AN INVESTIGATION INTO THE CONSTANCY OF THE FORM OF THE FRONTAL SINUS

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By

Marie E. Lathrop, DMD

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INDEX

INTRODUCTION

Dental radiographs have proven to be a valuable aid in identification of persons in forensic science. Radiographs reveal the "distinctive shape of restorations, bases under restorations, tooth and root shapes, and sinuses" (1). Schuller, in 1943, proposed that the frontal sinus exhibited such individual variation that antemortem radiographs of this structure were sufficient for positive identification of skulls (2). Asherton went further and stated that the frontal sinus was as unique to an individual as finger prints.

The age in which we live presents many situations where the only remains available for identification may be the skull or portions thereof, such as nuclear accidents or airline disasters. In these instances, if the teeth are missing or are restoration free, then the only means of establishing identity may be to utilize other distinct features of the skull, for example the frontal sinus.

The frontal sinus arises in the space between the two tables of the frontal bone early in the first decade of life. It grows both vertically and laterally in an apparent random fashion. The outlines of the pneumatized cavities of this sinus are easily viewed in frontal cephalometric radiographs. These films are routinely taken by orthodontists and often by others in the medical and dental professions, thus providing antemortem dental records which could be utilized by forensic scientists for identification.

The purpose of this study was to analyze the growth patterns and the constancy of these patterns in the development and enlargement of the frontal sinus during the first four decades of life. This was done by examining frontal sinuses as viewed in standardized frontal cephalometric radiographs on a longitudinal basis for the first twenty years and a cross sectional basis for ages twenty through forty.

The data was obtained from these samples using a computerized digitizer and was analyzed to determine pattern changes during development. These changes were expressed as ratios, and differences calculated between adjacent age groups of the same individual. The objective was to determine if the pattern of the frontal sinus is distinctive, or even unique, and once established, does it remain constant enough throughout growth and thereafter, to be of value for identification in forensic science?

REVIEW OF LITERATURE

History:

The frontal sinus was first drawn by Leonardo Da Vinci (1452-1519) and first described by Coiter (1534-15767). For over three centuries, the presence of this unique structure was considered little more than a curiosity of nature. Near the end of the nineteenth century, many rhinologists were doing surgery on the frontal sinus, thus renewing interest in its anatomy. Prior to radiographs, the only data available on the structure of the frontal sinus was via observation of cadavors by anatomists such as described by Steiner (1887) and Onodi (1911).

When "x-rays" were discovered, it became possible for the frontal sinus to be observed in the living person. This has opened new doors in the study of the frontal sinus, allowing one to diagnose disease, or for academic purposes, to ascertain the growth and development of the sinus and its use for identification. (3)

Growth and Development of the Frontal Sinus:

The frontal sinus arises in the space between the inner and outer tables of the frontal bone. It develops from two main points, the frontal recess of the middle nasal meatus (4,5,6,7), and from the anterior ethmoid air cells (4,6,8,9). Development begins in the horizontal portion of the frontal bone during the fourth or fifth month of fetal life and is not topographically frontal until some time after birth (7).

During the first year of life, the frontal sinus is present only on the horizontal or orbital plate of the frontal bone (4,5). Pneumatization of the vertical plate takes place during the second year (4,5,8). It is not until the third or fourth year that its ascent is past the level of nasion and, therefore, visible radiographically (4,5,8,9).

Prior to radiology, the most common way to ascertain growth of the frontal sinus was by dissection of autopsy specimens. In 1918, Davis studied the anatomy and growth of the nasal accessory sinuses in 160 specimens ranging in age from newborn to 16 years (8).

The first investigator to study the longitudinal development of the frontal sinus was Maresh in 1940 (9). He evaluated radiographs taken at periodic intervals of one hundred children, ranging in age from birth to age 17. He first noted the frontal sinus above nasion at an average age of 3 years and found that the sinus had reached the level of the orbital plates by 7 to 9 years of age (with ranges from 3 to 13 years). Although Maresh did not statistically analyze his data, he demonstrated his finding by superimposition of the sinus at various age levels within the same individual.

In 1965, Asherton reported the findings from a study conducted on the growth and form of frontal sinus' in twins (3). In this cross sectional study, he analyzed radiographs of 74 pairs of twins with 200 non-twin children as controls. The children ranged in age from one year to 14 years. A few sets of adult twins were also studied. Each subject had a radiograph of the frontal sinus taken in the occipito-mental view. He compared each twins frontal sinus' to the other and then compared the twins sinus' to the non-twin controls. According to Asherton, the frontal sinus was recognizable radiographically as early as one year (ethmoidal form), and the upper edge reached the superior orbital margin by the age of 3. He states that the "adult form" of the sinus was evident as early as age 5, however, the definition of this stage is not given. He concluded there was no difference between the two groups, as growth and form in both showed a high degree of variability and individuality.

In 1984, Brown, Mollison and Chin analyzed the growth of the frontal sinus on a longitudinal basis utilizing cephalometric radiographs (10). These were taken at yearly intervals for approximately 100 children, beginning as early as 2 years of age. Twenty-eight subjects had the final cephalogram taken at 24 years or older. In this group, the median age for the first appearance of the frontal sinus was 3 years for males and 4 years for females. This is in contrast to Maresh, who felt there was no significant sex difference in the timing of the appearance of the "budding" frontal sinus (9). Brown, Molleson and Chin also found that the total enlargement of the frontal sinus was greater in males than in females (10). They hypothesized that this may be due to the fact that growth of the frontal sinus began later for females and ceased earlier. The average age at which the main enlargement of the frontal sinus ceased was approximately 14 years for females and 16 years for males, although six males continued to show frontal sinus growth at 24 years of age. The authors of this study felt that these findings indicated that enlargement of the frontal sinus was similar in timing to Tanner's figures for the cessation of changes in stature and, thus, that enlargement of the frontal sinus follows the trends for growth in height (11).

There is little agreement as to when growth of the frontal sinus ceases. Asherton felt that adult form was evident as early as age 5 (3). Davis found in his anatomic study that growth proceeded at a rate of approximately 1.5mm/year until the fifteenth year (8). Oppenheimer reported "full development is present by the eighteenth year" (12). Schuller stated that the frontal sinus continued to grow until the twentieth year, but that older people showed an increase in size of the frontal sinus - possibly relating to shrinkage of the frontal lobes of the brain (2). Weiman and Sicher also refer to a "senile enlargement" of the frontal sinus, but they felt this was due to a thinning of cortical bone that was related to loss or retardation of function of the masticatory apparatus (13).

Factors That Affect Pneumatization of the Frontal Sinus:

Throughout the studies that sought to analyze the growth of the frontal sinus, there is repeated mention of the large degree of variability in the development, as well as the form, of the frontal sinus (2,3,7,9). Schuller states, "The most striking feature of the roentgenographic appearance of the pneumatic spaces is the individual variation of their size and configuration." (2) Asherton felt all evidence indicated "the development of the form of the adult frontal sinuses is completely random . . . and do not develop to any consistant or predictable pattern." (3)

It has been suggested that the form of the frontal sinus is related to function, although its function remains unclear (13,14,15). Decrease of skull weight, adaptation to environmental influences, resonation of sound, and humidification of air have been proposed as possible function of the frontal sinus (14,15,16). No evidence exists to prove any of these claims.

Despite the lack of evidence to support a functional basis for the form of the frontal sinus, there are other factors which influence pneumatization of the frontal sinus, and hence its size and shape. Shapiro and Schorr outline three factors that they feel affect the pneumatization and hence the ultimate form of the frontal sinus; craniofacial configuration, hormonal factors and character of bone (5).

Differences in craniofacial configuration can be related to congenital abnormalities or ethnic variations. The frontal sinus is thought to act as a "structural bridge between cranium and face, a result of differential growth patterns between the neural inner table of the frontal bone and the facial outer table (5,17,18). Hence, in congenital abnormalities, where there is a deficient maxillary complex, such as maxillofacial dysplasia, there is a decreased need to bridge the neural-facial gap, resulting in a small frontal sinus.

Similarly, subtle ethnic variations can influence the size and shape of the cranium and the face and, thus, the frontal sinus (2,5,19). Turner and Porter, in 1921, found that the "frontal sinus in mixed European crania, whether dolicocephalic, mesacephalic or brachycephalic, are of large-average size and are more frequently present than the same cavities in the relatively pure races and in the skull types constituting these races (19).

Schuller reported that the presence of the frontal suture was more frequent in Europeans (8.7%) than Mongols (5.1%), Malayans (5%), Negroes (1.2%), and Australian aborigines (1%). And in the presence of this suture, the frontal sinus tended to be small.

Shapoiro and Schorr suggested that in dolicocephalic crania, characterized by long, narrow head and face, the outer table of the frontal bone drifts anteriorly with the nose, creating a void between inner and outer tables that is filled in by a larger than average frontal sinus (5). In brachycephalic crania with short, wide heads, there is a less protrusive nature to the face and, therefore, a smaller frontal sinus.

Harris, Wood et al compared standardized radiographs of two ethnic groups (Black versus Cape Coloured) (20). They examined various frontal sinus features such as sinus, height, width and area between these two groups and identified subtle variations between the Cape Coloured group and the Black group. However, they concluded that these differences were insufficient for "definitive identification".

Hormonal growth factors can also affect the pneumatization of the frontal sinus. Growth factors can either increase or decrease the bone cell matrix as well as hasten or retard the cessation of bone growth (21). Increased secretions of these growth factors, often seen in cases of hyperpituitarism, leads to increased deposition of bone on both the external surface of the outer table of the frontal bone and the interior surface of the inner table. This leads to an increased discrepancy between these two tables and, hence, a markedly enlarged frontal sinus (5). Juvenile hypothyroidism is also associated with prominant development of the frontal sinus, perhaps due to oversecretion of growth hormones to compensate for target gland deficiency (2,5).

Conversely, in cases of diminished pituitary function, such as is seen in a pituitary dwarf, there is often hypoplastic or absent frontal sinuses. Adult cretins also tend to have underdeveloped frontal sinuses (5).

"Other considerations being equal, ie ethnic and hormonal, the ability of a mucosal sinus to penetrate into bone is influenced by character of bone (5). Thick bone presents an obstacle to the advancing mucosa. Thus, conditions such as osteopetrosis or autosomal osteosclerosis can lead to hypoplastic or absent frontal sinuses. Thin bone, such as that seen in osteogenesis imperfecta, is readily invaded by the mucosa and florid pnematization is seen (5).

In addition to craniofacial configuration, hormonal factors and character of bone, other factors also appear to influence the form of the frontal sinuses. Many authors have suggested there is a gender difference in the form of the frontal sinus, with male sinuses appearing larger and more loculated than female sinuses (2,6,10,22). Harris, Wood et al studied these gender differences and concluded they were insufficient for sex classification (20).

Koertoelyessy evaluated the relationship between climatic conditions and occurance and size of the frontal sinus (15). He found a relationship between cold conditions and small frontal sinus surface area. He speculated that this environmental influence on frontal sinus pneumatization was related to cold adaptation.

Schuller felt that constitutional factors may also influence or alter the "size, shape and outline of the frontal sinus." (2) These include inflammatory conditions, tumors and injuries. Inflammatory conditions such as tuberculosis or syphillis can cause destruction of the frontal bone and, hence, alter the form of the frontal sinus (2,3). Tumors, as well as inflammation can block the fronto-nasal duct and lead to ballooning of the frontal sinus. Tumors and injuries can lead to destruction or deformation of the forehead and, thus, to changes in frontal sinus form.

Although many factors influence the ultimate shape and size of the frontal sinus, these seem to be as variable as the individual and, thus, contribute to the unique nature of the frontal sinus.

Identification Via Frontal Sinus Prints:

The individual nature of the outline of the frontal sinus has been noted by many authors (2,3,6,7,9,20,24,25). As early as 1921, Schuller suggested identification of skulls by comparison of roentgen ray plates of the frontal sinus with antemortem films of the same sinus in emergency medico-legal cases and in criminal anthropometry (23).

In 1927, Culbert and Law, physicians from New York, described a medico-legal case where they were asked to identify the remains of a suspected former patient (24). They "conclusively identified the individual through the use of radiographs of the nasal accessory sinuses" (including the frontal sinus). The authors suggested that radiographs taken of men going to combat areas would aid in possible future identification because of "the lifelong permanence of the contour of the bony structures in an adult person."

In 1943, Arthur Schuller expanded on his earlier work and proposed a method to describe the configuration and to measure the extensions of the frontal sinus as seen in radiographs for the purpose of identification (2,23). In this technique, the head was oriented in a relatively standardized fashion and the primary x-ray beam passed through the supra-orbital margin, parallel to the Frankfort Horizontal plane. The sinus was analyzed by a relatively simple construction consisting of a vertical line corresponding to the median sagittal plane and a horizontal line corresponding to the jugum sphenoidale. Additional lines were added corresponding to the upper and lateral border of the combined frontal sinuses and to the larger of the frontal sinus, resulting in two rectangles. From these rectangles, three measurements are taken; the total width, the width and height of the larger sinus. Schuller stated that "these three measurements, combined with the description of the frontal septa, of the arches of the upper border of the frontal sinuses and of separate cells in the supraorbital region should allow one to identify the frontal sinus of each individual skull." He went on to suggest that the above measurements would be sufficient as "fundamentals for the classification of large numbers of cases and may be used as the basis of a filing system for the x-ray pictures" (2).

In 1942, Turpin, Tisserand and co-workers studied the correlation between frontal sinuses in twenty-four pairs of twins (26). Standardized sub-occipito-mental radiographs were taken and were projected to a paper screen, where a template was made of each individuals frontal sinus. These templates were weighed and compared, with the assumption that the weight of each template was proportional to the total surface area for that frontal sinus. The square roots of the areas were compared between the twins at varying ages. There was no correlation between the difference in square roots between each twin. As these investigations were primarily interested in observing the similarity between twin sets, the individual nature of the frontal sinus was not investigated, although the results indicate a dissimilarity between frontal sinuses, even in identical twins.

In 1965, Asherton investigated the frontal sinus of twins in childhood (3). As a control, the sinuses of nearly 200 children at varying ages were also studied. This investigation was discussed previously. During this study, Asherton noted the random nature of the form of the frontal sinus among individuals and extended the investigation to include adults. A group of over

2,000 ex-servicemen ranging in age from 20 to 50 were radiographed in a standardized occipito-mental view (the method of this standardization is not discussed). Tracings of frontal sinuses of 71 of these subjects are illustrated in the paper, as well as some radiographs, however, no statistical analyses of the data was presented.

Asherton suggested a method to classify and calibrate the varying forms of the frontal sinus to facilitate filing known as the frontograph. The frontograph was obtained by superimposing coordinate system on a tracing of the standardized frontal sinus radiograph. The horizontal axis was at the level of the supra-orbital margin and the vertical axis was located in the midline. To these axis, a protractor was oriented which contained an arc of circles at .5cm intervals and lines radiating from the center at 10 degree intervals. The dimensions were measured from the center. Asherton also illustrated a linear frontal sinus protractor which is oriented in a similar way on the supra-orbital margin and the midline, but has lines spaced across the x-axis at 1cm intervals and the height and width of the frontal sinus of these intervals was measured and can be charted.

Although no statistical analysis was done by Asherton, he concluded from his investigation that there was a great degree of variability when comparing frontal sinus graphs between individuals and that the frontal sinus did not change in adults. He felt that these two factors allowed the frontal sinus to be sufficient for conclusive identification when ante-mortem radiographs were available.

For over 20 years, little work was done regarding the use of the frontal sinus for identification. In 1987, Harris, Wood and co-workers rekindled interest in the subject with their pilot study, "The Frontal Sinus: Forensic Fingerprint?" (25). They set out to "rigidly" standardize occipito-mental radiographs so they could be compared more reliably for identification purposes. Thirty-two patients were radiographed and tracings from these radiographs were measured in both the horizontal and vertical dimensions and the number of edge loculations on the superior border were compared. The authors found that "no two frontal sinuses were alike". They differed with respect to width, height and number of edge loculations. The conclusion was drawn that the image of the frontal sinus was a suitable means for identification, provided that the postmorten radiograph was taken at a similar angulation as the antemortem radiograph and that identification be restricted to adults where growth had ceased. No statistical analysis was done to re-enforce this clinical impression.

In December of 1987, the same group of authors compared standardized frontal radiographs of two different ethnic groups with equal numbers of males and females in each group to ascertain if variations between groups would serve as a basis for identification (20). The radiographs were analyzed both quantitatively and subjectively. The latter consisted of counting the number of edge loculations, as well as determining the presence of the metopic suture. Quantification included the measurement of total surface area [similar to Turpin and Tisserand (26)], height and width [similar to Schuller (2)], and intra-orbital width. Measurements were compared between races and between sexes using the students t-test. Although some statistically significant differences were found, the authors concluded that, "If no antemortem radiographs exist,........it seems unlikely that any radiographic feature of the frontal region can serve as an indicator of either the corpses sex or race" (20).

Thus, in the studies that have been done to date, none have shown quantitatively the consistancy of the form of the frontal sinus during growth and in adulthood. The study that follows will analyze the form of the frontal sinus using standardized radiographs and will show the relationship of the shape of the frontal sinus to the individual during growth and in adulthood.

METHODS AND MATERIALS

Sample

Standardized frontal radiographs of 27 children and 13 adults were utilized to study the growth and change of the frontal sinus on a longitudinal basis. The films were standardized by using a Bolton-Broadbent Cephalometer with fixed head orientation (27).

The radiographs of the group of children were obtained from the records of the Oregon Growth Study. The subjects selected had previously been identified as a group with a normally developing occlusion and consisted of 12 males and 15 females (28). Selected head films of these children were analyzed at intervals of approximately every third year, starting as young as three years of age for one subject and extending to twenty-six years of age for another subject (Table 1).

Approximately 130 tracings of the frontal sinuses were made from these radiographs by four first-year orthodontic residents. Each resident traced all the films for a particular subject.

The adult sample consisted of 13 subjects, 9 females and 4 males, between the ages of 20 and 40 who had frontal radiographs taken as a portion of the beginning records for routine orthodontic treatment. A subsequent frontal headfilm was obtained as either a progress record or a final treatment record. The second radiograph was taken between 2 and 5 years following the original film, and comparisons were made between tracings of the same individual (Table 1).

Analysis of Data

The images of the facial skeleton and of the frontal sinus from each radiograph were traced onto an 8x10" piece of acetate paper. The borders of the orbits and of the midline structures of the face were also included.

Two reference planes were fabricated from these outlines and were added to the tracings in order to construct an X-Y coordinate system. The X-axis was a line parallel to the tangent of the supra orbital margins and placed one-half inch inferiorally. The Y-axis was placed perpendicularly to the X-axis at the mid point between the medial borders of the orbits.

A protractor, with lines radiating from the center at 10 degree intervals, was placed beneath the tracing paper and oriented to the X-Y axis (similar to Asherton). The center of the protractor was placed with its midpoint at the junction of the X-Y axis. This point was transfered to the acetate tracing paper and was referred to as "center point". Five points were transfered from the protractor onto the tracing of the frontal sinus outline at 10 degree intervals on either side of the Y-axis, resulting in 11 points in all (Fig. 1).

The 11 points were registered sequentially, beginning with the center point and proceeding from left to right on a computerized digitizer. The distance between the center point and each point on the outline of the frontal sinus was calculated by the computer and expressed in mm. the distances were numbered 1 through 10, from left to right. The relationship of these distances to each other was believed to be indicative of the shape of the frontal sinus and, thus, of its individual nature.

The average of the 10 distances was computed, and this average value was divided into each individual distance, resulting in a ratio value for each of the 10 points. These were known as "ratio one" through "ratio ten." Ratios were utilized in an effort to evaluate the constancy of the shape of the frontal sinus, factoring out size increases during growth, or as a result of radiographic enlargement.

Data was grouped into three-year age ranges for the group of children, beginning as early as age 3 in two individuals. Analysis of ratio values was done between adjacent age groups in the children. Adult frontal sinuses were studied by comparing ratio values between the two ages that were available for each participant.

Males and females were considered separately.

Statistical Analysis

1. The ratios were compared between age groups of the same individual by calculating the absolute difference between the ratio value for each point.

2. The mean of the differences between the ten ratio values was calculated by dividing the total of the differences for each individual comparison by 10.

3. The standard diviation of the differences of ratio values about the mean within age groups was calculated using the formula:

$$S = \Sigma \sqrt{\frac{(X - \bar{X})^2}{N-1}}$$

4. The students t-test were run between males and females of the same age group. The Null hypothesis was stated as follows: Ho: Mean ratio difference males = mean ratio difference females. Hi: Mean ratio difference males ≠ mean ratio difference females. This was to determine if there was a significant difference due to gender in the constancy of the outline of the frontal sinus at the 95 degree confidence level.

5. Linear regression analysis and Pearson's r were calculated for the 7 age groups in males and females. This was done to determine the relationship of mean ratio differences in the various age groups.

Analysis of Error

Technical, tracing and digitizing errors were all considered in order to allow for appropriate interpretation of the results. Technical errors included enlargement, image blurring due to the penumbra effect and variation in head orientation. These effects were minimized by utilizing the same x-ray machine set up for all radiographs, and the same experienced technicians for both exposure and development of these films. Enlargement, although present, was considered not to contribute much to error due to the fact that the frontal sinus was oriented very near the film and that ratios were used for analysis, rather than absolute measurements. Blurring due to the penumbra effect and variations in exposing and developing the radiographs was present in all subjects and could contribute to tracing error. Slight differences in head orientation could lead to distortions that would contribute to error when making comparisons on the same individual. This factor was controlled by utilizing a standardized head holder.

Measurement error was considered to be composed of tracing error and digitizing error. The radiographs of 14 subjects (9 children and 5 adults), were randomly selected and replicate tracings of the frontal sinus were made. The replicate tracings were analyzed by the computer digitizer in the same manner the original tracings had been. Differences between the distance calculation for each point on the original and duplicate tracings were computed, and the mean and standard error of the mean for each point was calculated. The standard error of the means of these differences for all 10 points were averaged resulting in the mean value for the combined standard errors. This value was considered to represent total measurement error amd was expressed in mm.

Digitizing error was evaluated by re-digitizing the same tracing of the frontal sinus eight times. Standard error of the mean was calculated for each of the points and these values were averaged to arrive at the amount of error due to digitizing.

Tracing error was considered to be error remaining after factoring out digitizing error from total error.

Total error = digitizing error + tracing error.

RESULTS

The data obtained from this study are presented as follows:

Table 2: Indicates the results of the analysis of error. The total measurement error is .6mm. Approximately 87% of this error is associated with tracing and 13% with digitizing.

Tables 3a & 3b: The data presented are the mean values of the absolute differences between ratio values for the ten points in adjacent age groups for an individual. The average difference for each age group is given at the bottom of each column. It is interesting to note that each of these values decreased with increasing age for both the males and the females - suggesting that the variability of an individuals frontal sinus decreases with age.

Figure 2: Illustrates the data obtained from Tables 3a and 3b. This graph shows the relationship between age and variability in the form of the frontal sinus is negative.

Figure 3: Gives the results of linear regression analysis on the male and female samples. This analysis indicates that the variability of each age group lessened in a predictable fashion - following the pattern of a straight line. The high values of Pearson's r confirms this correlation.

Table 4:	Reports the results of a comparison, by way of the "students t-test" of the mean ratio differences between males and females at the different age catagories. There were significant differences, at the 5% confidence level, in two age groups. This is not surprising, as these groups, the 12-15 year and 15-18 year, correspond to ages in which male and female growth patterns differ.
Figures 4a - 4e:	Depict the differences between ratio values for each of the ten points as they relate to the mean (x-axis) in 5 of the adults studied. This relationship of the ratio values around the mean is indicative of the shape of the frontal sinus.
Figures 5,6,&7:	llustrate the change in variability in the form of the frontal sinus in growing individuals.
Figures 8a - 8c:	Show the variation in the shape of the frontal sinus between different individuals.

DISCUSSION

The purpose of this study was to evaluate the constancy of the pattern of the frontal sinus from childhood through adulthood. Ratio values for the ten points placed on the outline of the frontal sinus were utilized in order to evaluate its shape without the influence of enlargement due to growth or variation in head position. As these ten points were placed by orientation of a protractor at a constructed X-Y axis in the nasal region, the smaller the frontal sinus - the greater the source of error, because in a small frontal sinus, the pneumatization of the vertical portion is radiographically superimposed upon the air spaces of the horizontal portion and the ethmoid air cells, and thus not clearly identifiable on a frontal x-ray. In addition, the ten points used to define the outline of the sinus very closely approximate each other, increasing the chance of digitizing error. In Table 3a, two of the adults had small frontal sinuses at or below the level of the supra-orbital margins. These subjects showed the greatest variability in the shape of the sinus of the adults studied. Maresh reported that at 8 years of age, only 50% of children had frontal sinus development above the supra-orbital margins. (9) Because a great amount of error in evaluating and interpreting the shape of the frontal sinus is possible in individuals with small sinuses, error could account for a portion of the high variability in the outline of the frontal sinus noted in young children and its subsequent decrease as an individual ages and the frontal sinus grows.

In Tables 3a and 3b, the mean of the differences in ratio values for each age group is given, as well as the differences for each particular individual studied. In the overall sample, as well as for each child studied longitudinally, the mean differences of ratio values decreased with age, suggesting that the outline of the frontal sinus became less and less variable with increasing age. The decrease in variability in form for an individual was probably due to an increase in size of the frontal sinus, as well as establishment of unique patterns during growth due to differences in genetic makeup and environmental conditions. The pattern of decreasing variability showed a negative linear regression with a high correlation coefficient (Figure 3).

Males and females tended to show the same decrease in variability of outline of the frontal sinus with the exception of two age groups, the 12-15 year and 15-18 year groups (Table 4). According the Tanner, there is a marked acceleration in growth at adolescence known as the "adolescent growth spurt". (11) This phenomenon takes place in all children, but varies in intensity and duration. Females, on average, undergo the growth spurt two years prior to males. Brown, Molleson, and Chin showed that the median age in which the main increase in size of the frontal sinus ceased was 15.68 years for males and 13.72 years for females, suggesting that the enlargement of the frontal sinus followed the trends noted by Tanner for growth in bone lengths. (10)

The significant differences in variability between males and females at the adolescent age groups indicate that the growth that takes place during the "spurt" lessens the variability in females sooner than in males. Again, this is probably due to earlier increase in size as well as stabilization of form following the major changes associated with growth.

Following the adolescent growth spurt, skeletal growth, and most probably frontal sinus growth dimishes and stops. This leads to further decreases in variability in the 18-21 year group and the adult group.

Minimal variability is essential for the use of frontal sinus images for identification purposes. Asherton stated that in order for a structure to be useful for identification, "it should be permanent or fixed and unalterable...". (3) The high variability seen in the younger age groups in this study would drastically reduce the value of radiographs of the frontal sinus from these groups for identification. Conversely, an examiner could rely on information obtained from antemortem radiographs of non-growing or adult individuals, because their variability over time is very small.

The method utilized in this study to evaluate the shape of the frontal sinus could be employed as a system for classification of antemortem radiographs. Asherton felt that structures for identification need to have their individual characteristics classified so that each person has a unique position in record files. (3) The system Asherton suggested was the frontograph, which, although similar to the method used in this investigation, relied on the size as well as the shape of the frontal sinus. By utilizing size as a variable for classification, one enconters problems associated with obtaining a post-mortem radiograph with not only the exact orientation of the ante-mortem film, but also with replicating the original radiographic set up. Alteration in the set up could lead to elongation or shortening of one radiographic image when compared to another, thus distorting the size variable.

Harris and co-workers described a method to obtain similar angulation of ante- and post-morterm radiographs. (25) This method is useful when the identity of a corpse is suspected, however, it is not satisfactory for identification when identity is not suspected.

The use of ratios in this study to describe the form of the frontal sinus is believed to factor out size and possibly angulation variables. Therefore, ratios could be used to classify and catagorize the images of frontal sinus obtained from radiographs of missing persons. The ratio values could be stored on a computer to be matched with a frontal sinus radiograph from a cadaver of unknown identity. Although this technique would probably not be ideal for conclusive identification, it could be utilized as a screening process to obtain a list of possible identities.

The list of possibilities from the screening process could then be analyzed in a similar manner to identification based on suspected identities, which involves obtaining a similar radiographic angulation of the frontal sinus, and comparing these images by "hand", rather than via of a computer or a computer-generated technique. This is due to the intrinsic amount of error generated by tracing and digitizing radiographs for analysis. The total error for this study was .62mm with .08mm due to digitizing error and .54mm due to tracing error (Table 2). Therefore, the use of tracings and measurements obtained from these tracings is too variable to be of use as the sole basis of identification, but comparison of the radiographs themselves by an examiner would remove these sources of error from the identification process.

Even with the error considered, the extremely low differencs of ratio values seen in the non-growing groups in this study suggest that the form of the frontal sinus, once established, is constant and nonchanging. This feature, along with its uniqueness to the individual, confirms the usefulness of the frontal sinus as a characteristic in which conclusive identification can be based.

SUMMARY AND CONCLUSIONS

Identification by utilization of frontal sinus images has been suggested by numerous investigators (2,3,6,7,9,20,24,25). The unique nature of this sinus to the individual is well accepted, however, the constancy of this form had not previously been investigated. The purpose of this study was to evaluate the variability in pattern of the frontal sinus as an individual grows and matures, in order to establish if and when the form of this sinus becomes constant. Males and females were studied separately

1. In both males and females, variability in the form of the frontal sinus decreased in a predictable pattern with increasing age. There were no significant differences in variability between males and females except in two age groups : 12-15 and 15-18 years. This was felt to be related to differences between males and females in the timing of the adolescent growth spurt.

2. Variability in the late adolescent group (18-21) and the adult group (21+) was minimal, suggesting that the pattern of the frontal sinus, once established was relatively constant.

3. The constancy of the pattern of the frontal sinus in mature individuals indicates that the radiographic images of this sinus could be utilized for identification purposes. Images of the frontal sinus in pre-adolescent and adolescent individuals would not be as reliable for this purpose.

TABLE 1

Ages corresponding tracings of frontal sinuses

Ia Children

Female									Males						
F61	10-	12-	15-1	17-1				4	M21.1	6-	9-1	12-	14-1	19-	5
F25	12-	14-1	18-	12-1				4	M155.2	9-1	11-6	14-1			3
F122	7-	9-	10-11	13-10				4	M026	12-	14-11	18-	19-		4
F47	6-	9-	12-	15-	19-	24-		6	M056	6-	9-1	12-	15-2	17-3	5
F83	6-	9-	15-1	23-5				4	M100	9-	12-	15-	17-1		4
F35	5-6	9-	13-					3	M309	6-	9-	12-	15-1	16-1	5
F158	3-	12-	15-1	17-1				4	M254	8-11	12-6	15-2	17-1	21-	5
F213	9-	12-	15-	18-	19-			5	M194.1	6-	9-	12-	13-7		4
F99	8-	12-	15-	17-	21-1	26		6	M89	3-	6-	9-	12-	15- 18-4	6
F51	7-	9-	12-	15-	18-2	24-		7	M89.2	9-1	12-	15-	16-		4
F266	7-8	9-2	12-1	15-1	18-	21-5		6	M108	9-2	11-9	15-	17-9	23-	5
F25.1	6-1	9-	12-	14-11	18-5			5							
F239	7-6	9-	12-	15-	18-	21-	26-2	7							
F62	10-	12-	15-1	17-1				4							
Total								75							55

Ib Adults

Females			Males		
B.C.	38-9	41-11	R.W.	36-4	38-3
M.T.	32-2	37-4	R.B.S.	34-8	36.9
M.B.	40-1	42-6	P.C.	41-0	42-10
L.V.	27-5	29-4	M.D.	29-3	33-11
J.L.	26-11	29-11			
A.H.	37-7	40-1			
S.S.	23-0	25-3			
L.L.	23-6	28-5			
J.L.	22-5	26-4			
C.D.	30-10	32-11			

Ages appear as years - months

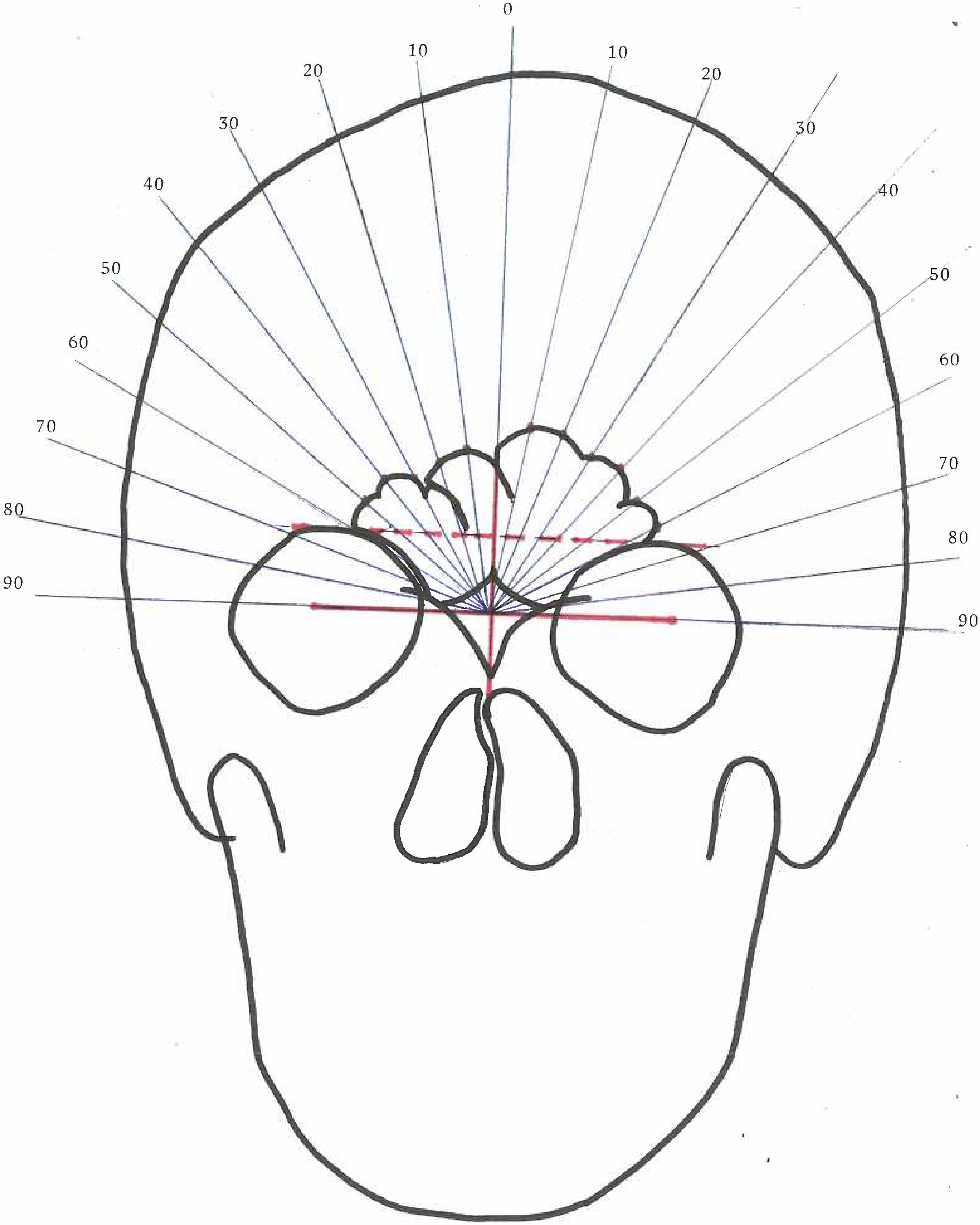


FIGURE 1

(See Next Page)

FIGURE 1: Illustrates the superimposition of the protractor on the x-y coordinate system.

Eleven points are placed on the tracing of the frontal sinus at 10 degree intervals - 5 on either side of the y axis and the center point at the junction of the x-y axis.

TABLE 2

ANALYSIS OF ERROR

*	Total Error (Measurement Error)	- - .62mm	
**	Tracing Error	- - .54mm	87%
*	Digitizing Error	- - .08mm	13%

* Total error and digitizing error calculated by averaging the standard error of differences for the 10 points from the replicate measurements.

** Tracing error was considered to be equal to the total error minus the digitizing error.

TABLE 3a - Females

SUBJECT	3 TO 6	6 TO 9	9 TO 12	12 TO 15	15 TO 18	18 TO 21	over 21
F51			.153	.142	.057		
F25				.035	.061	.017	
F122		.259	.427	.178			
F47		.413	.259	.106	.079	.033	
F33		.323	.313		.064		
F35		.198	.226				
F158			.111	.045	.035		
F213			.111	.069		.048	
F99			.330	.049	.026	.163	.021
F31			.544	.179		.073	
F266		.061	.073	.078	.018	.025	
F290	.469	.330	.087	.112	.037	.036	
F251-1		.450	.341	.137	.019		
F239			.315	.363			
F52			.365	.077	.062		
Laura V							.051
Suzette S							.040
Joan L							.028
Margie T							.072 *
Bev C							.051
Cindy D							.011
Lari L							.033
Alice H							.026
Marilyn B							.013
Jackie L							.110 *
TOTALS	.469	2.034	3.655	1.570	.458	.395	.456
SUM	1.000	7.000	14.000	13.000	10.000	7.000	11.000
AVERAGE	.469	.291	.261	.121	.046	.056	.041

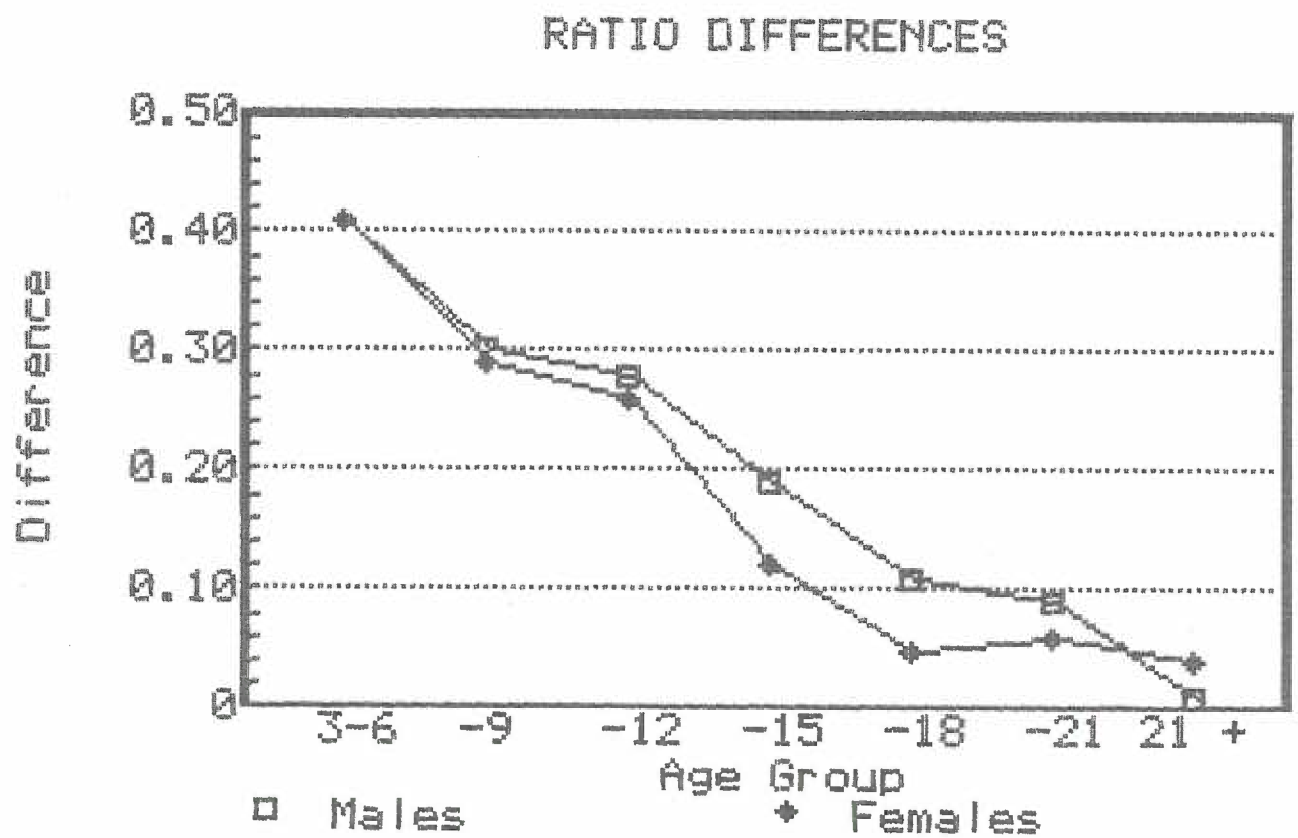
* notes adults with frontal sinus at or below the level of the supra-orbital margin.

Tables 3a and 3b - Show the mean differences in ratio values for the 10 points between adjacent ages for each individual. Means have also been calculated for each age catagory utilizing the data from the table.

TABLE 3b - Males

SUBJECT	3 TO 6	6 TO 9	9 TO 12	12 TO 15	15 TO 18	18 TO 21	over 21
M21.1		.336	.140	.041	.168		
M155.2			.292	.341			
M026				.229	.193	.179	
M056		.383	.247	.076	.038		
M100			.414	.203	.182		
M309		.205	.296	.216	.066		
M254			.373	.281	.101	.049	
M194.1		.343	.229	.054			
M89	.343	.248	.099	.050	.038		
M60			.296	.096	.136		
M89.2			.321	.390	.090		
M108			.317	.284	.109	.052	
Reg W							.011
Mark D							.020
Raoul B							.016
Pat C							.011
TOTALS	.343	1.515	3.024	2.261	1.121	.280	.058
SUM	1.000	5.000	11.000	12.000	10.000	3.000	4.000
AVERAGE	.343	.303	.275	.188	.112	.093	.014

FIGURE 2



Illustrates graphically the change in mean ratio differences in various age groups utilizing data obtained from Tables 3a and 3b.

FIGURE 3a

LINEAR REGRESSION ANALYSIS

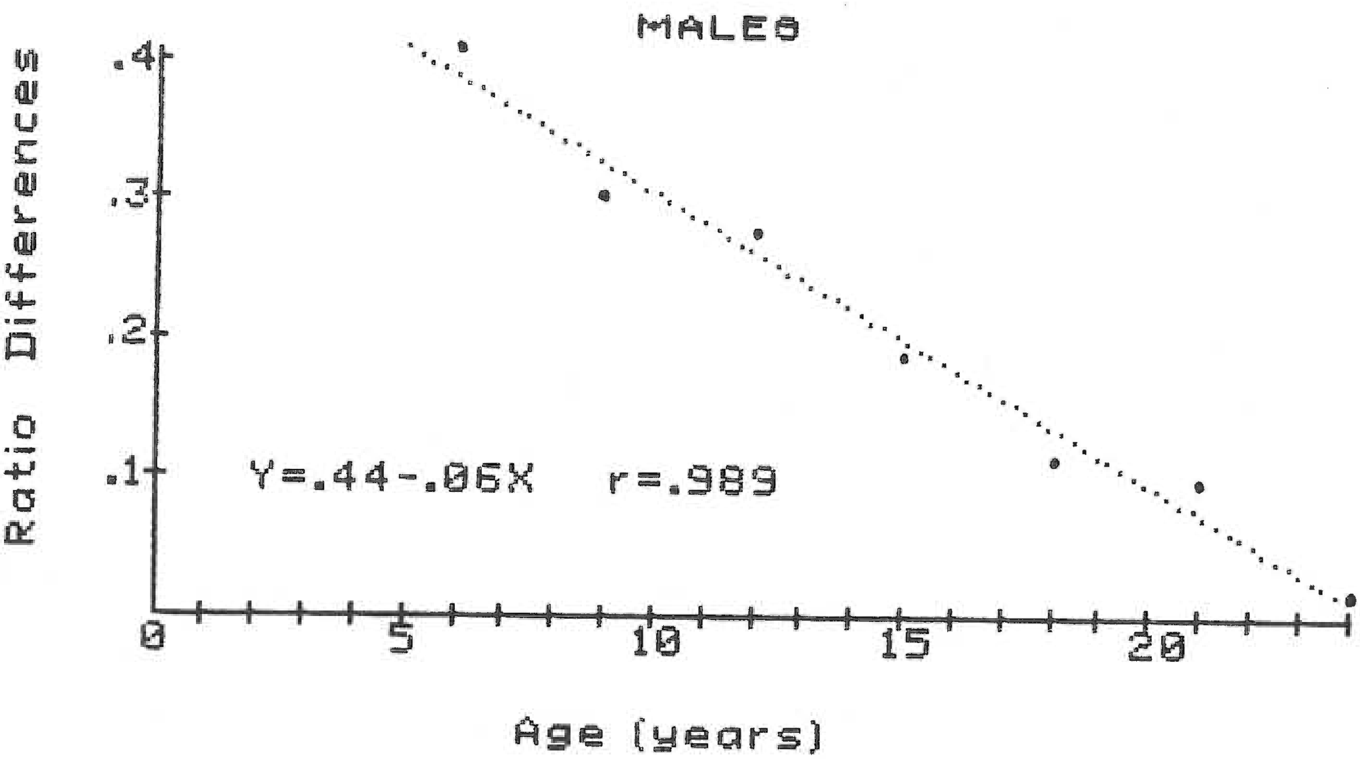


FIGURE 3b

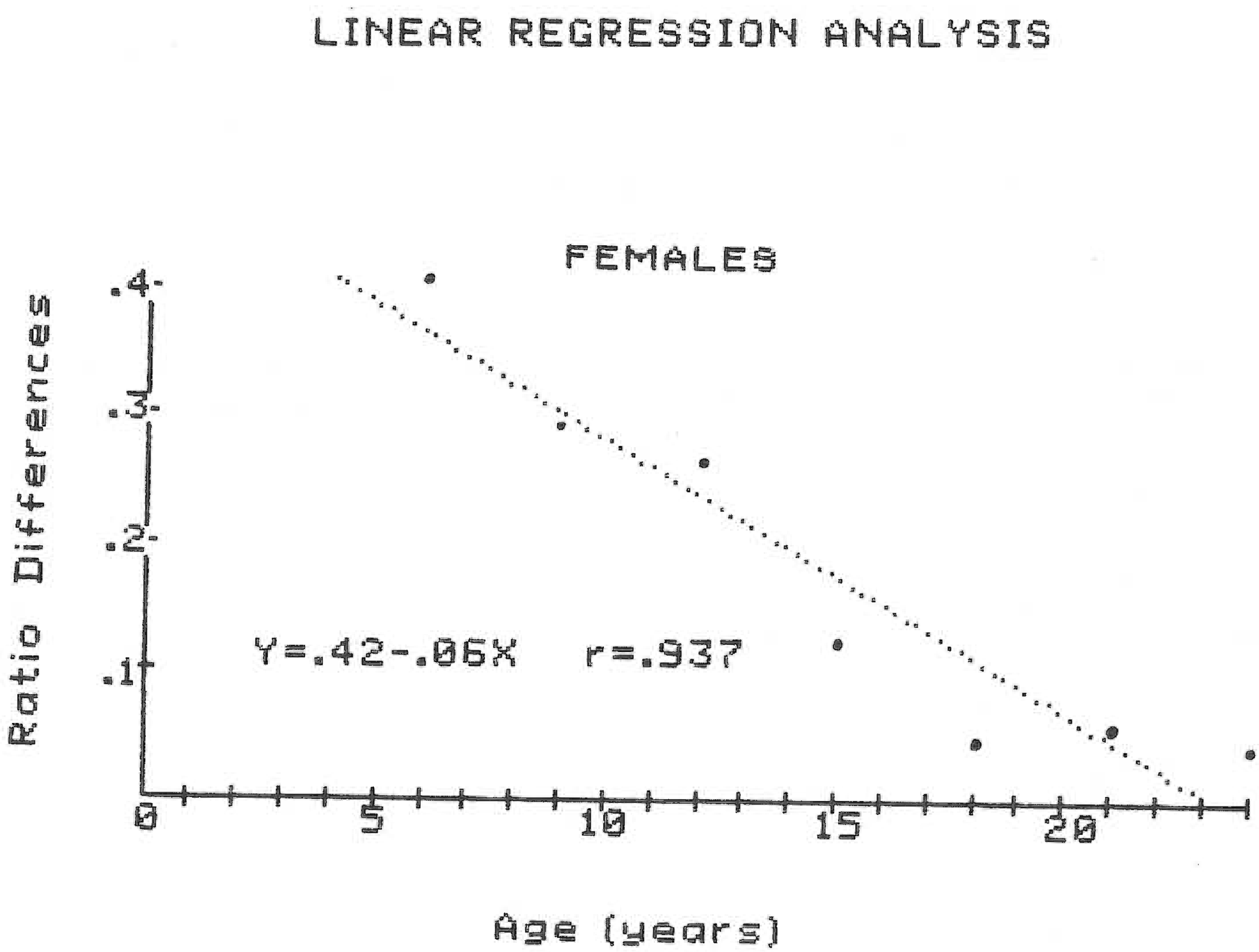

LINEAR REGRESSION ANALYSIS
FEMALES
Ratio Differences
.4
.3
.2
.1
Y=.42-.06X r=.937
0
5
10
15
20
Age (years)

TABLE 4

Student's t-test

Age Group	Degrees Freedom	t-value	
6 - 9	10	.188	accept Ho
9 - 12	23	.280	accept Ho
12 - 15	22	2.42	reject Ho ($P < .05$)
15 - 18	17	2.42	reject Ho ($P < .05$)
18 - 21	8	.464	accept Ho
> 21	10	1.03	accept Ho

Null Hypothesis (Ho): Mean ratio difference males = mean ratio difference females.

Alternate Hypothesis: Mean ratio difference males ≠ mean ratio difference females.

FIGURES 4-8: Depict ratio values of each of the ten points (shown on the x-axis) as they relate to the mean. Comparisons of ratio values at different ages gives an indication of the variability of the form of the sinus.

FIGURES 5,6,7: Illustrate the differences in ratio values at varying ages in growing individuals.

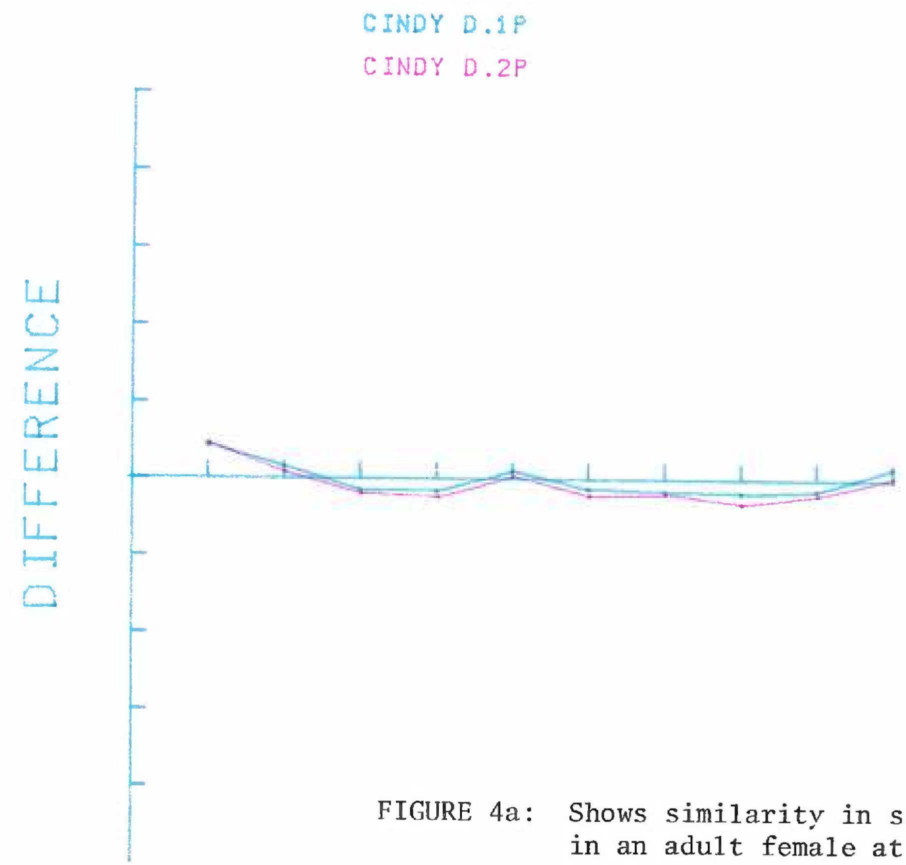


FIGURE 4a: Shows similarity in sinus form in an adult female at two different ages.

Mean difference is 1.1%

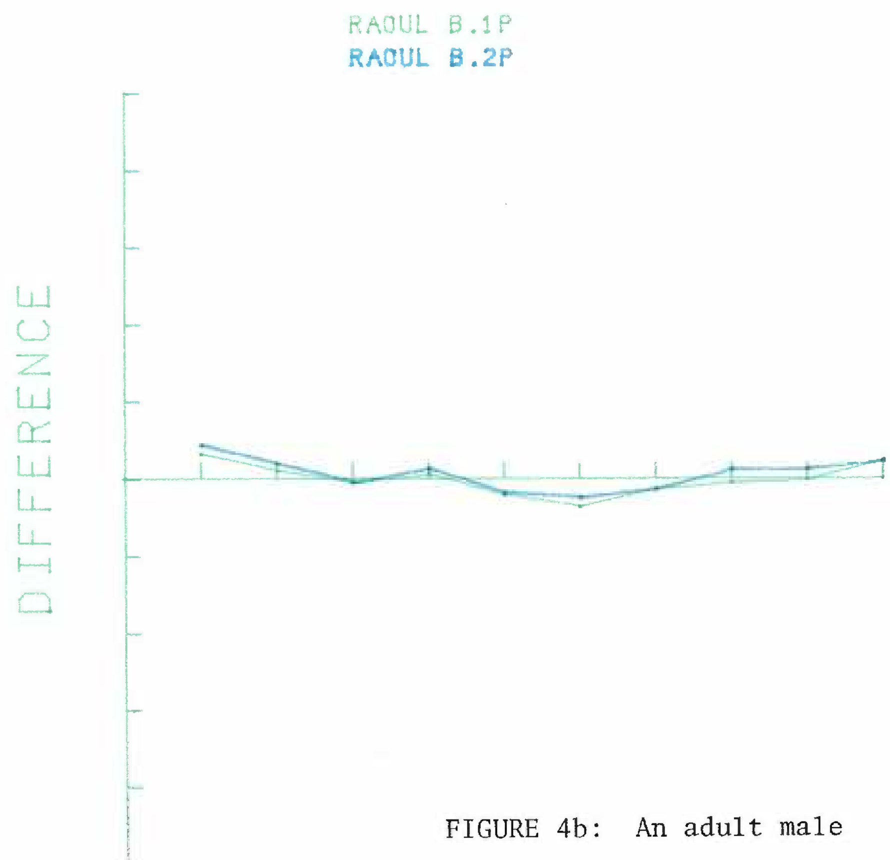


FIGURE 4b: An adult male

Mean difference 1.6%

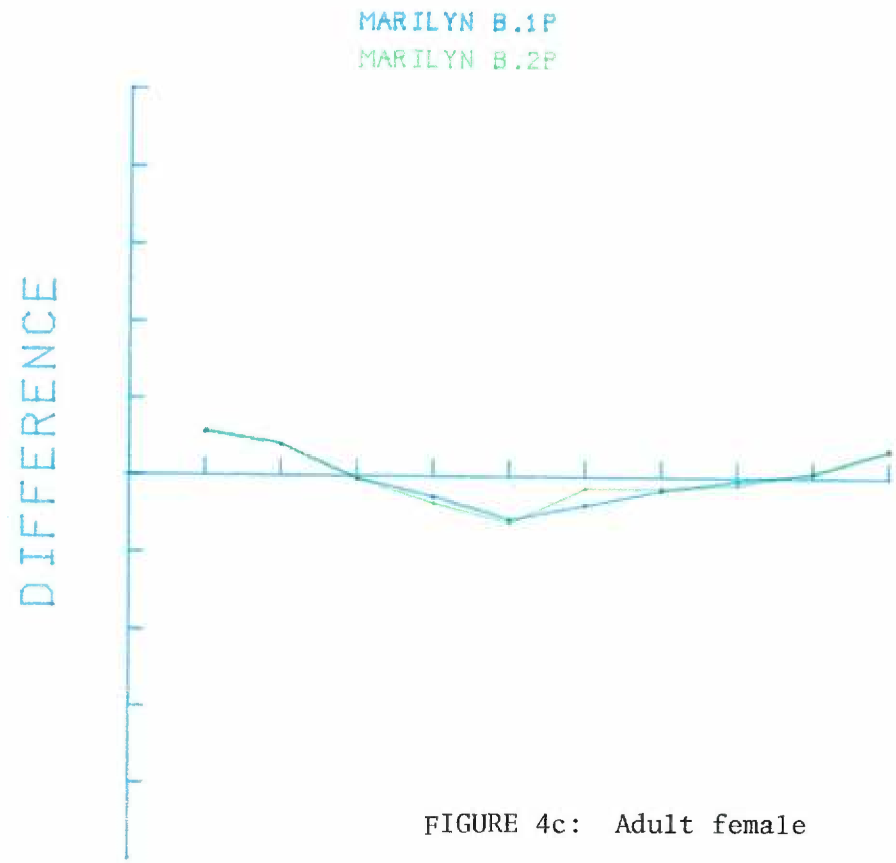


FIGURE 4c: Adult female

Mean difference 1.3%

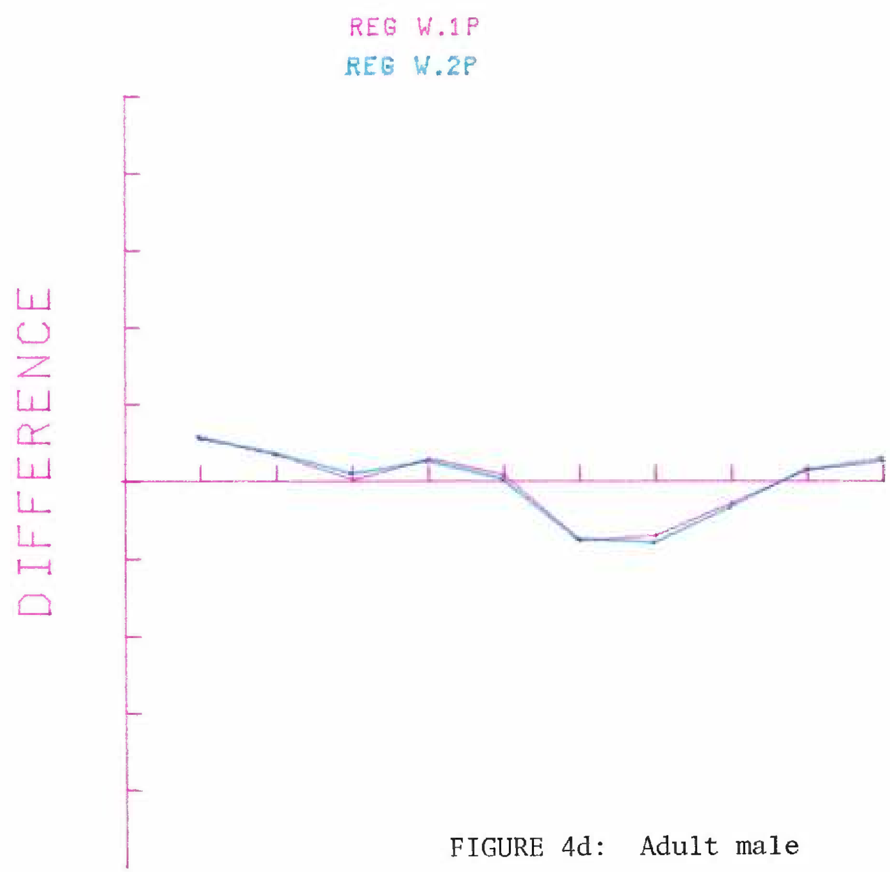


FIGURE 4d: Adult male

Mean difference 1.1%

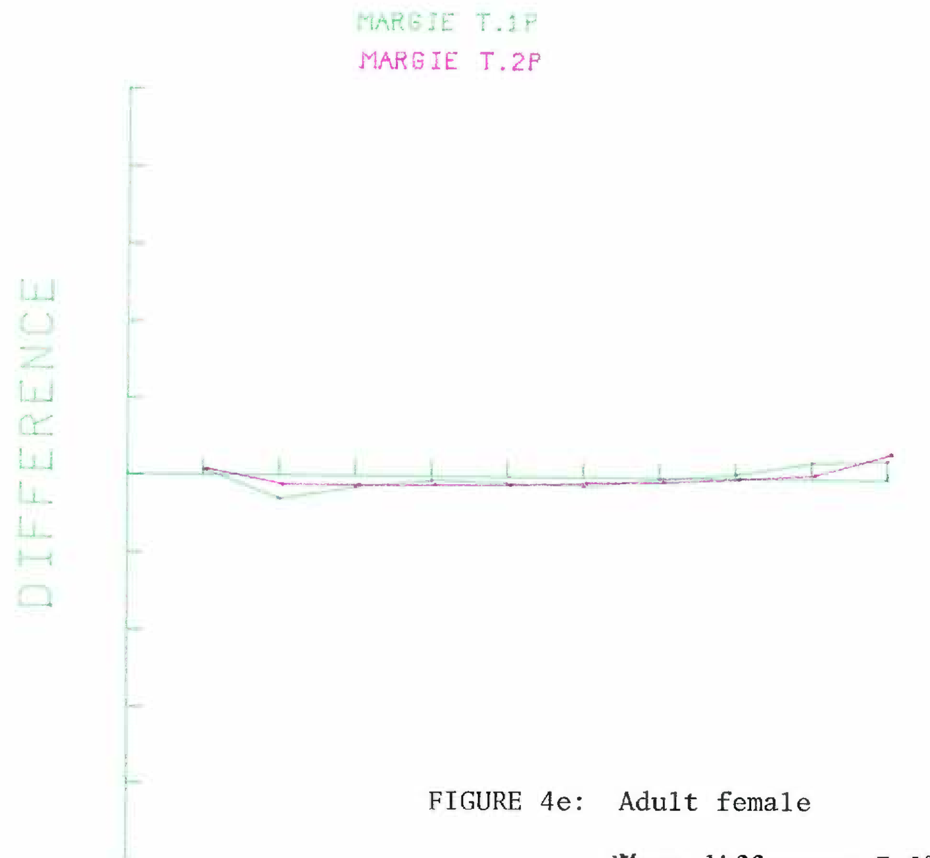


FIGURE 4e: Adult female

Mean difference 7.2%

(Note: This subject had small frontal sinus)

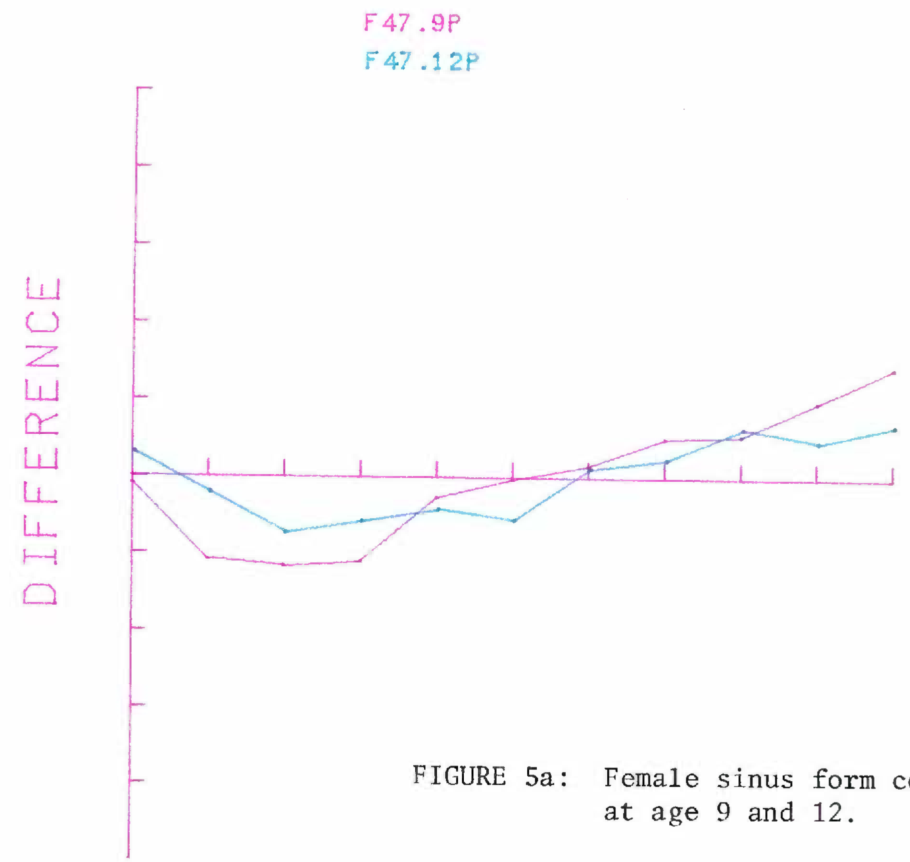


FIGURE 5a: Female sinus form compared at age 9 and 12.

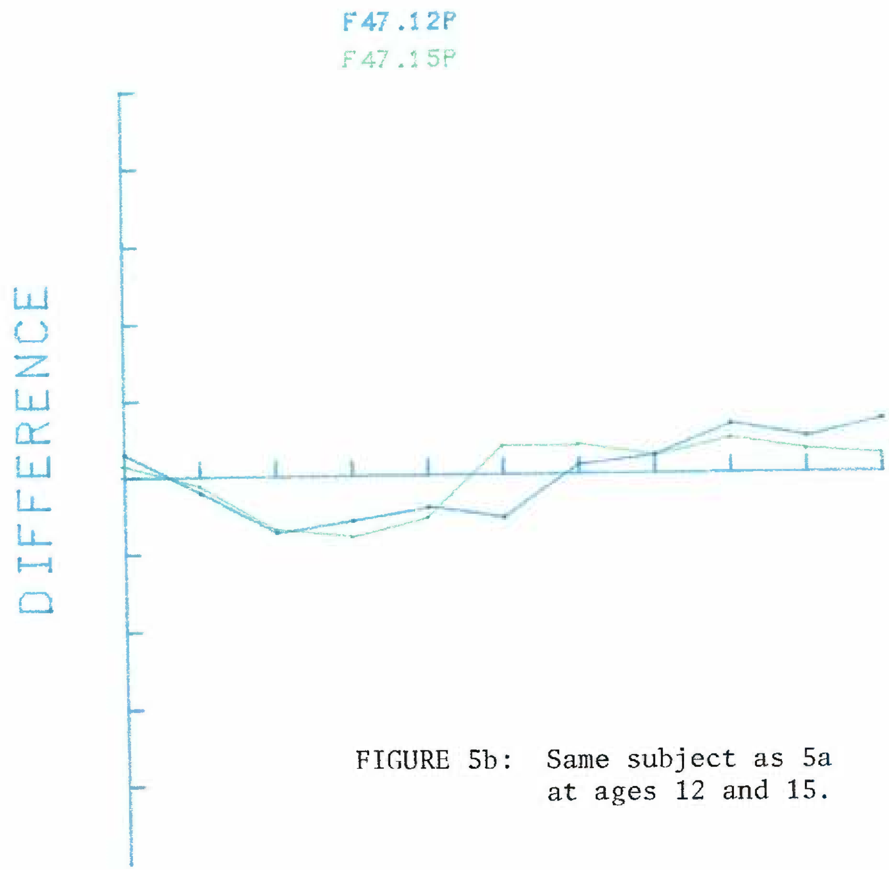


FIGURE 5b: Same subject as 5a at ages 12 and 15.

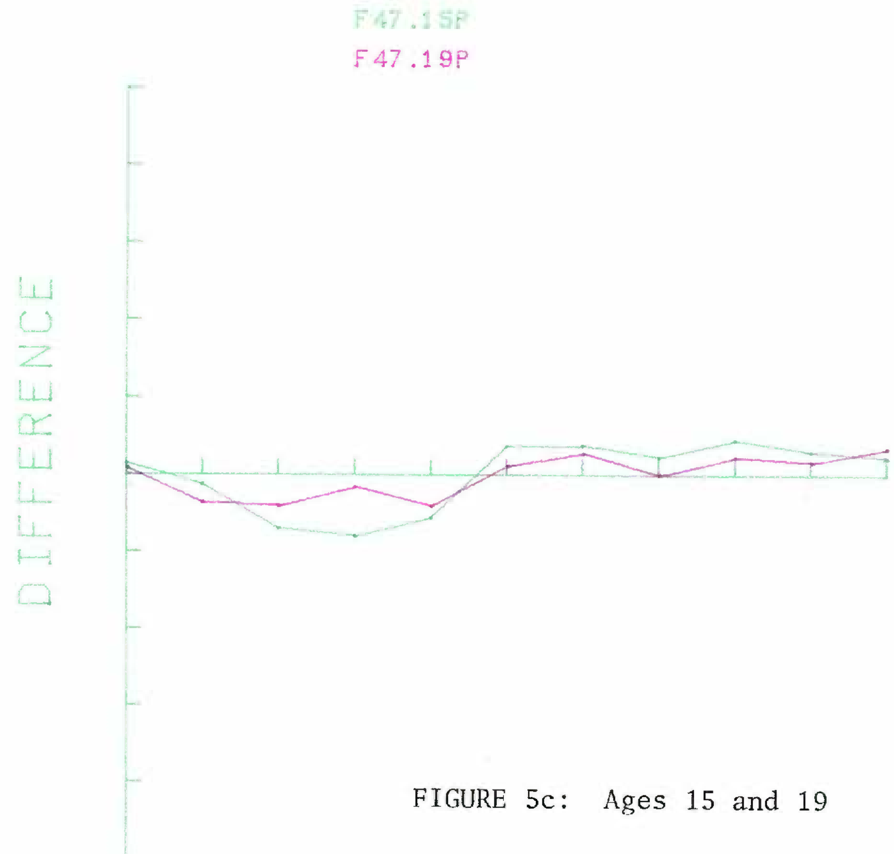


FIGURE 5c: Ages 15 and 19

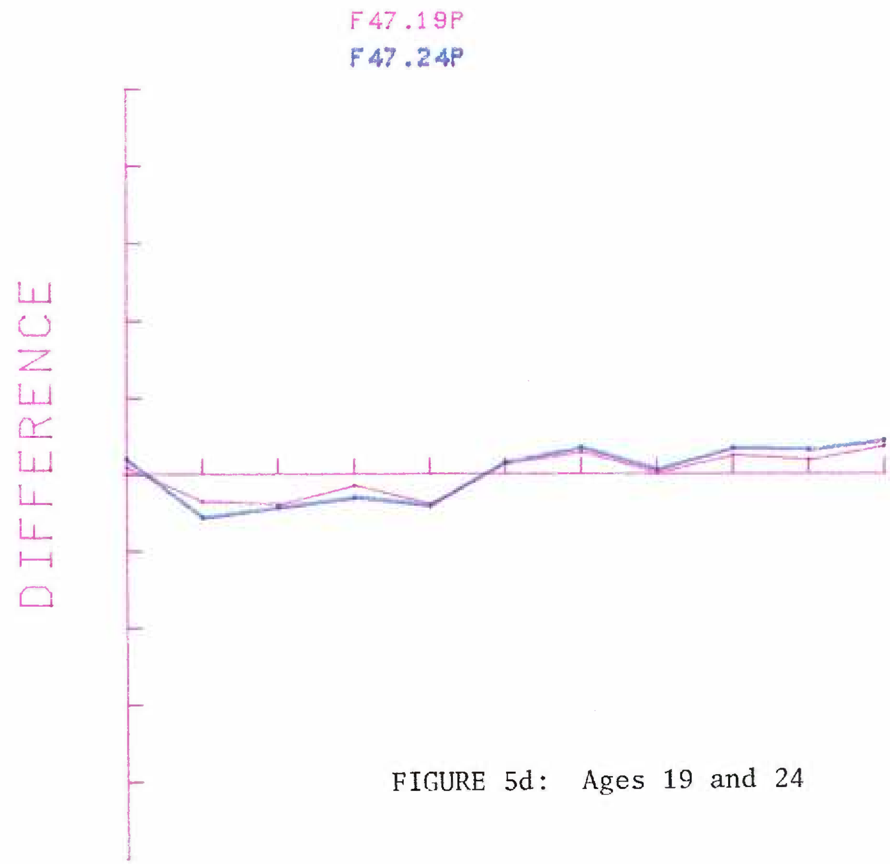


FIGURE 5d: Ages 19 and 24

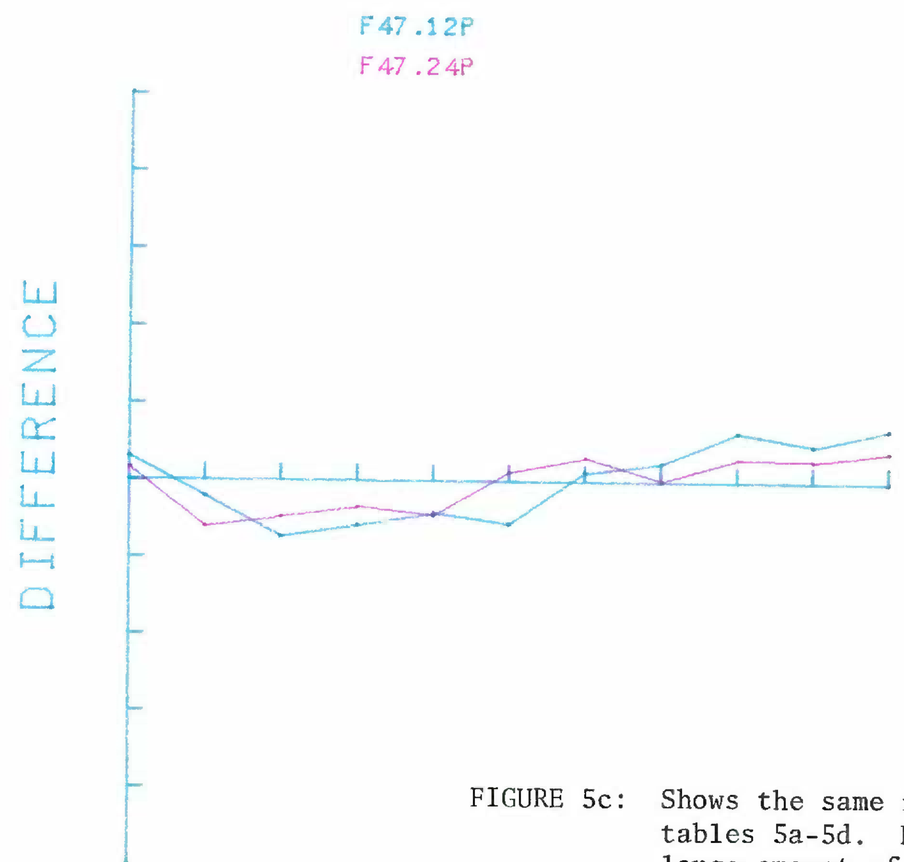


FIGURE 5c: Shows the same female from tables 5a-5d. Note the large amount of variation in form between adolescence and adulthood.

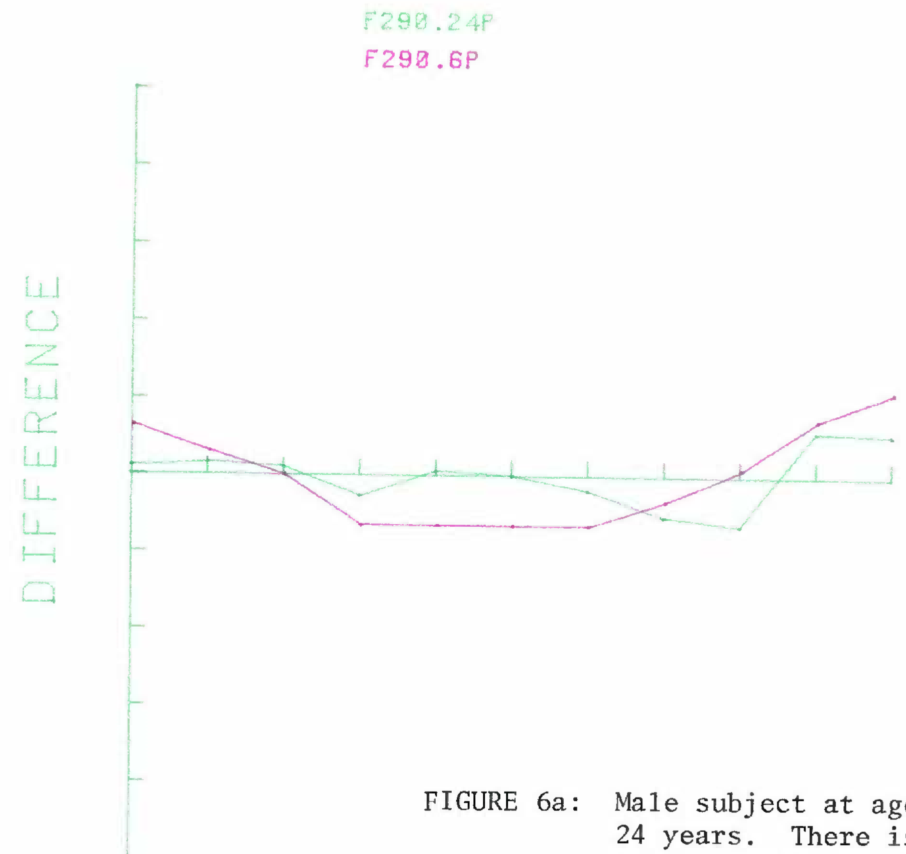


FIGURE 6a: Male subject at ages 6 and 24 years. There is very little similarity between the two sinus forms.

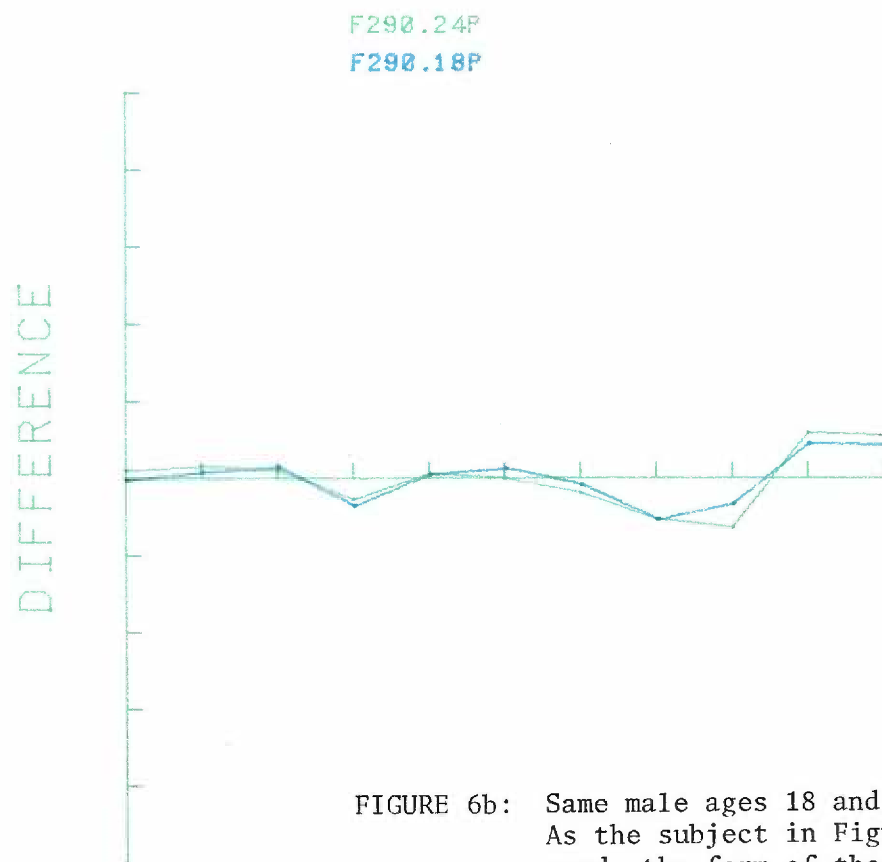


FIGURE 6b: Same male ages 18 and 24. As the subject in Figure 6a aged, the form of the sinus became less variable.

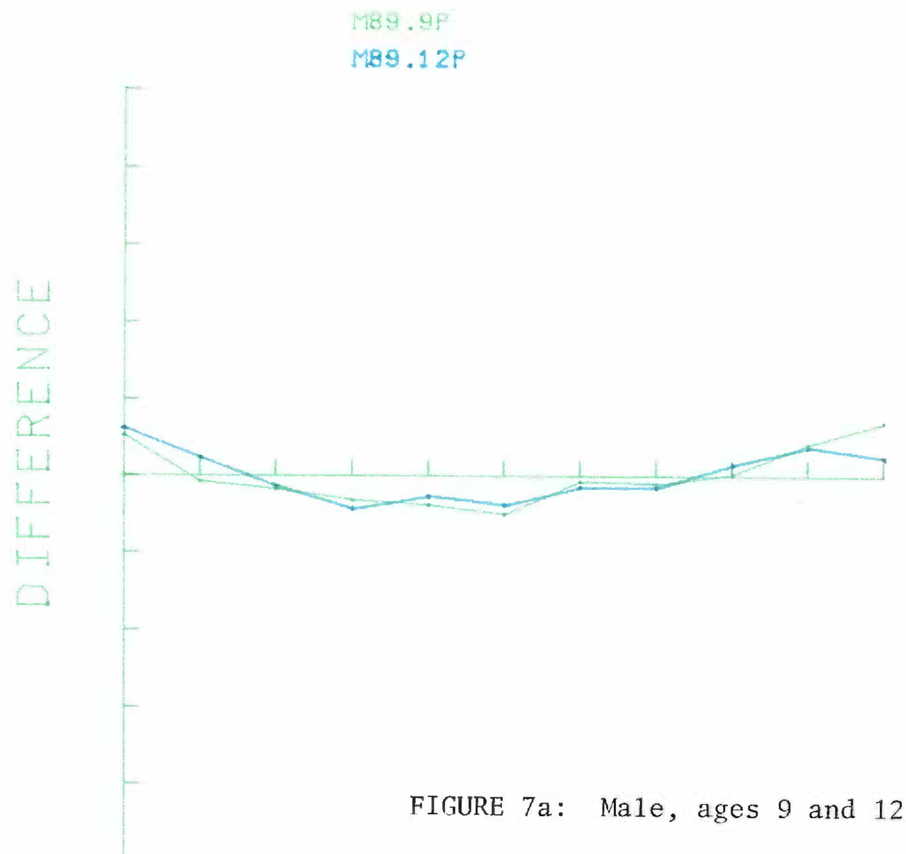


FIGURE 7a: Male, ages 9 and 12.

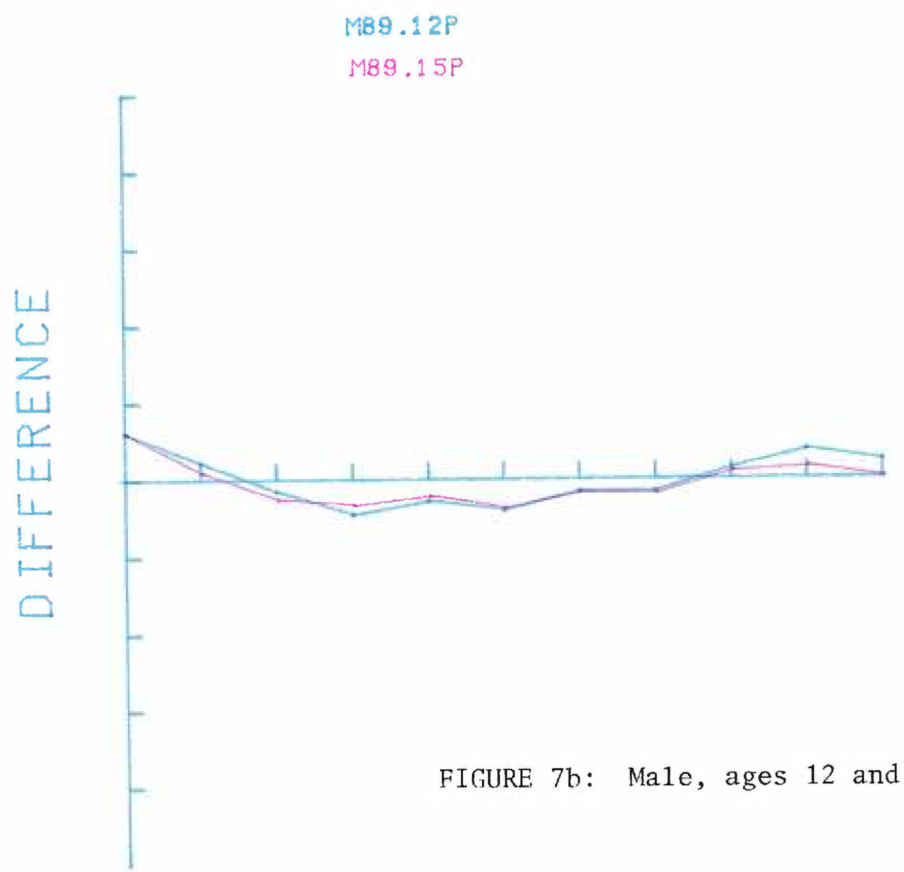


FIGURE 7b: Male, ages 12 and 15

FIGURES 8a,b,c: Illustrate the differences in frontal sinus form between different adult subjects.

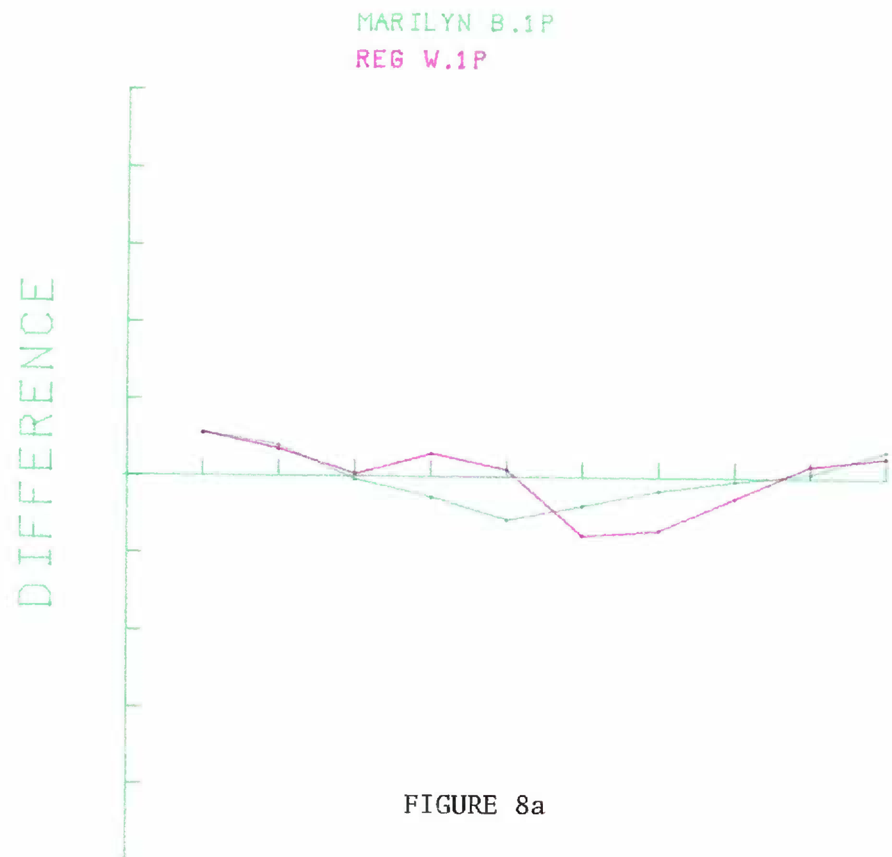


FIGURE 8a

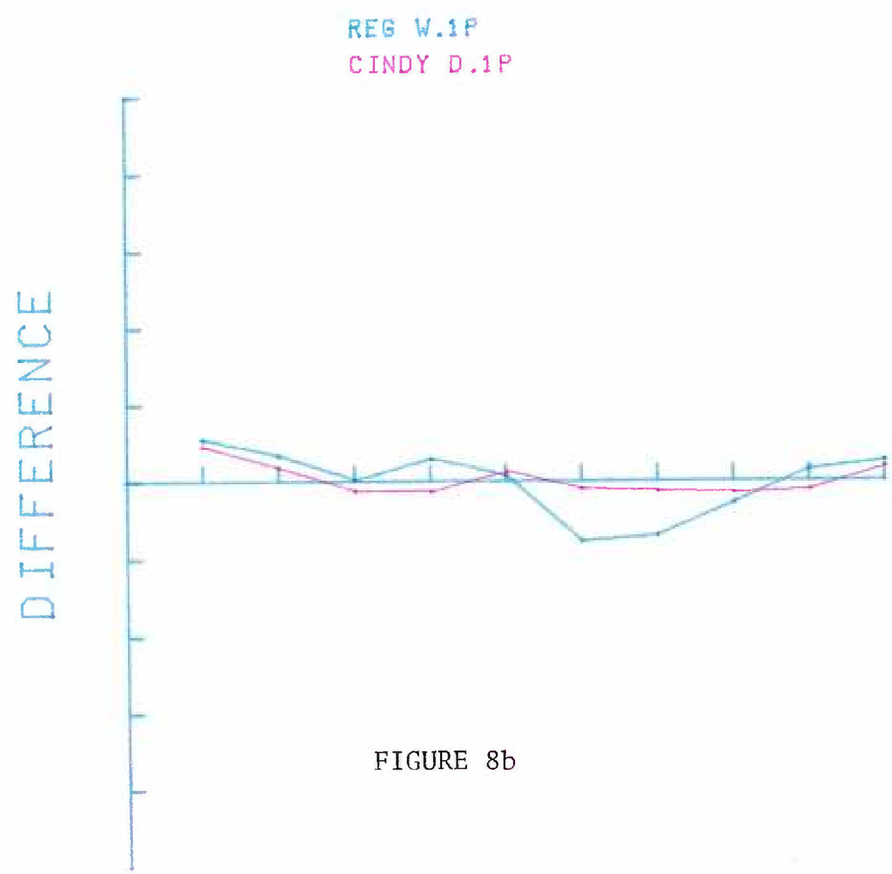


FIGURE 8b

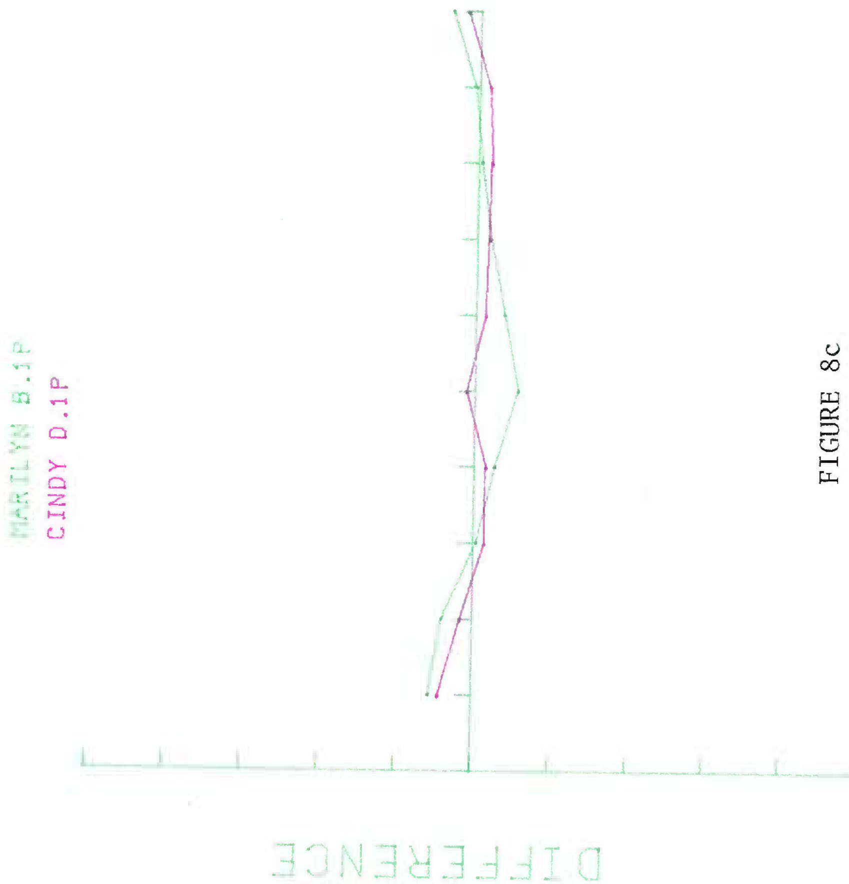


FIGURE 8c

BIBLIOGRAPHY

1. Devore DT: Forensic Dentistry. Dent Clin N Am, 21(1):69-83, 1977.

2. Schuller A: A note on the identification of skulls by x-ray pictures of the frontal sinus. Med J. Australia, 1:554-556, 1943.

3. Asherton N: Identification by Frontal Sinus Prints. A.K. Lewis and Company, Ltd., 1965.

4. Van Ayla OE: Irrigation in Treatment of Disease of Frontal Sinus. Arch Otol, 19:24, 1934.

5. Shapiro R, Schorr S: A consideration of the Systemic Factors that Influence Frontal Sinus Pneumatization. Invest Radiol, 15:191-202, 1980.

6. Pendergrass, Schaeffer, Hodes. The Head and Neck in Roentgen Diagnosis. Thomas, Springfield, IL, 301-327, 1956.

7. Schaeffer JP: The Nose, Paranasal Sinus, Nasolacrimal Passageways and Olfactory Organs in Man. P. Blakiston's Son and Co., Philadelphia, 1920.

8. Davis WB: Anatomy of the Nasal Accessory Sinuses in Infancy and Childhood. Ann Otol Rhin and Laryng. 27:940, 1918.

9. Maresh MM: Paranasal Sinuses From Birth to Late Adolescence. Am J Dis of Children. 55-78, 1940

10. Brown WAB, Mollison TI, Chin S: Enlargement of the Frontal Sinus. Ann Hum Biol, 11:221-226, 1984.

11. Tanner JM: Growth at Adolescence. Blackwell Scientific Publication, Oxford, Second Edition, pg. 3, 1962.

12. Oppenheimer MD: Accesory Sinuses of Children. JAMA, 73:656.

13. Weiman JP, Sicher H: Bone and Bones: Fundamentals of Bone Biology. C.V. Moseby, St. Louis, First Edition, pg. 110, 1947.

14. O'Malky JF: Evolution of the nasal cavities and sinuses in relation to function. J Laryngol Otol, 39:57-64, 1924.

15. Koervelyessy T: Relationship Between the Frontal Sinus and Climatic Conditions: A Skeletal Approach to Cold Adaptations. Am J Phys Anthropol, 37:161-172, 1972.

16. Negus V: The function of paranasal sinuses. Arch Otolaryngol, 66:430-442, 1957.

17. Moss ML, Young RW: A functional approach to craniology. Am J Phys Anthropol, 18:281-292, 1960.

18. Enlow DH: The Human Face: An Account of the Post Natal Growth and Development of the Craniofacial Skeleton. Harper and Row, New York, 1968.

19. Turner AL, Porter WG: The structural type of the mastoid process upon the skiagraphic examination of one thousand crania of various races of mankind. J Laryngol Otol, 37:115-121, 161-175, 1922.

20. Harris AMP, Wood RE, Nortji CJ, Thomas CJ: Gender and Ethnic Differences of the Radiographic Image of the Frontal Region. J of Forensic Odonto-Stomatology. 5:51-57, 1987.

21. Horowitz SL, Hixon EH: The Nature of Orthodontic Diagnosis. C.V. Mosby, St. Louis, Chapter 8, 1966.

22. Grays Anatomy. Lea & Febiger, Philadelphia, 27th Edition, pg. 195, 1962.

23. Schuller A: Das Rontgenogram der Stirnhole: Ein Hilfsmittel fur die Identitalsbestummung von Schadeln. Monalschrift fur Ohrenheilkunde, Laryngologie und Rhonologie, 55:1617-1620, 1921. (from Culbert & Law)

24. Culbert WL, Law FM: Identification by comparison of Roentgenograms. J Am Med Assoc, 88:1634-1636. 1921.

25. Harris AMP, Wood RE, Nortji CJ, Thomas CJ: The Frontal Sinus: Forensic Fingerprint? A Pilot Study. J Forensic Odontostomatol, 5:9-15, 1987.

26. Turpin R, Tisserand M et al: Etude Correlative des Sinus Frontaux des Jumlaux. Comp Rend Soc De Biol, 136-203, 1942. (from Asherton).

27. Broadbent BH: A New X-ray Technique and Application to Orthodontia. Angle Orthodontist, 1:45, 1931.

28. Marshall K: "An Investigation into Pont's Index and Archwidth Changes". Thesis, Oregon Health Sciences University, 1987