiography to identify skeletal details presupposes at least two sets of x-ray films, i.e. ante- and post-mortem; all too frequently, antemortem skull films are not accessible.

In order for a forensic investigation to be scientific, it must be reproducible. The era of the expert witness being an expert witness "because I say so" is hopefully past.[5] Ego and pride must step down and make way for hard scientific evidence. To that end, identification achieved via photographic superimposition have been viewed with skepticism by forensic science workers and by counsel, judges and juries hitherto.[1,6]

Critics of the technique cite the difficulties of enlarging an antemortem photograph to true-life size and the problems of accurately positioning the skull of a suspected victim in the attitude represented in the antemortem photograph. Moreover, portraits are rarely so carefully oriented. Most commonly, a facial view is seen slightly from either the left or right side (three-quarters view); therefore, a precise matching is defeated at the start.[7,8]

In spite of the odds of positive identification utilizing facial photographs, the skull is one of the best preserved parts of the human body; and the head and face are regarded as highly individualized. Since there exists an apparatus which permits the taking of standardized roentgenographic films of the skull in the frontal (postanterior) view, a cephalometric method of systematic identification was envisioned.[9,10]

The current investigation is basically cross-sectional in nature, utilizing the oriented frontal cephalograms and corresponding enlarged 8 x 11 inch non-standardized photographs of patients of the Oregon Health Sciences University Orthodontics Department.

Selected cephalometric and corresponding photographic anatomical landmarks were identified and a method of comparison was devised based on ratios rather than absolute measures. In doing so, an attempt was made to match the "unknown" faces to the frontal headplates by deriving statistical correlations between the two; seeking out the existence of any consistent and possibly predictive relationship between the indices of the integumental contour to its underlying bony frame.

LITERATURE REVIEW

From the very beginning of civilization, man was fascinated by images of himself. The Greeks and Romans sculptured statues of the forms and faces of their gods. Later artists such as Daumier, Leonardo da Vinci, Durer and many others became intrigued with the human face and its proportions and angles, both ugly and beautiful.[11,12]

The human face is an area of interest to many disciplines besides the arts - Physical Anthropology, Surgery and Genetics to name a few. Through the years, each discipline sought ways of analyzing the face in order to realize their own goals.[13] As it became apparent that the eye alone is not capable of analyzing components of the face and their inter-relationships with other parts, the need to measure and record objectively is essential for practical as well as academic reasons.[14]

Following the trends of scientific thought, the second half of the 19th century experienced the allure of numbers in the field of anthropology- the faith that rigorous measurement could guarantee irrefutable precision, and might mark the transition between subjective speculation and a true science as worthy as Newtonian physics. By the end of Darwin's century, standardized procedures and a developing body of statistical knowledge had generated a deluge of more trustworthy numerical data.[15]

Hard Tissue Evaluation of the Face (with Emphasis on the Frontal View).

One could either strictly analyze the face as you see it or one could delve into the underlying bony skeleton. Lischer in 1919 pointed out that the size and form of the head and face of man were conditioned largely by the bony structures to which the soft parts were attached.[16]

For over 150 years, physical anthropologists have been preoccupied with race and sex differentiation in the adult skull. In an effort to solve these two problems, innumerable measurements have been taken and indices calculated. To that end, countless observations and classificatory systems have been set up. In effect, skulls have been measured and described to within an inch of their lives, so to speak.[17]

Hrdlicka in his book entitled "Anthropometry" (1920) gives insight into anthropometric nomenclature and techniques. He defined 1) Anthropometry, a division of anthropology, as the systematized art of measuring and taking observations on man, his skeleton, his brain and other organs by the most reliable means and methods and for scientific purposes; 2) Craniometry, on the other hand, is considered a subdivision of anthropometry and records hard tissue landmarks on the living person as it was done with a craniostat in measuring the dead skull. Inaccuracies arose from measuring skulls through varying thicknesses of soft tissue.[18]

Other renowned workers of that era such as Broca (1879), Topinard (1855) and Martin (1914) have similar publications on the subject in French. Their measuring instruments vary from a metric linen spring tape graduated in millimeters, the spreading and sliding calipers of Hrdicka and a Western Reserve Septer.[17]

There is no limit to the type and number of measurements that can be made in anthropometrics. New methods and new instruments may be introduced by investigators to meet the demands of any particular problem. One should bear in mind that the personal factor of human error is a recognized condition in this field - measurements and landmark location are never 100% exact.[18]

Many landmarks used in anthropometric measurement today were formulated at a series of international congresses on "Prehistoric Anthropology"; two of which were held at Monaco (1906) and at Geneva (1912). One of the agreements that transpired was this: "That a landmark in anthropometry is as near as possible a definite point from or to which to measure. Some such points are more fixed than others, but all present some normal variation".[18]

These methods of directly obtaining data from the skull and head took a tremendous turn following the discovery of Roentgen rays and the X-ray machine. In 1931, Broadbent introduced the radiographic cephalometer that has since become an invaluable research tool.[10] Its initial application was as an instrument to study craniofacial growth in children. The properties of facial morphology were abstracted in point and line, capturing the face in 2-dimensions from which numerous angles and facial dimensions were attained. To that end, it also provided data on normative population study and growth standards for assessing dentofacial developmental progress similar to Todd's method of assessing skeletal age from wrist film.[10,19]

In that same era, Hofrath and Maves, the former who independantly developed a similar cephalometric technique in Germany, were prescribing it for prosthetic planning and for following operative procedures.[20,21]

The concept of standardized radiographic head images transpired since Broadbent's introduction of the cephalometer. It allowed for the very first time a tool to both anthropologists and orthodontists which enabled them to register the craniometric landmarks of the face and cranial base of the living head which heretofore had only been measured on dead skulls with a craniostat. Some 1700 children were followed in the Bolton Child study by Broadbent since the inception of the cephalometer.[10] To date, countless standard cephalometric measurements have been described to form "analyses" of craniofacial morphology. (Egs: 22,23,24,25,26,27,28) However, all of these anlyses 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. Besides, linear and angular measurements of cephlometric landmarks made in the same sagittal plane gave more accurate and reproducible results for longitudinal evaluation.[29]

The frontal projection (antero-posterior view) was utilized occasionally for growth studies but until computer research in 1968, detailed objectivity for the clinician was not forthcoming. Lack of interest and experience combined with difficulty in attaining consistently satisfactory orientation in the frontal positioning in the headholder at the time of exposure limited the progress in the frontal analysis.[30]

Another factor was the lack of acceptable reference points and planes and the acquisition of sufficient clinical data in both normal and treated patients to enable establishment of standards for actual clinical use.[31]

Davis, in 1918, was the first to use the postero-anterior film for the study of asymmetry of the paranasal sinuses.[32] Following that, Broadbent (1931) combined both lateral and frontal projections for ortho-diagraphic analysis.

Potter and Meredith (1948) made a comparison of two methods of obtaining biparietal and bigonial measurements on 94 white children within the postnatal age limits of 4 and 5 years. One procedure called for direct measurement of the child; the other involved radiography and measurement of the postero-anterior cephalogram. Both procedures were carried through a high plane of scientific rigor. They found that (1) biparietal diameter was depicted more validly by direct measurement and 2) bigonial diameter was measured more reliably by the roentgenographic procedure than by direct measurement.[33]

Doering (1950), Woods (1950) and Warren (1959) studied the frontal headfilm for dimensional changes during growth, both Woods and Warren corrected their measurements for size distortion in two planes of space.[31]

In 1954, Harvold did two studies on asymmetry on the unilateral cleft palate subjects and proposed the first parameters for asymmetry of the upper facial skeleton. He constructed his "X" line to define the midsagittal axis on the P-A radiographs. This line consisted of a horizontal line connecting the lateral parts of the zygomatic-frontal sutures to which a perpendicular line through the root of the crista galli was drawn. In doing so, he concluded that the Anterior Nasal Spine was less than 1.5 mm. from this line in 90% of the cases he reviewed. His sample consisted of 67 children.[34]

Subtelny (1955) used the laminagraphic technique frontally for a comparative study of normal children and unoperated cleft palate children.[35]

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.[31]

Wei (1970) investigated the subject of craniofacial width dimensions on 106 Chinese subjects cephalometrically. For each width measurement on the frontal radiograph, the corresponding distance of the landmark from the vertical porionic axis was obtained from a standard oriented lateral film. The data were fed into a computer and statistically analyzed. He found that generally the correlations were of a low magnitude for various cranial, facial, and denture widths. He concluded, however, that multivariate procedures would have been more apt than his published method.[36]

The qualitative usefulness of the postero-anterior cephalogram has long been recognized for radiological diagnosis in the fields of the medical sciences. Etter (1963) used the frontal radiograph in some opacification studies of normal and abnormal paranasal sinuses. He concluded that radiologists should be more aware of the considerable variation of the paranasal sinuses, especially of the sphenoid sinuses.[37]

Potter and Gold (1975) reported that this view gives the best view of the ear. Otolaryngologists described it as the transorbital view because the petrous pyramid and the ear were seen within the orbit if the skull was properly positioned.[38]

Martinez (1983) evaluated frontal cephalograms of 400 orthodontic patients for pathologies, skeletal anomalies and variations of normal. He demonstrated that 36.2% of the radiographs exhibited skeletal anomalies; none were overtly pathological[39].

Keats (1982) published an atlas of Normal Roentgen Variants that may simulate disease that provided a good source of reference.[40]

Although refinements have been made to the technique and machines utilized by these early cephalometric pioneers, many of the underlying problems still persist. Problems such as enlargement, distortion, penumbra effect, graininess of the film, and secondary radiation have been investigated and improved upon by various workers.

In order to deal with the problem of differential enlargement, innovative specialized mechanical devices have been constructed. These include the "orientator" of Broadbent (1975)[41], the "compensator" of Wylie and Elasser (1951)[42], and the "modified compensator" of Vogel (1967)[43]. In general, these solutions have been too tedious to be feasible for routine usage.

Baumrind and Frantz (1971)[44,45] raised another inherent error on cephalometry - that of landmark identification. They concluded from their study "that the distribution of errors for most landmarks is not random but is, rather, systematic in that each landmark has its own peculiar envelope of error". They also suggested that the impact of observed errors in landmark location on clinical decisions can be reduced through the routine use of replicated estimates for each landmark. To this end, the access of a computer would simplify and improve the reliability of cephalometric evaluation.

Savara (1972) expressed that the future holds a definite need for computer-aided analysis in order to reach more accurate and reliable norms;

it would also allow quick assessment of vast amounts of raw data.[47]

Richardson (1981) made use of a cartographic digitizer on 50 lateral cephalograms to establish the superiority of computer-aided devices in terms of speed of processing and storage, as well as the accuracy of locating points on a curved outline.[48]

With the entry of computer technology into the field, many researchers saw the chance to develop their own types of computerized cephalometric anlayses.[46,49,50]

Next on the horizon of progress in craniofacial morphological analysis was the three dimensional approach. Broadbent (1931, 1975) was the first to emphasize the complimentary use of the lateral and frontal radiographs to study and measure growth of the head. He stated that "the anterior film was to be studied not only for its own value, but also for its contribution to an understanding of structures that appear in the lateral view".[10,43]

Sassouni (1958) described a method of correlating information from the lateral and postero-anterior views by horizontal orientation of the tracings side by side on graph paper.[51] Both Broadbent and Sassouni attempted to achieve a three dimensional understanding of the head through the study of both views.

A third view, the basilar view, was described by Schueller (1905) and subsequently by Merrill (1949). Berger (1964) proposed a method of aligning this basilar view to that of the classical two orthogonal views using the Frankfort Horizontal plane as a common factor. He demonstrated a method for determining the midline of the basilar view by drawing a line through the vomer, the posterior part of the nasal septum and the crista galli.[52]

Nahoum, et al (1964) described a technique of orienting the structures of these three cephalograms to one constructed plane based on drafting principles of a three dimensional projection.[53]

Kaban and co-workers (1981) demonstrated more clearly the clinical deformity present in his cases of hemifacial microstomia utilizing his methods of three dimensional analysis. He used the same three views substituting the submental projection for the basilar and derived a vertical reference plane connecting anterior nasal spine to glabella (or sella turcica).[54]

Grayson (1983) presented a three dimensional multiplane cephalometric analysis that permits visualization of skeletal midlines at selected depths of the craniofacial complex. He localized craniofacial asymmetry in the frontal and basilar views and supported his findings by determining the plane of sectioning on the lateral cephalogram with the landmarks chosen.[55]

These approaches dealt with so far were based on biplanar or orthogonal images of the skull. Given that the geometric relationships between the system components were known, it would be mathematically possible to construct a three dimensional map using any two of these three views by identifying the same set of landmarks on each of the two images. It became obvious that the comparative complexity of the task of locating the same landmark on the three views was a real obstacle unless metallic implants were employed.[56]

Baumrind, et al (1972) introduced the concept of coplanar stereometry to the area of X-ray cephalometrics. They began their research as early as 1968 producing a stereopair of films:

1) A conventional projection following the 2nd Roentgenographic Cephalometric Workshop criteria from which all conventional two dimensional cephalometric measurements can be computed.[57]

2) A coplanar projection exposed from an "offset" perspective to enable supplementary data to be derived and correlated with the first view.

Combining the pair of stereo images, a true three-dimensional coordinate system of all structures can be plotted and analyzed with the aid of the computer.

Soft Tissue Evaluation of the Face (With Emphasis on the Frontal View)

Man's face serves as a mirror of expression and emotion. It is a matter of ordinary observation that every human face presents lineaments of character which stamp it with individuality. The variations of the facial features have been carefully examined by students of physical anthropology and continue to attract an increasing number of well-trained investigators. Their methods of inquiry have reached a high degree of development and constitute a highly specialized technique. Thus, photographic and X-ray studies, geometric drawings, plastic reproductions, instruments of precision, comprehensive record sheets, statistical and graphical methods of presentation are all employed.[16]

Assessment of facial appearance, although clearly a three-dimensional problem is attempted in two-dimensions by the majority of techniques currently available. Facial form may be abstracted into two planes of space: 1) frontal and, 2) sagittal (profile). There have been several analyses used for evaluating the facial profile.[56,57,58,59,60] Contrary to this evaluation of the frontal view net with more inconsistencies due to the three dimensional nature of the face.

Not adhering to the concept of variation, the figure artist can systematically construct a well-balanced face based on principles of construction and observing relationships not generally, if at all, found in our studies of surface anatomy. "The face is constructed on a ball with an extension for the lower face and the sides of the ball are then accurately located at specific levels on this ball and plane."[61,62,63]

Brodie (1946) quotes E.H. Angle, saying "we know that while all human faces are greatly alike, yet 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.

He pled for abandonment of the norm concept and that one should cease comparing each individual we treat with some pattern that has been arrived at either by an inner sense of proportion or by the careful compilation and averaging of large series of measurements of different indiviudals.[64]

Being made aware that each of us is an individual, how has man attempted to measure and evaluate his own face? Through the natural forerunner, anthropometry (from Greek, anthropos, "human" and "metron", measure), 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; Martin, 1928; Gunther, 1933; Goycki, 1956; Martin and Saller, 1962; Weiner and Lourie, 1969).[65] Soft tissue measurement technique differed from that of hard tissue by the amount of pressure being exerted by the ends of the calipers, measuring tape or ruler. It is quite apparent that this requires skill and experience for consistent results.

In the present era, Farkas and his co-workers could be considered a major contributor of such forms of valuable data. He had applied his skills to large samples: delving into those cases with craniofacial anomalies,[66,67,68,69,70,71] as well as normative data.[65,69] In his published book on "Anthropometry of the Head and Face in Medicine" (1981), he admits 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. In all the figures derived, he recommended repeated measurements and recorded the average.[65]

Although photographic methods had been used in anthropology to record characteristics qualitatively, it was not until 1940 when Sheldon published his work on somatotyping that the camera began to be used as a measuring instrument in the assessment of body physique.[73]

Photogrammetry of the face (indirect anthropometry) 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[74] to produce prints of standardized views and sizes allowed photogrammetry to be scientific, accuarate and documentary.

The use of oriented photographs for the study of the face was advocated by Herzberg as early as 1952.[75] Ferris (1927)[76], Jackson (1937)[77], and Weinberger (1948) were among those who have developed a method of making, from each negative, two positives; one in the mirror image of the other. "Both positives were cut in the median line, and both right and left halves reunited by photomontage."[78] This is a striking way of demonstrating the presence of facial asymmetry.

Other photogrammetric documentation of the face concentrated on the lateral profile view.[60,79,80,81,82] Reliability studies of this indirect method of measuring were few.

Tanner and Weiner (1949) modified and standardized this technique to an extent that certain body dimensions could be measured to a degree of accuracy equal to that obtained in anthropometry. They also stated "that it seems that not only body dimensions, but many of the head and face can be obtained from our photographs." To date, he has no written publication to substantiate his statement.[83]

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 also concluded that if selected anatomical points were pre-marked on the individual, many measurements could be taken as accurately on the photographs as on the individual himself.[84]

Since then, it was not until 1980 that Farkas, Bryson and Klotz carried out a reliability study on photogrammetry of 36 young white Caucasians. To establish the maximum number of reliable measurements in the various areas of the head and face, they compared a large number of facial measurements taken from standard photographs with direct measurements of the faces of the same people. A measurement was considered reliable only if the average difference between indirect and direct measurement was no greater than 1 mm. or 2 degeres. He showed a 40.2% fewer number of measurements obtainable from both lateral and frontal photographs as compared to direct measurement. The greatest loss of 53.8% were those of the head whose landmarks were obscured by hair. Lateral prints gave more valid measurements (13 out of 20 were reliable) than frontal prints (10 were reliable), but measurements of the orbits, lips, and mouth were more precise from the frontal view.

Out of the 20 determined reliable measurements, almost half were inclinations, of which 8 were vertical, and 3 were horizontal. Farkas felt that the distortion caused by photographing accounted for the greatest differences between the direct and indirect measurements. To produce the best results, the subject must be photographed with the landmarks indicated on the skin, and the head must be positioned and checked repeatedly during photography to ensure that the required level was maintained. Moreover, photographs were not sharp enough to allow for accurate identification of some landmarks (e.g., alare, subalare, palpebrae superius and inferius). Besides, photographic print being two-dimensional did not allow for accurate measurement of surface lengths of parts of the face.[74]

On the same note, facial proportions were evaluated based solely on photogrammetric records without the support of direct measurements.[11,85,86,87,88] Most of the classic formulae concerning idealistic proportions of the face were developed first by the Egyptian; later by Polykleitos, a famous sculptor of ancient Greece and subsequently revived in the Renaissance by Leonardo da Vinci and Durer.[65]

Ainsworth, et al (1979) stated that the use of a proportion index that comprises a few anthropometric data permitted a more complex judgment of the face and established a basis for more detailed comparison than did the analysis of single absolute measurements.[89]

Most recently, facial proportions were expounded in a publication by Nakajima and Yanagisawa (1985).[90] Based on a sample size of 34, frontal facial photographs were evaluated in the form of index-comparison. Landmarks were defined according to Rickett's criteria.[61]

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 section.

For centuries, cartographers have analyzed terrain in three dimensions and have presented their findings in the form of contour maps. This was known as stereophotogrammetry. The basic principle is that of binocular vision. If two binocular stereophotographs of an object were juxtaposed, the eye would be able to perceive the object in depth as well as length and breadth.[91]

Stereo images provided a means of creating a spatial model of the object. Likewise, the face could be measured in three dimensions following the same principles. A stereometric camera is used to take overlapping photographs or stereopairs. The images comprising a stereopair are suitably oriented onto a stereo plotting device. The operator sees a three dimensional optical model of the two photographs, and 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.[92]

Zeller (1939) published a contour map of a man's face for which he used a 40 cm. base Wild stereocamera and an A-4 Wild autigraph plotting machine; the contour interval appears to be 10 mm.[93]

Bjorn, Lundquist and Hjelmstrom (1954) used the same type of camera, but more complex plotting machines, to investigate post-operative swellings by means of an automatic planimeter attached to the plotting machine.[94]

Savara (1965) using a "custom-built" camera, recorded facial contours and claimed an accuracy of 0.2 mm. on a "Kelsh" plotter.[95]

Burke and Beard (1965, 1967), being much aware of the expense incurred in the stereo equipment, evolved a simplified camera system utilizing two "Multiplex" projectors for the study of facial morphology. Following that in 1972, they investigated the accuracy of the technique and found that the standard deviation for linear distance in respect to repeat stereopairs of a single individual was 0.69 mm. He conceded quite ironically that more elaborate equipment was necessary and a trained operator was required to produce each stereoplot thus making records expensive.[96,97]

This technique has since evolved to be termed 'biostereometrics', the science which permits the three dimensional measurement of body form. Berkowitz (1977) compared stereophotographs of five patients with cranio-facial anomalies. He assessed both shape and relative changes in position of facial features incident to corrective manipulation. He concluded that reference points used in comparison should be located elsewhere farthest removed from the surgical site.[98]

Savara, et al (1985) further applied the techniques of biostereometric photography and current state-of-the-art computergraphics to a series of patients with complex craniofacial malformations. He proposed that this three dimensional input modality be merged with other sources such as computerized tomography, biplane cephalometry and digitized dental casts to form a composite data set.[99]

Other researchers, having explored and measured every possible work on the face, have turned to a more logical and inexpensive alternative. Still using standard photographs, they sought to correlate their findings with that derived from the corresponding cephalograms to come up with a composite hard-to-soft tissue analysis.

Eisenfeld, et al (1975) modified a computer program which displayed iconically a predicted face based on input data from frontal photographs and postero-anterior cephalograms. This included a print-out of statistical correlation of relationships between hard and soft tissue landmarks. The feasibility of their study tested the hypothesis that positional variation in elements of the soft tissue face can be described from the position of a sufficient number of underlying skeletal landmarks which can be identified radiographically.

The data presented described only those measurements for which significant correlation was found or measurements which helped to determine the basic make-up of the face. Other hard and soft tissue relationships were measured, but because of the small sample size (9), meaningful statistical information could not be derived.[100]

Meanwhile, in Manchester, United Kingdom (1971-1977), Rabey formulated a 'morphoanalysis' system to analyze craniofacial morphology in three planes of space. Based on his fixed relations theory[101], a recording machine called an analytic morphograph has been developed to convert his foregoing theory into clinical practice. A sophisticated electronic pressure monitoring system was incorporated into the cephalostat that gives a zero reading if both external acoustic meati is properly positioned. This orients the x and y coordinates. A third coordinator (z) is derived via a piece of lead shot affixed to the point 'orbitale'.

Standardized cephalograms and photographs were taken in the orthogonal, frontal, lateral and basal views with grid films. Subsequently, tracings were made and data fed into the computer to generate histomorphograms. Rabey had evaluated 100 individuals; there was mention in both his publications of error consideration. His system seems to me not to be cost-effective and also too complex to the point of not being practical for general usage.[102,103] In the past 15 years, demand for corrective surgery for craniofacial deformities, as well as for esthetic concerns, is increasing. The need for more affirmative prediction of the surgical outcome became imminent.

Paulus (1979) came up with what was referred to as a new photographic template technique. It produces a "positive-negative" black and white print of the patient's face. Basically, the film is developed in the same solution as that used for cephalometric x-rays. This template, or transparency, enables superimposition over the cephalogram coinciding the lead markers placed at orbitale and pogonion. There is no doubt that this technique aids in visualization of soft tissue changes; its predictive value, however, is questionable.[104] Unknowingly, a similar technique known as photocephalometry was already developed a year prior to Paulus' work by Hohl, Wolford, Epker and Fonseca (1978). Their three patients each had 3-4 radiopaque metallic markers affixed to landmarks on the face, followed by standard lateral and frontal cephalograms and photographs taken and enlarged to allow the superimposition of the radiopaque markers. Sources of error were not mentioned but cited to be under continued investigation.[105] To summarize, the benefits of the 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 soft-to-hard tissue relationship, particularly of soft tissue thicknesses. The value of predictability is left to be enlightened.

Fanibunda (1981) developed a more accurate techinque for the production of life-size facial photographs to enable measurements to be correlated directly to radiographs. He incorporated a graduated scale in the form of a metallic ruler onto the cephalostat unit along the mid-sagittal plane. This appeared in every subsequent standard photograph and radiograph, and serves as an external standard of reference which allowed an estimate of the enlargement of the photographic images to be made.[106]

In 1983, Fanibunda modified the design of his cephalostat by mounting the camera rigidly to the wall such that its point of perspective was simliar to the x-ray tube. The cephalostat was photographed and the resultant transparency stuck on the viewing screen of the camera. This gave an additional reference and allowed a cephalostat unit to be employed for routine radiographs as well.[107]

It was not until 1984 that a study on errors of projection and landmark location was published on the subject of photocephalometry (Phillips, et al). Their article reported on the quantification of the two classes of error involved in the estimation of measurements from two dimensional images of a three dimensional object as cited by Buamrind and Frantz (1971).[44,45] Related to photocephalometry they were: 1) the magnification and distortion errors involved in the super-imposition of the photographic and cephalometric images; and 2) the location errors of the lateral and frontal photographic landmarks. They utilized the set-up similar to that used by Hohl and Associates (1978). Standardized cephalograms and photographs were taken in the natural position with a 1 cm. stainless steel wire plexiglass grid locked into position. In addition to the centimeter ruler, a free-hanging chain was also incorporated for the orientation relative to a gravity defining a true vertical plane. The sample comprised 12 adult female patients (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.[108]

Subjects and Source Materials

The sample is cross-sectional and consisted of patients from the Oregon Health Sciences University, Orthodontic department. The subjects, twenty females (aged ranging from 12-0 to 13-1) and ten males (aged ranging from 12-1 to 19-9) were selected based on the following criteria:

a) Possessing a posterior-anterior cephalogram of good resolution taken without the nasal rest. These were part of their initial diagnostic records. The radiographs were obtained using the Bolton-Broadbent Cephalometer with the subject's head oriented to Frankfort Horizontal as vertical reference and the trans-porion ear-rod axis as the horizontal reference. Exposures were made by the same experienced radiology technician using a standard department technique.

b) A non-standardized frontal facial photograph taken the same day utilizing a 35mm Minolta SLR camera on Kodachrome 25 slides. These were obtained by the same dental assistant at a subject-camera distance varying from 4 to 5 feet. Selection was based on those photographs that had a fairly good frontal orientation to facilitate later landmark identification.

Subsequently, the slides were sent to the photographic department of the Medical School, OHSU to be processed into 8½ x 11 inch black and white enlarged prints. The enlargement was carried out to approximately life size without compromising on the clarity of facial outline.

Error Estimation

As this study utilized both radiographs and photographs, the consideration of the errors involved will be important to the interpretation of the results obtained.

Ten subjects were randomly selected from the original sample. The error study entails replicate tracings made of the frontal cephalograms on two separate occasions one week apart. Landmark location were also determined at a week's interval. For the photographs, ten duplicate enlargements were made of the same ten individuals and the relevant landmarks were determined over the same lag period. This serves to minimize the source of intra-operator error with regards to landmark location.

An initial cross-check was made on a single subject between manually calculated measurements versus computer-digitized data. The difference was within $\pm$ 0.5 mm. It was felt acceptable to carry on using solely the digitizer for the rest of the data compilation.

Subsequently all the 20 replicate tracings and photographs were digitized and stored as two separate groups. The print-outs of the distance measurement were visually inspected for gross measurement error. In this manner, the landmark location points were checked for accuracy and redigitized if a difference of greater than $\pm$ 1 mm was detected.

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

$$S.E.Meas = \sqrt{\frac{\Sigma ED^2}{2N}}$$

With respect to technical errors which included such projectional errors as enlargement and image blurring by the penumbra effect and intensifying screens; all these were minimized by utilizing the same X-ray machine set-up. The correction enlargement factor for the postero-anterior cephalograms was calibrated and found to be of an average value of 7.8% (minimum = 7.1%, maximum = 8.8%; all landmarks were anterior to the sella plane).Further all exposures were made by the same radiology technician. Hence equipment variation was nil but head orientation errors may have occurred resulting in a pose that was not truly a postero-anterior view by definition.

However, as the probability of such a distortion occurring was equal for each and every subject and since eventually proportion indices were derived rather than absolute measurements, it was felt to be valid within the circumstance for a comparative analysis with its corresponding soft tissue (photographic) counter-part.

It should be noted at this point that angular measures being a more reliable form of measure compared to linear measures because they remain quite constant regardless of enlargement factor is well-recognized.[46] As this is but a preliminary study, only indices from linear measures are reported.

With regards to the photographic prints, they were non-standardized with respect to head orientation and subject-lens distance. Again it was felt that the enlargement inherent made the situation more realistic in lieu of the "post-mortem scenario."

Landmarks and Measurement Procedures for Hard-Tissue

An outline of the relevant parts of the facial skeleton was traced on an 8 x 10 inch acetate tracing paper affixed to the radiograph. The following landmarks* were then identified on the film and recorded on the overlay acetate by means of a small pin-hole.

1. Root of Crista Galli (Cg)
2. Anterior Nasal Spine (ANS)
3. Prosthion (Pr)
4. Menton (Me)
5. Zygomatic point (Zy) R & L
6. Mastoid point (Mas) R & L
7. Gonion (Go) R & L
8. Alare (Ar) R & L
9. Molar Alveolar point (Ma) R & L
10. Inner Canthus (IC) R & L
11. Point X - intersection between lateral border of orbit and temporal line. R & L

Two reference lines were drawn on each tracing to facilitate land-mark location on an x-y axis coordinate system.

1. Horizontal Reference Line - Supra-orbital line (SOL) defined as a tangent drawn touching the upper borders of the orbital rims.
2. Vertical Reference Line-from Crista Galli, a perpendicular was projected to the SOL. This is considered as the mid-line of the face (ML).

* See Appendix A for definition of landmarks.

* See Diagram 1 for landmark location on schematic cephalometric tracing.

All registrations were made sequentially on an electronic digitizer with automatic coordinate locating equipment. The cursor precision was 0.20 mm. With this digitizer, it was possible to register any point in an X-Y co-ordinate system at any chosen origin and axis directions; thus the x and y components of the total variability could be isolated for each landmark.

Twelve linear facial dimensions were computed as shown on the list in the next page. From these, relative ratios were generated and converted to an index base x 100. (see Appendix B). In computing biologic indices[109], it seemed customary to divide the smaller of the two dimensions by the larger.Following this convention, 18 facial indices were thus computed.

In analysing the cephalometric tracings, the following list of linear distances were calculated between the selected landmarks:-

1. Upper Face Height (UFH) : SOL - ANS
2. Mid Face Height (MFH) : ANS - Pr
3. Lower Face Height (LFH) : Pr - Me
4. Total Face Height (TFH) : SOL - Me
5. Upper Face Width (UFW) : Zy - Zy
6. Maxillary Width (Max W) : Ma - Ma
7. Lower Head Width (LHW) : Mas - Mas
8. Mandibular Width (Mand W) : Go - Go
9. Nose Height (NH) : Cg - ANS
10. Nose Width (NW) : Ar - Ar
11. Innercanthal Width (ICW) : IC - IC
12. Outercanthal Width (OCW) : X - X

Landmarks and Measurement Procedures for Soft Tissue

The facial photographs were converted from colored slides to black and white prints measuring 8½ x 11 inches. Landmarks chosen on these enlarged prints were made on a dual basis:

a) The landmarks had to be reasonably easily relocated.

b) They have to be in as close proximity as possible to the previously marked bony landmarks. This clearly eliminated those areas covered by hair which were more clearly defined on the radiographs.

The following forms the list* of Soft-tissue landmarks thus selected:

1. Point C - soft-tissue crista galli
2. Subnasale (Sn)
3. Prosthion (Pr)
4. Menton (Me)
5. Zygion (Zy) R & L
6. Otobasion Inferius (Obi) R & L
7. Gonion (Go) R & L
8. Subalare (Sa) R & L
9. Cheilion (Ch) R & L
10. Inner Canthus (IC) R & L
11. Outer Canthus (OC) R & L

(* See Appendix C for definition of landmarks)

These points were identified by means of a small pin-hole. A horizontal and a vertical axis were drawn on the photographs. These two reference lines were meant to correspond to that made on the cephalogram tracings. They were:

1. Horizontal Reference Line - tangent to upper borders of the Eyebrows (SOL)
2. Vertical Reference Line - from the mid-point of the inner-canthal distance, a perpendicular was projected to SOL.

Once orientation was established, these points were digitized on the same Apple Graphics Tablet following the same orderly sequence of entering the coordinates into the computer's memory bank.

After the same series of linear facial dimensions derived from the cephalometric data, 12 corresponding photographic linear measurements were computed. The numbering system is alphabetized in this instance for easy distinction between the two, i.e. hard vs. soft tissue, as listed on the following page.

Once again, 18 corresopnding soft tissue indices were computed. (Appendix D.)

In analysing the Photographic prints, the following list of corresponding distances were calculated between the selected landmarks:-

A. Upper Face Height (UFH) : SOL - Sn

B. Mid Face Height (MFH) : SOL - Pr

C. Lower Face Height (LFH) : Pr - Me

D. Total Face Height (TFH) : SOL - Me

E. Upper Face Width (UFW) : Zy - Zy

F. Width of Mouth (MW) : Ch - Ch

G. Lower Head Width (LHW) : Obi - Obi

H. Mandibular Width (Mand W) : Go - Go

I. Nose Height (NH) : C - Sn

J. Nose Width (NW) : Sa - Sa

L. Innercanthal Width (ICW) : IC - IC

M. Outercanthal Width (OCW) : OC - OC

Statistical Analysis of Data

This will include the following steps:

1. Computation of the Mean and Standard Deviation for the hard-tissue as well as for the soft-tissue Indices.
2. Tne Null Hypothesis is stated as H_o: Hard-tissue mean = Soft-tissue mean and the H_i: Hard-tissue mean ≠ Soft-tissue mean. The various Cephalogrametric Index Means were compared with the corresponding Photographic Index Means by utilizing the Student's t Test to determine if there is a significant difference at the 95% confidence level.
3. Pearson's linear correlation co-efficient (r) was computed for each of the 18 pairs of Hard and Soft-tissue Indices to ascertain any possible relationship between them.

RESULTS

Four tables were compiled from the data obtained in this study.

Table Ia and Ib present the computed measurement errors on the 12 facial dimensions based on the cephalometric and photogrammetric data respectively. The findings reflect that the sources of errors of measurement were greater for photogrammetric than for cephalometric landmarks. All of the cephalometric measures were within $\pm$ 0.5mm margin of error. In that same regard of consistency, the percentage error calculated were well within 2%.

Of the photogrammetric measures, two proved unsatisfactory in regard to its strict measuring error. These were Mid face height with a S.E.Meas.of 1.14 (greater than the set limit of $\pm$ 1.0mm) and Mandibular Width with a S.E.Meas. of 1.41mm. The difficulty lay in locating the points Subnasale in the former and Gonion in the latter.

In addition, Mid face height was the only photogrammetric measure that exceeded the overall 2% range for percentage error estimate. It had a calculated value of 6.25% instead.

Table II lists the means and standard deviations for the 18 cephalometric and photogrammetric indices. It is interesting to note that what ranked the most as well as the least variable indices were coincident for both the hard-tissue and soft-tissue data. In terms of standard deviation alone, the most variable index is Nasal height: lower face height (S.D: 15.83 cephalometric;15.3 photogrammetric) and the least variable is Inner canthal width (S.D:1.52 ceph.;1.7photo.)

Table III is a comparison,by means of the 2-way Students' t-tests, of the 18 cephalometric indices to those of the corresponding photogrammetric indices. Of these, the mean values were significantly different for 13 indices at the 0.05 probability level whilst chance would predict only 5. These were Upper face height, Lower face height, Lower head width, Nasal height:lower face height and Outer canthal width:upper face width.

Table IV lists the relevant correlation coefficients between the cephalometric indices and the correspnding photogrammetric indices. The r-values were generally of very low magnitude. Of these, three had a negative value implying that the two indices tested did not increase or decrease concomitantly.

The two indices that had a moderate correlation were Total face height (r=0.68) and Outer canthal width (r=0.67).These did not offer a significant co-efficient of determination to suggest a regression analysis.

Discussion

With the aid of the findings of this investigation, the questions originally posed in the introduction can now be reexamined. First, one has to recognise that the design of this study incorporated an atypical source of data; that derived from non-standardized photographs. Although the original rational seemed logical, the ensuing results exemplified the magnitude of error incurred thus obviating the hope for a significant correlation between hard and soft tissue analyses.

In discussing the aims and objectives, the word 'index' was used to symbolize a ratio of two facial dimensions expessed as a percentage. Based on the supposition that proportions should remain relatively constant in the presence of enlargement; this level of comparison was maintained as such throughout the investigation. Subsequently, it became quite apparent that the whole scheme of photogrammetry and cephalometry is susceptible to a pernicious form of mismeasurement in which error in the orientation is propagated to affect the positions of all the orientation dependant landmarks. This problem is of considerable importance in cross-sectional analysis.

The Frontal analysis based on photographic data seemingly suffers from the same types of errors as other analyses, to yet a probable greater degree. In the light of the present sample where the selected anatomical points were not pre-identified by markers on the subject's faces prior to capturing the image on print, the uncertainty on the observer's part to subsequently locate those points resulted in an inconsistent and probably a conservative estimate of the magnitude of error reported for each landmark.

Previous studies on similar subjects utilizing photography as an anthropometric tool have all advocated landmark identification to facilitate accurate measurement.[74,83,84] In those instances too, photography was a supplementary tool to the traditional anthropometric instruments rather than a full partner in the collection of data. Certainly, one reason why photography has not been used more in the past is that anthropologists have rightly doubted the accuracy of the photographic record. The rendition of a clear image is dependant on such a multitude of variables such as lighting, lens-subject distance, a constant principle plane of focus, posing and film idiosyncrasies; that to be predictable in the offering of a consistently reproducible measurement is not viable.

Despite the former discourse in the path of utilizing ratio comparison which was thought to have rendered the non-standardized measurements immuned from the influence of absolute differences; this had not been fool-proof as was discovered at the end of this study.

The purely photographic position is as quoted from Gaven and Washburn as such: "the ultimate accuracy of the technique depends on the line resolution obtained in the emulsion of the film. No amount of enlarging, obviously, will produce detail which is not recorded on the original negative; enlarging is a convenience merely." In the technique employed here, it was realised that the use of a single point source for the camera flash unit had thrown an unequal distribution of light onto the subject's face. Despite the mounted backlight to eliminate shadows; some facial outlines were merged into shades of gray while others reflected patches of white. These ill-defined zones of the facial features hampered the landmark identification process severely. (e.g. Subnasale).

Futhermore, it was a problem trying to find the hard and soft tissue landmarks that corresponded upon which relevant indices could be formulated for meaningful comparisons. For instance, the most likely awarded landmark for defining the upper limit for face height would have been the all popular Nasion; this point however, is neither distinguishable on the frontal radiographs nor the facial photographs. The alternate Supra-orbital margin was selected to serve as the cephalometric definition but the corresponding superior margin of the eyebrows were so ill defined that one has to endevour a guess as to where to draw the line. To illustrate the point further, Gonion too was notably difficult to identify in obese subjects in whom the angle became so obtuse that it would no longer be described as a distinct point.

Apart from the fact that most of the landmarks chosen were obscured by this magnification and angulation blurring effect, it was also impossible to deduce a reduction ratio as there was too much free-play in the photographic technique. Variation in posing[74] the subjects contributed the worst source of error in the sample; one was never absolutely sure if the subject's face was asymmetric or turned. The difficulties in making consistent observations are so great and the advantages of having an accurate record of ear, nose, eyes etc. so obvious that the use of standardized photographs as a record for observations needs no comment.

In addition, the initial idea of selecting those subjects posed smiling revealing their upper front teeth in order to utilize some dental landmark to facilitate a closer comparison to the cephalometric image was proven to be unsuccessful. Instead it created additional sources of variables in locating the point cheilion. This mouth landmark and others that were strongly influenced by the muscles of mimicry were too unreliable for satisfactory use. According to Farkas et al, these dimesions were distinctly preferably obtained from living anthropometry.[65]

It became quite apparent that all these sources of confusion can be minimized provided the total photographic procedure was planned for the specific purpose of producing a standard, scale picture suitable for taking measurements and observations. In addition, an understanding of individual morphologic variations affecting the determination of certain landmarks is of primary importance for cross-sectional studies. Shortcomings in this respect was clearly evident in the results from this study.

Last but not least, there remains one criterion by which two sets of measurements may be compared; and this is their relative reliability and their repeatability from one occasion to another. Strangely enough, despite and perhaps because of the profusion and variety of measurements on the living, there are very few studied reports of their reliability and this is one of the reasons for the long continued difficulty in securing agreement as to which measurements are preferable. The only study found was that conducted by Phillips et al on 12 subjects. They reported an absolute mean error of less than or equal to 2.0 mm for 57% of their frontal landmarks. On that score of comparison, it would appear that the mean errors depicted in Table Ib were well within those confines.

Having flawed the art of photography as an inadmissable scientific tool unless uniformly standardized, cephalometry too has its share of criticisms. Measurement error in cephalometry is really an ambiguous term covering a multitude of variables as mentioned earlier. Of these, distortion is a source of substantial error in distances not parallel to the mid sagittal plane and in the present context the transporion axis.

The Bolton-Broadbent Cephalometer[10], by providing a movable X-ray casette holder for the lateral and frontal cephalograms, permits the object-film distance to be kept at a minimum for all subjects; but results in a variable correction factor for each film. The need for correcting for such errors depends upon the accuracy desired. To meet the needs of scientific requirement, an average corrected enlargement factor was calculated based on a sample of 234 frontal cephalograms and found to be 7.8%. This was felt acceptable in comparison with the unknown enlargement involved in the photogrammetric data.

Errors seen in positional artifacts in the lateral cephalograms were magnified when the frontal view is considered. The arduous task in landmark identification was significantly affected by the amount of superimposition of bony structures. This had also been the experience of Eikrem who delved in asymmetry analysis based on the frontal view.[110] As a result, the availability of suitable anatomical points that could match the more facile soft tissue landmarks rendered from the photographs was markedly reduced.

Results of this study corroborate the findings of earlier forensic anthropologists. As Plato is reputed to have said, "It is an easy thing to fault another's oration, it is a much more difficult task to produce a better one in its place".

The low correlations found were clearly falling short of any predictive value to reinforce a possible identification. The terms probable and positive denoting an increasing order of scientific assurance from hypothesis to fact circumvent the investigator's state of mind as the computer so rapidly generates the formulated data.

Summary and Conclusion

A method of skeletal versus integumental correlation analysis is presented employing linear measurements which described facial components in terms of indices. The readings made from oriented frontal cephalograms were compared against those derived from enlarged non-oriented frontal photographs of the 30 subjects in the cross-sectional sample. The computer set up expedited the process of data analysis.

This investigation has revived the awareness of the variation on the soft tissue veneer overlying the facial skeleton as the different parts of the dentofacial skeleton are variants by themselves. There was also an added appreciation for standardized technique when utilizing data from photographs for quantifying measures.

In the context of forensics, the usefulness of this method of photocephalometry would always result in a face that bears a basic resemblance to the unknown individual. However, the degree of resemblance can vary from rather poor to a startlingly faithful likeness. Within this spectrum of resemblance, it is very difficult to predict the outcome in any individual case. In a more general sense, the present study represents a contribution towards the methodology of investigations based on photocephalometry.

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Figure 1. Landmark location on frontal cephalogram.

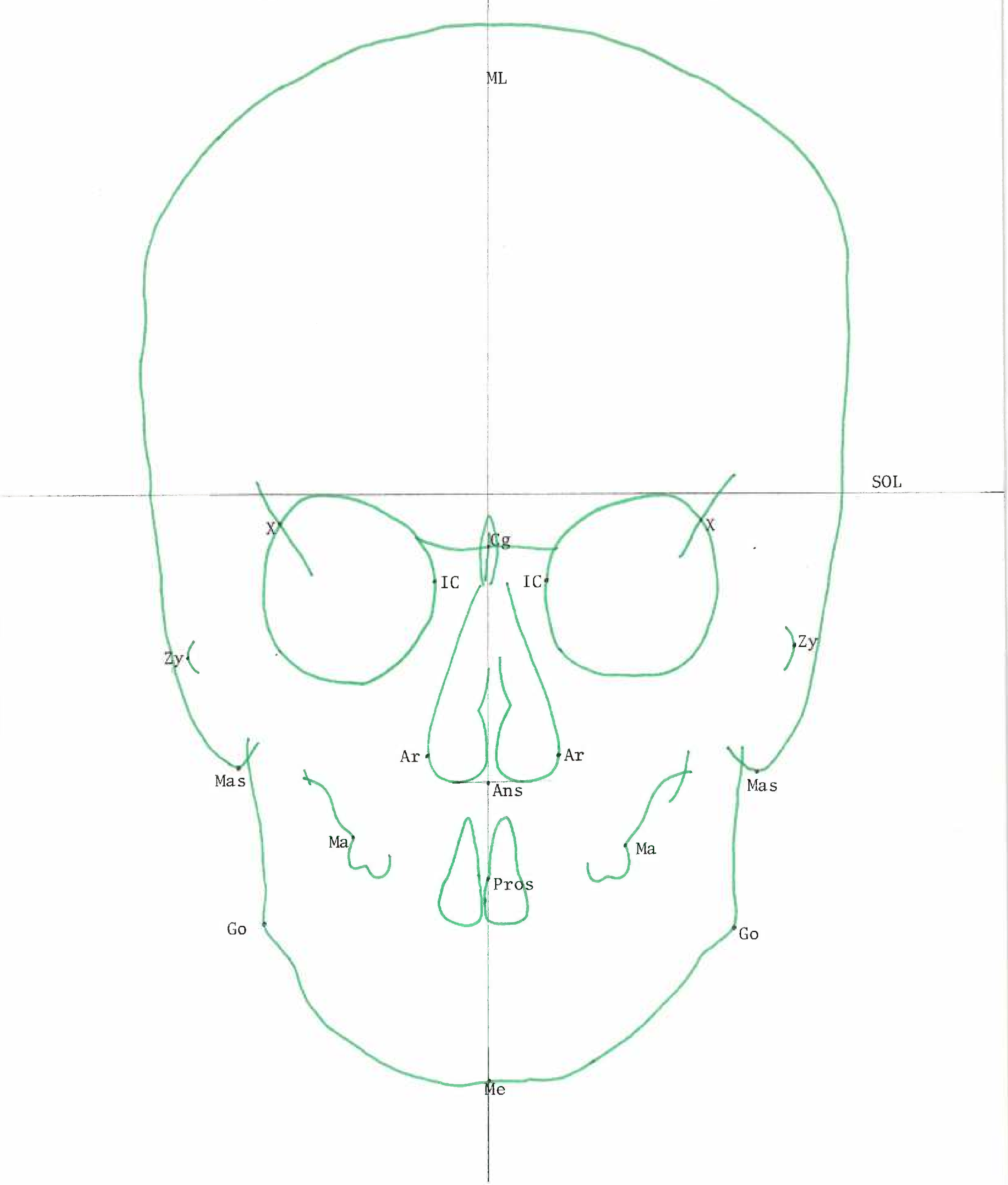

Figure 2. Landmark location on frontal photograph.

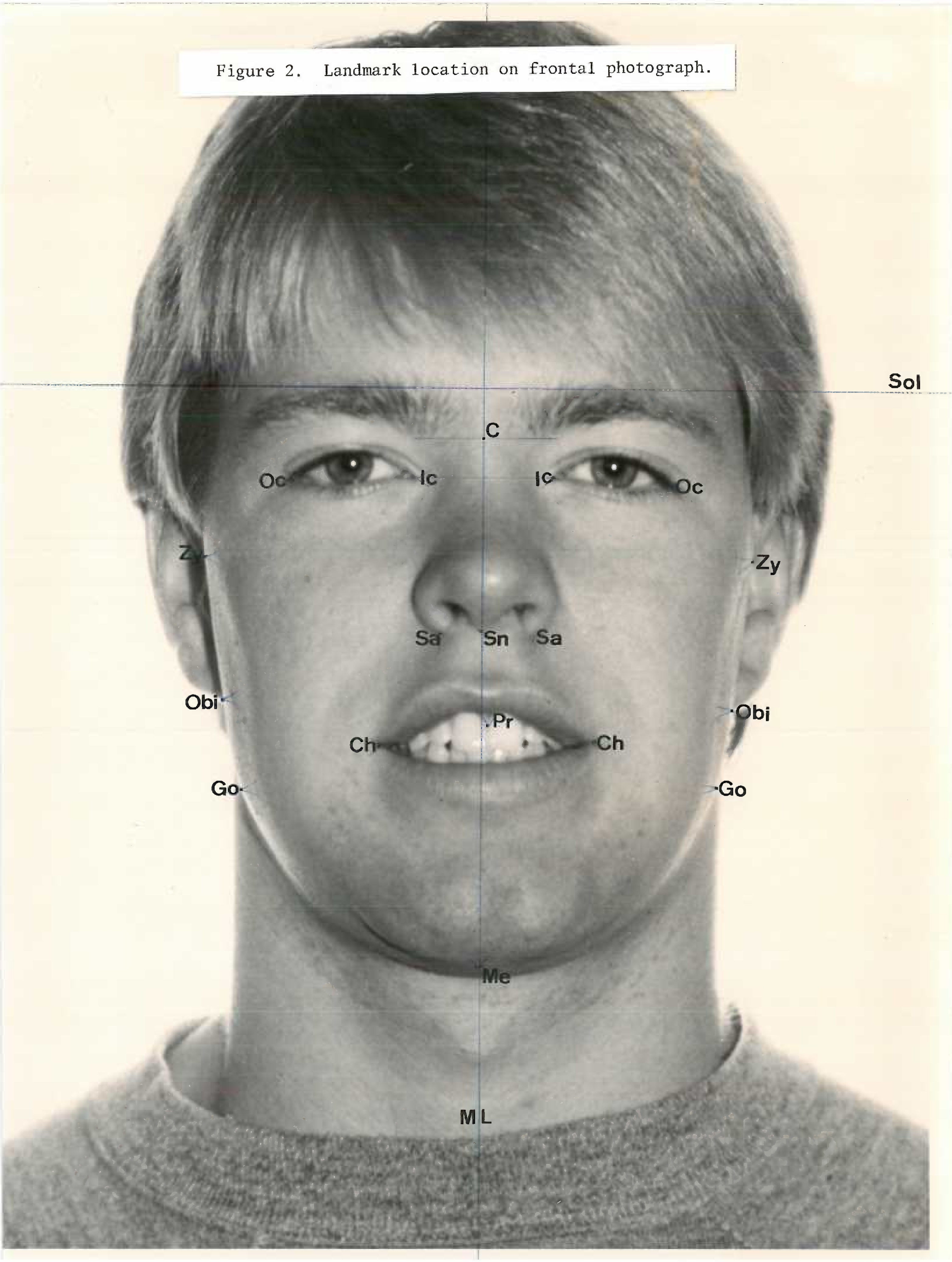

TABLE Ia

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

I. Cephalometric Data.

Facial Dimensions	S.E.Meas.* (mm.)	Percentage Error**
a) Upper Face Height	0.35	0.56%
b) Mid Face Height	0.35	1.53%
c) Lower Face Height	0.42	1.06%
d) TOtal Face Height	0.39	0.31%
e) Upper Face Width	0.27	0.22%
f) Lower Head Width	0.43	0.38%
g) Mandibular Width	0.29	0.31%
h) Nasal Width	0.47	1.67%
i) Maxillary Width	0.26	0.43%
j) Inner Canthal Width	0.36	1.60%
k) Outer Canthal Width	0.23	0.27%
l) Nasal Height	0.37	0.77%

*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

II. Photographic Data.

Facial Dimensions	S.E.Meas.* (mm.)	Percentage Error**
a) Upper Face Height	0.37	0.62%
b) Mid Face Height	1.14	6.25%
c) Lower Face Height	0.44	0.98%
d) Total Face Height	0.52	0.42%
e) Upper Face Width	0.77	0.65%
f) Lower Head Width	0.84	0.74%
g) Mandibular Width	1.41	1.39%
h) Nasal Width	0.49	1.84%
i) Mouth Width	0.53	1.04%
j) Inner Canthal Width	0.38	1.31%
k) Outer Canthal Width	0.94	1.13%
l) Nasal Height	0.40	0.80%

* S.E.Meas. = Standard error of 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 II

	CEPHALOMETRIC INDEX		PHOTOGRAPHIC INDEX	
	Mean	Standard Deviation	Mean	Standard Deviation
1) Upper Face Height	49.45	1.98	48.39	3.22
2) Mid Face Height	18.14	1.92	14.76	2.04
3) Lower Face Height	32.43	2.06	35.69	6.59
4) Total Face Height	99.74	5.91	103.37	6.48
5) Lower Face Width	42.8	4.11	44.74	4.46
6) Mandibular Width	75.69	3.63	85.28	3.73
7) Maxillary Width	47.47	2.31	43.5	3.09
8) Lower Head Width	89.38	5.81	92.62	6.56
9) Nasal Height:Total Face Height	38.23	3.06	41.02	3.15
10) Nasal Height:Upper Face Height	77.27	4.18	84.76	2.68
11) Nasal Height:Lower Face Height	118.81	15.83	112.29	15.30
12) Nasal Width:Nasal Height	59.34	4.4	52.36	5.96
13) Nasal Width:Inner Canthal Width	124.36	9.73	89.82	10.61
14) Nasal Width:Maxillary Width	47.5	3.35	50.86	5.08
15) Nasal Width:Lower Head Width	25.36	1.62	23.1	2.59
16) Inner Canthal Width	25.87	1.52	35.23	1.7
17) Outer Canthal Width	70.63	4.56	67.98	4.45
18) Outer Canthal Width:Upper Face Width	70.23	2.47	70.06	3.42

TABLE III

CEPHALOMETRIC MEAN versus PHOTOGRAPHIC MEAN	t-value	$\alpha = 0.05$
1) Upper Face Height	1.51	Accept Ho*
2) Mid Face Height	6.47	Reject Ho
3) Lower Face Height	2.54	Reject Ho
4) Total Face Height	2.23	Reject Ho
5) Lower Face Width	1.72	Accept Ho*
6) Mandibular Width	9.92	Reject Ho
7) Maxillary Width	5.53	Reject Ho
8) Lower Head Width	1.99	Accept Ho*
9) Nasal Height:Total Face Height	3.42	Reject Ho
10) Nasal Height:Upper Face Height	8.12	Reject Ho
11) Nasal Width:Lower Face Height	1.59	Accept Ho*
12) Nasal Width:Nasal Height	5.08	Reject Ho
13) Nasal Width:Inner Canthal Width	12.92	Reject Ho
14) Nasal Width:Maxillary Width	2.97	Reject Ho
15) Nasal Width:Lower Head Width	3.87	Reject Ho
16) Inner Canthal Width	22.06	Reject Ho
17) Outercanthal Width	2.24	Reject Ho
18) Outercanthal Width:Upper Face Width	0.22	Accept Ho*

* Accept Null Hypothesus : no significant difference between the cephalometric index mean and photographic index mean.

Degree of freedom = 58

TABLE IV Linear Correlation between Cephalometric and Photographic Indices

Cephalometric versus Photographic Index	Pearson Coefficient, r value
1) Upper Face Height	+ 0.33
2) Mid Face Height	+ 0.22
3) Lower Face Height	- 0.23
4) Total Face Height	+ 0.68
5) Lower Face Width	+ 0.37
6) Mandibular Width	+ 0.27
7) Maxillary Width	+ 0.16
8) Lower Head Width	+ 0.48
9) Nasal Height: Total Face Height	+ 0.24
10) Nasal Height: Upper Face Height	+ 0.07
11) Nasal Height: Lower Face Height	+ 0.30
12) Nasal Width: Nasal Height	+ 0.06
13) Nasal Width: Inner Canthal Width	+ 0.13
14) Nasal Width: Maxillary Width	- 0.17
15) Nasal Width: Lower Head Width	- 1.09
16) Inner Canthal Width	+ 0.46
17) Outer Canthal Width	+ 0.67
18) Outer Canthal Width: Upper Face Width	+ 0.41

Appendix A

Hard Tissue Landmarks

1. Root of Crista Galli (Cg) - where the crista galli meets the horizontal image of the sphenoid planum
2. Anterior Nasal Spine (ANS) - a constructed point formed from the intersection of the midline of the facial skeleton and the inferior borders of the pyriform aperture
3. Prosthion (Pr) - Lowest point of the alveolar bone between the maxillary central incisors
4. Menton (Me) - a constructed point projected from the mid-line to the inferior border of the mandible
5. Zygion (Zy) - most lateral point on the zygomatic arch. R&L
6. Mastoid point (Mas) - inferior tip of the Mastoid process. R & L
7. 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 the posterior border of the mandible. R & L
8. Alare (Ar) - most lateral point on the outline of the pyriform aperture. R & L
9. Molar Alveolar Point (Ma) - where the maxillary second molar meets the maxillary tuberosity or alternatively the point of deepest concavity of the maxillary tuberosity. R & L

10. Inner Canthus (IC) - most medial point of the orbital outline. R & L

11. Point X - intersection between supero-lateral border of the orbit and the temporal line taken as the outer canthus in measurement. R & L

Appendix B

Hard Tissue Indices

i) UFH Index $= \frac{1}{4} \times 100$

ii) MFH Index $= \frac{2}{4} \times 100$

iii) LFH Index $= \frac{3}{4} \times 100$

iv) TFH Index $= \frac{4}{5} \times 100$

v) LFW Index $= \frac{3}{8} \times 100$

vi) Mand W Index $= \frac{8}{5} \times 100$

vii) Max W Index $= \frac{6}{5} \times 100$

viii) LHW Index $= \frac{7}{4} \times 100$

Nose

i) NH:TFH Index $= \frac{9}{4} \times 100$

ii) NH:UFH Index $= \frac{9}{1} \times 100$

iii) NH:LFH Index $= \frac{9}{3} \times 100$

iv) NW:NH Index $= \frac{10}{9} \times 100$

v) NW:ICW Index $= \frac{10}{11} \times 100$

vi) NW:MaxW Index $= \frac{10}{6} \times 100$

vii) NW:LHW Index $= \frac{10}{7} \times 100$

<u>Eyes</u>

i) ICW Index $= \frac{11}{12} \times 100$

ii) OCW Index $= \frac{12}{4} \times 100$

iii) OCW:UFW Index $= \frac{12}{5} \times 100$

Appendix C

Soft Tissue Landmark

1. Point C - mid-point of line connecting inner tips of eyebrows
2. Subnasale (Sn) - mid-point 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.
3. Prosthion (Pr) - the lowest point of the gum septum between the maxillary central incisors. If not visible, alternative nearest point adjacent to inferior margin of upper lip.
4. Menton (Me) - a constructed point projected from the mid-line to the inferior border of the chin.
5. Zygion (Zy) - most lateral point of each zygomatic arch close to the bony zygion.
6. Otobasion Inferius (Obi) - point of attachment of the earlobe to the cheek, also the lowest border of ear insertion.
7. Gonion (Go) - most lateral point on the mandibular angle close to the bony gonion.
8. Subalare (Sa) - point at the lower limit of each alar base where the alar base disappears into the skin of the upper lip.
9. Cheilion (Ch) - commissure of the lips.
10. Inner Canthus (IC) - inner commissure of the eye fissure.
11. Outer Canthus (OC) - point at the outer commissure of the eye fissure.

Appendix D

Soft Tissue Indices

i) UFH Index $= \frac{A}{D} \times 100$

ii) MFH Index $= \frac{B}{D} \times 100$

iii) LFH Index $= \frac{C}{D} \times 100$

iv) TFH Index $= \frac{D}{E} \times 100$

v) LFW Index $= \frac{C}{H} \times 100$

vi) Mand W Index $= \frac{H}{E} \times 100$

vii) Mouth W Index $= \frac{F}{E} \times 100$

viii) LHW Index $= \frac{C}{D} \times 100$

Nose

i) NH:TFH Index $= \frac{I}{D} \times 100$

ii) NH:UFH Index $= \frac{I}{A} \times 100$

iii) NH:LFH Index $= \frac{I}{C} \times 100$

iv) NW:NH Index $= \frac{J}{I} \times 100$

v) NW:ICW Index $= \frac{J}{K} \times 100$

vi) NW:Mouth Index $= \frac{J}{F} \times 100$

vii) NW:LHW Index $= \frac{J}{G} \times 100$

Eyes

i) ICW Index $= \frac{K}{L} \times 100$

ii) OCW Index $= \frac{L}{D} \times 100$

iii) OCW:UFW Index $= \frac{L}{E} \times 100$