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THE FUNCTIONAL MATURATION OF THE CERVICAL VERTEBRAE

by

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Submitted in partial fulfillment of the requirements

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GRADUATE STUDIES

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THE FUNCTIONAL MATURATION OF THE CERVICAL VERTEBRAE

Abstract

by

STUART D. COTLER

Orthodontists have increasingly recognized the part played by growth during the adolescent period in aiding or dissipating the effects of therapy, and treatment is planned accordingly. Unfortunately, specific indicators that might signal the onset of this period of rapid facial change are not precise. The present study examined the relationship between the normal maturation of cervical vertebrae II, III and IV and the maximum rate of facial growth at adolescence.

A sample of 12 males and 12 females (ages 6 to 16) were selected from the files of the Bolton-Brush Growth Study collection at Case Western Reserve University, Cleveland, Ohio. Time of maximum facial growth was determined from composite time series graphs of the facial dimensions that expressed the maxillary and mandibular alveolar lengths. The age of appearance of the "vertebral rings" were determined by inspection of the annual cephalometric radiographs. Results show a lack of sufficient correlations that would permit any form of clinical prediction to be made regarding peak facial growth at adolescence with maturation of cervical vertebrae II, III or IV or the ossification of its vertebral rings. Findings show a sexual difference between the vertical growth of cervical vertebrae II, III and IV and the horizontal and vertical growth of the face. This

sexual difference appears to relate to corresponding differences in the respiratory needs of males as compared with females at adolescence. Significantly high correlations were found to exist between the vertical development of the neck and the vertical development of the face. It is suggested that these correlations demonstrate the existence of a biologic continuity between them, and that an index could be constructed that would allow an assessment of the status of vertical facial development utilizing the cervical vertebrae.

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DEDICATED

to

My wife, and companion for life, Barbara,
who provided the love and the faith
when most needed

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INTRODUCTION

The factor of timing for active orthodontic treatment is an important consideration in treatment planning. One of the major problems in orthodontic diagnosis and treatment planning is whether there is growth potential remaining, and if so, to what extent.

All orthodontists are well aware of the adolescent or pubertal growth spurt, the approximate two-year period encompassing sexual maturity during which a developing child has a rapid rate of growth. The growth of the face during this period may be several times that of the period immediately before or after.

Clinicians have increasingly recognized the part played by growth during the pubertal period in aiding or dissipating the effects of therapy, and treatment is planned accordingly. Unfortunately, specific indicators that might signal the onset of this period of rapid facial change are not precise. The orthodontist attempting to utilize pubertal growth to assist his treatment presently must necessarily use such means readily available to him, e.g., onset of rapid increase in body height, early signs of physiological change (2° sex characteristics), the current chronological and dental age of the patient, and occasionally skeletal maturation assessments utilizing hand-wrist radiographs.

Many past investigators have researched possible new methods for predicting the timing of the pubertal growth spurt. However,

results to date have failed to produce a universally acceptable method for specifically predicting the precise time of the beginning of the circumpubertal facial growth spurt. According to the literature reviewed, the facial growth spurt occurs concomitantly with skeletal maturation and puberty (i.e., 2° sex characteristics). The use of skeletal age rather than chronological age can reduce variability, but determining skeletal age is not usually part of the background knowledge of most orthodontists, and to be accurately accomplished requires a certain amount of specific training. Thus, it remains, that a simple method that could predict, with acceptable accuracy, the oncoming facial growth spurt would be a most useful tool to the clinician in timing the beginning of treatment.

The purpose of this investigation is to determine if the normal maturational process of cervical vertebrae bodies II, III or IV can provide an accurate method for estimating the temporal nature of the facial growth spurt. The vertebral rings, as investigated and named by Bick and Copel (1951), to determine usefulness in estimating the growth spurt will also be evaluated.

KEY LITERATURE

Skeletal Maturation

The earliest known longitudinal study on growth was conducted by Count Philbert Gueneau de Montbeillard using his son as the subject. The period of the boy's growth observed was from the years 1759 to 1777. The growth curves showed that the velocity of growth decreased from birth onward, although the trend was altered twice. Between 6 and 8 years there was a leveling of the increments of growth, and between the ages of 13 and 15, there was a marked increase. This period of accelerated growth is now known as the adolescent or pubertal growth spurt. It has been recognized that this growth spurt is consistently present but varies in onset, intensity and duration with each child.

The need for a physiological measure of maturation was first emphasized by Crampton in 1908. Rotch (1909) extended this concept by suggesting a standard based on anatomic development. Progress in constructing a maturational-type standard was initiated by Hellman in 1928, who published a detailed description of the serial changes in the radiographic appearance of growth cartilage plates during the process of fusion of epiphyses with diaphyses.

Todd (1937) recognized the potential importance of Hellman's findings and referred to the serial changes in a growing bone as "determinators of maturity." Todd (1935) also identified certain

principles of maturation. He stated, "that before the growth which characterizes adolescence is manifest, the bone ends show certain definite changes by which incipient growth in stature and weight can be forecast." He also states that,

> There are two popular measures of physical development of a child. One is increase in size, a physical attribute of which nature is relatively careless; the other is increase in age, which is not a measure of the child at all but of the universe. The true measure of physical development is the progress of bodily maturity.

He described and defined in detail the specific changes in various bones prior to the time of fusion of epiphyses with diaphyses. The culmination of his efforts was the publication of the first atlas for assessing an individual's progress toward bodily maturity and was based on the bones of the hand and wrist, which he found were the simplest and most delicate indicators of skeletal maturity.

Todd's determinators of maturity were renamed "maturity indicators" by Gruelich and Pyle (1950) and defined as "those features of individual bones that can be seen in x-rays and which because they tend to occur regularly and in a definite and irreversible order, mark their progress toward maturation." The importance of this step, the identification and description of determinators of maturity, was immense. No longer was it necessary to search from one joint to another to find a newly ossified center, nor was it necessary to measure the size of an ossified shadow. It was now possible, by simple inspection, to judge the development of each center by noting the size and shape of the shadows cast by the newly forming bone tissue as it replaced the radiotranslucent

cartilage, and then by comparison of these shadows with a standard for each chronological age.

These skeletal maturity standards, whether in the form of an atlas or statistical tables, are given separately for boys and girls. This is because girls are maturationally more advanced at birth, and throughout the whole period of growth. Pryor (1925) was apparently the first to provide systematic documentation for this dimorphic feature, and his findings have since been confirmed in detail for practically every prenatal and postnatal skeletal appearance and fusion throughout the body.

Skeletal Maturation and Facial Growth

Multiple researchers have undertaken correlation studies between skeletal maturation and facial growth. Works by Nanda (1955), Nanda and Taneja (1972), Bambha (1961), Bambha and Van Natta (1963) and Hunter (1966) have established a positive relationship between the acceleration of both body height and facial growth at adolescence.

Nanda (1955) in a longitudinal study of several facial dimensions, formulated distance and velocity curves to illustrate the changes observed. He found a general circumpubertal increase in growth velocity, although the timing of both the onset and the peak rate of growth were different for the various dimensions of the same child. Circumpubertal acceleration in facial growth occurred approximately 9 months after that for body height.

Bambha's (1961) findings in general support those of Nanda and, in addition, he suggested that it was possible to estimate the time of onset of the adolescent facial growth spurt by observing the time of onset of the similar but preceding acceleration in body height.

Hunter (1966) challenged the findings of both Nanda and Bambha. He concluded that maximum facial growth was coincident with maximum height growth in the majority of subjects in his study. He also concluded that the antero-posterior length of the mandible, of all the facial dimensions studied, showed the most consistent coincidence with growth in height.

Bergersen's (1972) studies also demonstrated a high degree of association between the adolescent facial growth peak and a similar peak in standing height. His investigation concluded a significant correlation exists between the onset of the male adolescent spurt, for the particular facial dimensions studied, and standing height.

Tanner (1962) also believed that the peak velocity for growth in the face is reached within a few months after peak body height growth. He stated, "the difference in size between adult men and women is, to a large extent, the result of the difference in the adolescent growth spurt, prior to it, boys and girls are practically the same height." Tanner places the growth spurt range for males at 12.5 to 15 years, and for females at 10.5 to 13 years.

Prediction of Pubertal Growth Spurt

Many past investigators have possible researched methods for predicting the timing of the pubertal growth spurt. Bambha and Van Natta (1963) found skeletal maturation from hand-wrist x-rays a useful index of development, especially in early and late maturing individuals. Although their statistical results demonstrated general trends, it was pointed out that "there is enough individual variation to make the orthodontist's prediction on a given patient less than perfect." Burstone (1963) recognized the value of a growth spurt prediction analysis, but he found that chronological age as a possible correlation index has too wide a range to be clinically usable. However, Bergerson (1972) was able to develop a chart for predicting onset of growth spurt in males utilizing an age-wrist maturation correlation. By obtaining the skeletal age from wrist film comparisons according to the standards of Gruelich and Pyle (1950), his table allowed an extrapolation of a predicted chronological age for the onset of the two years of most intense circumpubertal growth. His range of accuracy was ± 5 months within 67% (first s.d.) and ± 11 months in 95% (second s.d.) of the population. He also found that in the males undergoing accelerated or retarded maturation, even greater reduction in variability was achieved. Utilizing his prediction table, there was as much as 75% improvement in the ability to predict the onset of the growth spurt as compared with estimates utilizing chronological age alone. Although this represented a significant reduction in variability, the Bergersen table required

an accurate reading of the skeletal age by comparing wrist films of the patient with the Gruelich and Pyle Atlas. Unfortunately, there is no corresponding table for females. Although scientifically excellent, Bergerson's procedure would appear to have only limited clinical application at this time.

The coincident timing of ossification of the adductor sesamoid bone in the thumb with the pubertal growth spurt has been investigated by Buehl and Pyle (1942), Pileski et al. (1973), Garn and Rothman (1962), Björk and Helm (1967) and Chapman (1972). Using the adductor sesamoid bone to attempt prediction, Björk and Helm (1967) showed that ossification of the sesamoid bone either preceded or coincided with the pubertal growth spurt. In their study, more than one-half of the sample showed the beginning of ossification one year before maximum pubertal growth. Björk points out that, "although significant at the .01 level, the sesamoid does not offer the clinician a tool that he can look at and invariable say the growth spurt will occur within three to six months." Chapman (1972) essentially agreed with Björk in his study on the sesamoid bone. Pileski et al. (1973) also found a high correlation between ossification of the sesamoid bone and maximum growth, but they agreed with Björk that the sesamoid bone was inadequate as a clinically useful tool for prediction. They also found, in contrast to Björk, that in 25.3% of the males and 19.5% of the females studied, ossification of the sesamoid bone did not appear until after maximum growth.

Helm et al. (1971) studied 8 areas of maturation in the hand

in an attempt to predict the growth spurt. They observed that, "the average sequence of complete epiphyseal union was distal, proximal, middle." Helm, in particular, felt, "the period of most intense growth may be expected between ossification of the sesamoid and onset of capping of the third middle phalanx."

Most recently Lamparski (1972) has developed a radiographic standard of reference for maturation evaluation utilizing the cervical vertebrae region. His conclusions that the normal growth and development of the cervical vertebral bodies can provide a reliable index to the maturational status of an individual is the major premise of the present investigation.

Growth and Maturation of the Cervical Vertebrae

The manner in which vertebrae increased in size with time had been a controversy for many years. It was not clear whether the length (vertical) changes occurred as a result of epiphyseal cartilages, as in the long bones, or due only to appositional and resorptive changes on the surfaces.

Haas (1939) carried out a microscopic study of the vertebrae of dogs. He found a cartilage plate at each end (superior and inferior) of the vertebral body which was similar in structure to the epiphyseal plate of any long bone. In order to determine whether growth takes place at these epiphyseal plates he conducted a series of experiments in which silver wire markers were placed in the bodies and in the epiphyses of the vertebrae. One-hundred and twelve days

later he found the distance between the markers in the body and in the epiphyses had increased, thus demonstrating that the epiphyseal plate did function to increase length of the vertebrae. The markers within the body of the vertebrae itself did not separate, indicating that no interstitial growth had taken place in this region.

Bick and Copel (1950), with a series of 15 human specimens from fetus to 23 years of age, demonstrated microscopically that cartilaginous plates cover the cephalic and caudal surfaces of each vertebrae until about 17 years in the female when these cartilaginous plates ossified. They also concluded that longitudinal growth of the vertebral body takes place by means of true diaphyseal-cartilage plates, as does longitudinal growth in the metaphyses of long bones.

In a separate study, Bick and Copel (1951) examined, histologically and radiographically, human vertebrae to determine the role played in growth by certain osseous ring-like structures which appeared on the cephalic and caudal surfaces of the vertebral body. They described these rings as narrow provisional cartilaginous (later bony) mounds which more or less encircle the rims of the cephalic and caudal surfaces of the body but may be lacking at the dorsal margin. The function was demonstrated to provide a site at which fibers from the long intervertebral ligaments insert into the vertebra (Figures 1 and 2). In their specimen series the rings began to ossify at 13 years (female), began fusion with the body at 17 years (male), and by 18 years (male and female) was completely fused (Figures 3 and 4). At all times until fusion began these vertebral rings developed

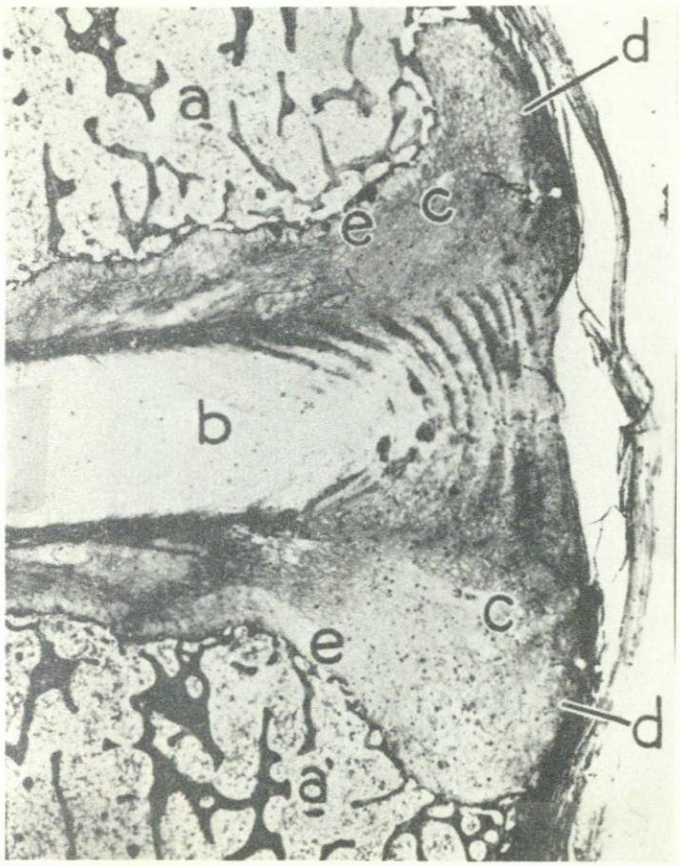


Fig. 1. Female, 6 years old.

a) Expanding endochondral ossification of the vertebral body.
b) Intervertebral disc and annulus fibrosus.
c) Area of calcified cartilage forming vertebral ring (outside line of diaphyseal plate).
d) Insertion of fibers of anterior longitudinal ligament.
e) Diaphyseal growth plate (Bick and Copel, 1951).

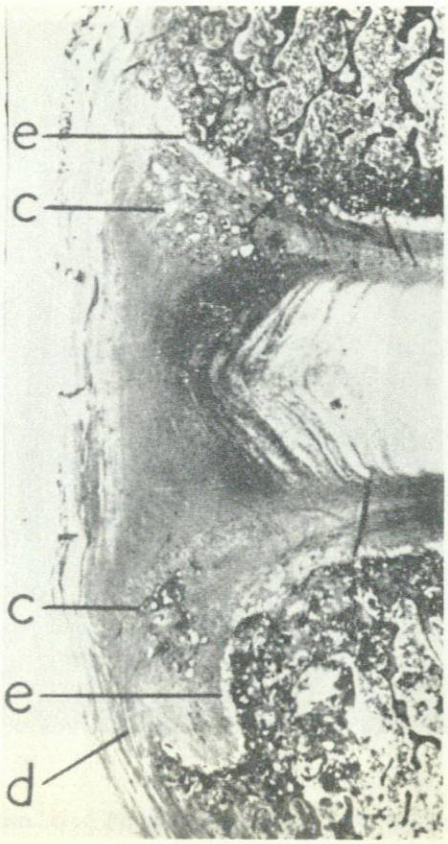


Fig. 2. Female, 13 years old. Clear evidence of ossification of the vertebral ring.

c) Ring lies outside epiphyseal growth plate (e).
d) Fibers of anterior longitudinal ligament can be seen inserting into area of ring. It is because of this arrangement of accessory ossification center and ligament insertion that the ring meets the definition of a traction apophysis.
e) Diaphyseal plate (Bick and Copel, 1951).

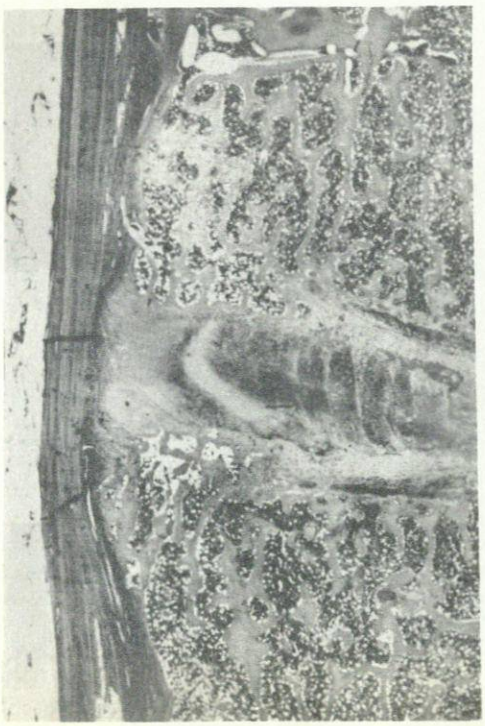


Fig. 3. Female, 14 years old. In this section the ring has begun to fuse with the ossific mass of the body (Bick and Copel, 1951).

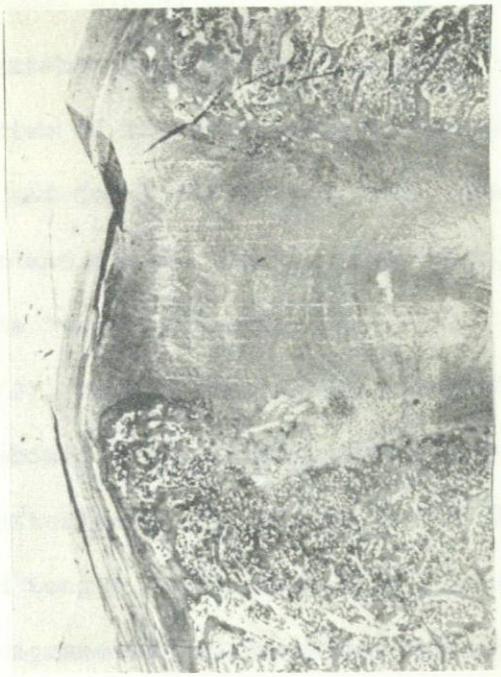


Fig. 4. Female, 15 years old. Fusion of the vertebral ring is complete in this female. Somewhere between the 15th and 17th year, ossification of the vertebral ring apophysis occurs in the male, according to Bick and Copel (1951).

outside the epiphyseal plates and did not take part in the longitudinal growth of a vertebra except to add on their own thickness when fused to it. In view of the attachment of the long vertebral ligament fibers, Bick and Copel classified these osseous structures as traction apophyses and coined the term "vertebral ring apophyses," or more simply, the "vertebral rings."

Bench (1963), citing the lack of research of the growth of the cervical vertebrae, conducted a serial study relating the growth of the cervical vertebrae to the growth of the face and changes in the hyoid bone and tongue. His study consisted of 165 lateral cephalometric roentgenograms of patients that included growth periods from age 3 years to age 25 years. Three vertical reference lines were established from the Frankfort horizontal plane to measure changes in the vertical growth of structures in the cervical column, face and tongue. He concluded that the vertical growth of the face has a low correlation with vertebral growth in the preschool child ($r = 0.1$); however, a high correlation was shown to exist in the pubertal and post-pubertal individual ($r = 0.7$). He also observed a relationship between various types of facial growth "types" and cervical vertebrae behavior. For example, patients with dolicocephelic facial patterns exhibited cervical columns that were straight and long. Patients with brachycephalic patterns, however, exhibited a curved column with very little height, but great depth, to the face. This tended to support Lindegard's (1953) contention that neck growth is an expression of somatotype and a part of the development of the individual.

Lamparski (1972), using a cross-sectional sample concluded that the maturational changes which take place in cervical vertebrae II to IV could be used to assess the skeletal age of an individual. In this study, he developed a radiographic standard of reference of the cervical vertebral region for chronological ages 10 to 15 for both males and females. He described the maturity indicators of the vertebrae as the initiation and development of concavities on the caudal border of the body of the vertebrae and increasing anterior and total vertical heights. His conclusions that skeletal age assessment utilizing the cervical vertebrae are statistically reliable and valid confirmed Todd's premise that any area of a healthy skeleton will show the same maturational development. This had proven advantages since its proximity to the skeletal shadows of the head has offered the clinical orthodontist an index of maturation with no other radiographs being required.

MATERIALS AND METHODS

Sample

The serial cephalometric records utilized in this study were obtained from the files of the Bolton-Brush Growth Study Center at Case Western Reserve University, Cleveland, Ohio. The sample consisted of a longitudinal headfilm series for each of 24 Cleveland children (12 males and 12 females), selected according to the following criteria:

1. availability of serial records from age 72 months (6 years) to age 192 months (16 years);
2. Absence of major orthodontic treatment.

Method

For each file, the identification number (Bolton number), sex, height, chronological age, facial and cervical dimensions were recorded. In all but a few instances, the radiographs were taken at yearly intervals (plus or minus thirty days), using a Broadbent-Bolton cephalometer at a source-object distance of 60 inches. In the few cases in which a portion of a series was unavailable, missing data were estimated by interpolation.

Measurements

Growth of the face (see Figure 5)

Cephalometric points

1. SE--point located by intersection of the shadows of the greater wings of the sphenoid with the floor of the anterior cranial fossa.

2. Ar (Articulare)--the intersection of the image of the posterior border of the ramus with the base of the occipital bone.

3. PTM--most inferior point of area formed by the divergence of the maxilla from the pterygoid process of the sphenoid.

4. SPr (Superior Prosthion)--point located by intersection of the maxillary alveolar process with the maxillary central incisors.

5. IPr (Inferior Prosthion)--point located by intersection of the mandibular alveolar process with the mandibular central incisors.

Planes of reference

1. PM vertical--vertical line that extends from SE to the most inferior point of PTM.

2. functional occlusal plane--a line that extends through the point of occlusion of the most posterior teeth with point of occlusion of most anterior bicuspids.

3. Mx parallel--a line that is drawn parallel to functional occlusal plane and which extends from superior prosthion to PM vertical (represents maxillary alveolar horixontal dimension).

4. Ram--an extension of the functional occlusal plane which intersects the anterior and posterior ramus borders (represents the A-P width of ramus).

5. Articulare (Ar) parallel--a line that is drawn parallel to the PM vertical and which intersects articulare.

6. MDL parallel--a line that is drawn parallel to functional occlusal plane and extends from inferior prosthion to Ar parallel (represents mandibular alveolar horizontal dimension).

Growth of the cervical vertebrae (see Figure 6)

The terminology used in this study to orient the cervical vertebrae will consist of:

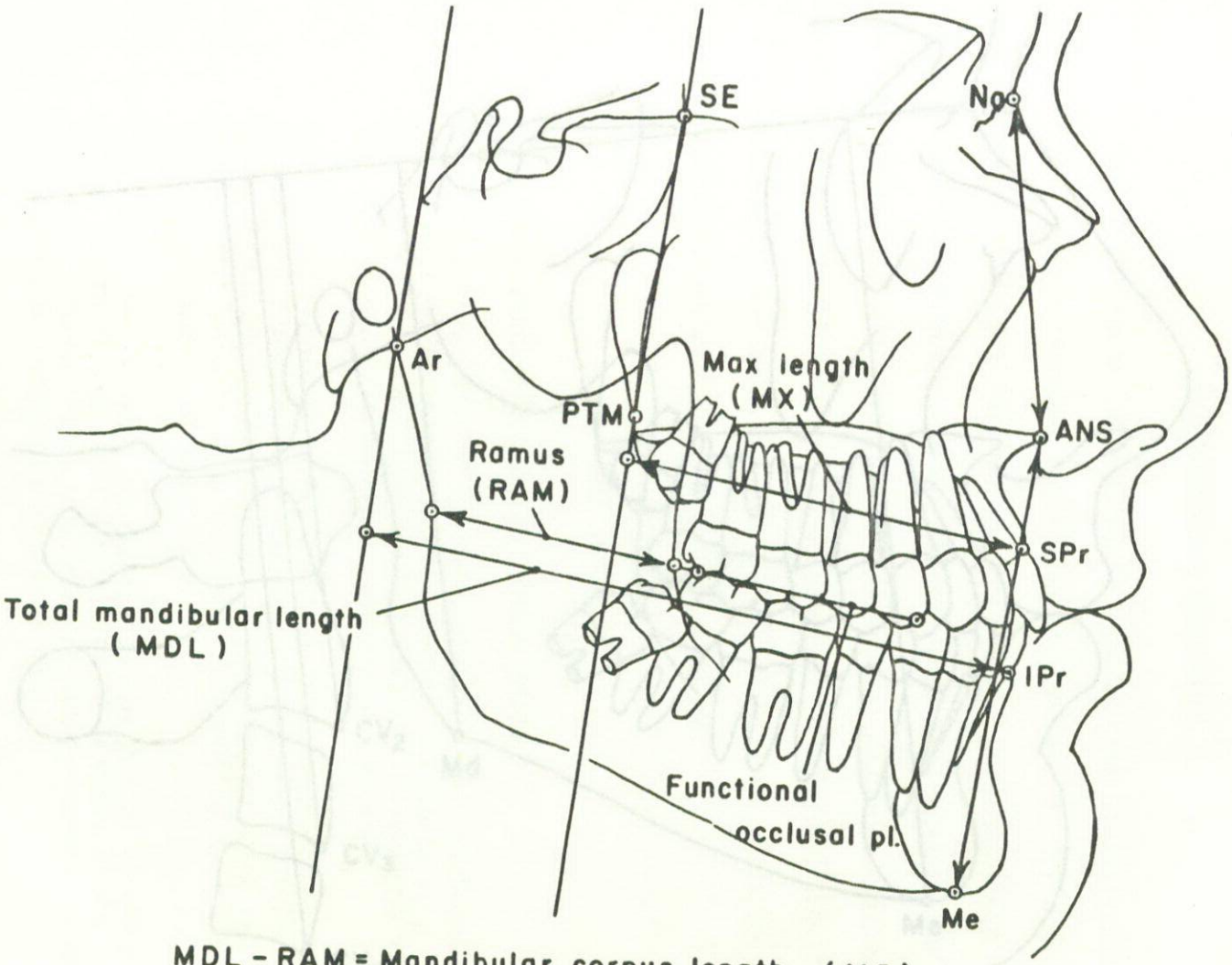
1. cephalic--the suprior border of the body of the vertebrae.
2. caudal--the inferior border of the body of the vertebrae.
3. ventral--the anterior or visceral side of the body of the vertebrae seen on a lateral cephalogram.
4. dorsal--the posterior or back-side of the body of the vertebrae seen on a lateral cephalogram.

Cephalometric points

1. S (Sella turcica)--the center of sella turcica as estimated by inspection.
2. N (Nasion)--the most forward point on the naso-frontal suture.
3. Me (Menton)--the most inferior point on the symphysis of the mandible.
4. Md--the most inferior point on the angle of the mandible.
5. CV_{II}--the most ventral-caudal (anterior-inferior) point on the body of cervical vertebrae II.
6. CV_{III}--the most ventral-caudal point on the body of cervical vertebrae III.
7. CV_{IV}--the most ventral-caudal point on the body of cervical vertebrae IV.

Planes of reference

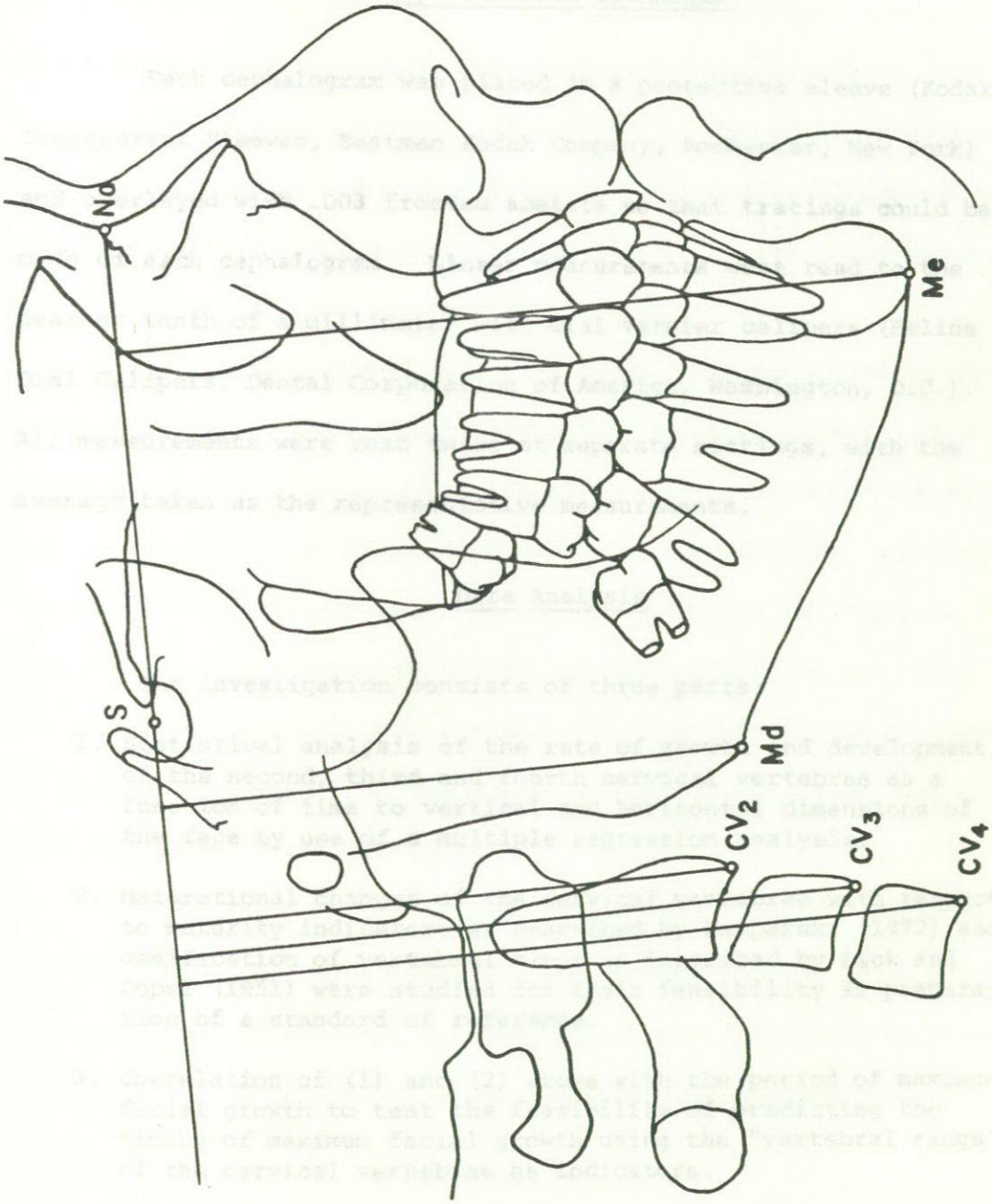
1. S-N--a line drawn from point S to point N.
2. SN-Me--a line drawn perpendicular from SN extending to Me.
3. SN-Md--a line drawn perpendicular from SN extending to Md.
4. SN-CV_{II}--a line drawn perpendicular from SN extending to CV_{II}.



MDL - RAM = Mandibular corpus length (MD)

Cephalometric Measurements

Fig. 5



Cephalometric Measurements

Fig. 6

5. SN-CV_{III}--a line drawn perpendicular from SN extending to CV_{III}.
6. SN-CV_{IV}--a line drawn perpendicular from SN extending to CV_{IV}.

Cephalometric Technique

Each cephalogram was placed in a protective sleeve (Kodak Transparent Sleeves, Eastman Kodak Company, Rochester, New York) and overlayed with .003 frosted acetate so that tracings could be made of each cephalogram. Linear measurements were read to the nearest tenth of a millimeter with dial vernier calipers (Helios Dial Calipers, Dental Corporation of America, Washington, D.C.). All measurements were read twice at separate sittings, with the average taken as the representative measurements.

Data Analysis

The investigation consists of three parts:

1. Statistical analysis of the rate of growth and development of the second, third and fourth cervical vertebrae as a function of time to vertical and horizontal dimensions of the face by use of a multiple regression analysis.
2. Maturational changes of the cervical vertebrae with respect to maturity indicators as described by Lamparski (1972) and ossification of vertebral rings as described by Bick and Copel (1951) were studied for their feasibility in preparation of a standard of reference.
3. Correlation of (1) and (2) above with the period of maximum facial growth to test the feasibility of predicting the timing of maximum facial growth using the "vertebral rings" of the cervical vertebrae as indicators.

Statistical Analysis of Cervical and Facial Development

The multiple regression program is composed of an analysis of seven dependent variables against chronological age (time) as an independent variable. These seven dependent variables are: Mx, Md, SN-Me, SN-Md, SN-CV_{II}, SN-CV_{III} and SN-CV_{IV}. The analysis consisted of (a) separate regression equations and lines for each dependent variable against time, and (b) correlations of these regressions using t-tests analyses of regression slopes.

It should be noted that this format considers several dependent variables against one independent variable (time). This is in contrast to the usual procedure which analyzes two or more independent variables in linear combination to account for a dependent variable. Therefore, commonly used multiple regression computer programs are not applicable for the present investigation. As a result, dependent variables are analyzed through a series of t-tests, which show differences in the degree of relationship among the dependent variables against time.

In addition to the regression analyses, summary graphs of the averaged linear measurements for males and females are plotted to compare growth patterns and examine the particular growth characteristics of this sample of males and females as a function of time.

Maturational Changes of Cervical Vertebrae

This section of the study is concerned with the development

of a provisional radiographic standard of reference according to the following criteria: (a) availability of a suitable film series from age 72 months (6 years) to 192 months (16 years), and (b) adequate identification of cardinal maturity indicators in all the films of the series. These maturity indicators fit the definition put forth by Gruelich and Pyle (1959) for the hand-wrist region and later applied to the cervical vertebrae region by Lamparski (1972).

Maximum Facial Growth Determination

Maxillary and mandibular linear dimensions, following the format put forth by Enlow (1971), are measured for the 12 females and 12 males from age 72 months to 192 months. Percentage increments of growth are calculated using the formula proposed by Nanda (1955):

$$\text{Growth Increment} = \frac{Y_2 - Y_1}{\frac{Y_2 + Y_1}{2}} \times 100,$$

where Y_1 and Y_2 are the values at the beginning and end of the time period, respectively. The facial dimensions are then plotted against chronological age. The actual peak period of the pubertal facial growth spurt, which is defined in the present study as the two years of maximum facial growth during adolescence, is identified from composite time series graphs of facial dimension and percentage increments. The data analysis is then compared to maturational stages of cervical vertebrae development. The main thrust of the study is directed towards the onset of ossification and fusion of

the vertebral rings of cervical vertebrae II, III and IV and its temporal relationships with the pubertal facial growth spurt.

RESULTS

Statistical Analysis

Tables I, II and III present analysis of cervical and facial development as functions of time. Table I shows the results of t-tests comparing the dependent variables, which represent the horizontal and vertical components of growth of the head and neck, for males versus females. There is a significant difference in growth against time for the head and neck between males and females. The t-values were calculated and compared to a 1-sided t-distribution curve. This was based on the expectation of larger dimensions for males at all chronological ages. Table II lists the t-values for the horizontal variables maxilla (Mx) and mandible (Md) compared to the dimensions of vertical growth for the cervical vertebrae (neck). For the males a significant difference in growth occurred for the maxilla and mandible compared to that for the cervical vertebrae. No significant difference in growth was found for the maxilla versus the mandible for males. For females, a significant difference in growth occurred for the maxilla (Mx) against $SN\text{-}CV_{III}$ and $SN\text{-}CV_{IV}$ at the $p<.05$ level. All other variables showed no significant difference in growth. Comparing variables within the neck, males show a significant difference in growth ($p<.05$) for variable $SN\text{-}CV_{II}$ compared to $SN\text{-}CV_{III}$ and $SN\text{-}CV_{IV}$. No significant difference in growth was found for females testing the vertical development of the face with the growth of the cervical vertebrae (neck) (Table III).

TABLE I

T-TESTS OF SIGNIFICANCE FOR REGRESSION RELATIONSHIPS (B)
BETWEEN MALES AND FEMALES

Dependent Variable	Male		Female		t Values	Significance	
	B	Std. Error B	B	Std. Error B		(2-Sided) P Less Than	(1-Sided) P Less Than
Mx	1.01	.14	.35	.26	2.21	.05	.05
Md	1.17	.13	.54	.23	2.40	.05	.01
SN-Me	3.06	.49	1.65	.71	1.63	NS	NS*
SN-Md	1.94	.23	1.02	.43	1.89	NS*	.05
$SN\text{-}CV_{II}$	2.00	.22	1.05	.43	1.95	NS*	.05
$SN\text{-}CV_{III}$	2.69	.26	1.60	.51	1.89	NS*	.05
$SN\text{-}CV_{IV}$	3.42	.60	1.93	.67	1.65	NS	.05

2-Sided Test

t_{262} .001 = ± 3.37

t_{262} .05 = ± 1.97

t_{262} .01 = ± 2.59

1-Sided Test

t_{260} .05 = 1.65

t_{260} .01 = 2.33

*Significance levels slightly greater than .05

TABLE II

T-TESTS OF SIGNIFICANCE FOR REGRESSION RELATIONSHIPS (B) BETWEEN VARIABLES OF THE HEAD AND NECK

	Dependent Variable	Male		Female	
		t Values	2-Sided P Less Than	t Values	2-Sided P Less Than
Mx vs. Neck	$Mx/SN\text{-}CV_{II}$	-3.71	.001	-1.40	NS
	$Mx/SN\text{-}CV_{III}$	-5.61	.001	-2.16	.05
	$Mx/SN\text{-}CV_{IV}$	-3.90	.001	-2.19	.05
Md vs. Neck	$Md/SN\text{-}CV_{II}$	-3.18	.01	-1.06	NS
	$Md/SN\text{-}CV_{III}$	-5.15	.001	-1.88	NS
	$Md/SN\text{-}CV_{IV}$	-3.65	.001	-1.96	NS
	Md/Mx	-0.84	NS	-0.54	NS
Neck vs. Neck	$SN\text{-}CV_{II}/SN\text{-}CV_{III}$	-1.99	.05	-0.81	NS
	$SN\text{-}CV_{III}/SN\text{-}CV_{IV}$	-1.12	NS	-0.39	NS
	$SN\text{-}CV_{II}/SN\text{-}CV_{IV}$	-2.22	.05	-1.10	NS

TABLE III

T-TESTS OF SIGNIFICANCE FOR REGRESSION RELATIONSHIPS (B) BETWEEN VARIABLES (VERTICAL) WITHIN HEAD AND NECK

	Dependent Variable	Male		Female	
		t Values	2-Sided P Less Than	t Values	2-Sided P Less Than
Vertical Drop of Face with Neck	SN-Me/SN-CV_{II}	1.97	.05	.71	NS
	SN-Me/SN-CV_{III}	0.67	NS	.06	NS
	SN-Me/SN-CV_{IV}	-0.47	NS	-.29	NS
	SN-Me/SN-Md	2.07	.05	.75	NS
	SN-Md/SN-CV_{II}	-0.17	NS	-.05	NS
	SN-Md/SN-CV_{III}	-2.15	.05	-.86	NS
	SN-Md/SN-CV_{IV}	-1.87	NS	-1.14	NS

However, a significant difference in growth did exist in males for the vertical drop of the chin (SN-Me) versus SN-Md and $SN\text{-}CV_{II}$. A significant difference in growth also occurred for the vertical descent of the posterior mandibular body (SN-Md) compared to cervical vertebrae III.

Figures 7 and 8 display the regression lines, using the equation Y^1 = (B) age + constant, where B is the regression coefficient (slope) and Y^1 is the estimated value of the dependent variable. Figures 9 and 10 show the relative increments for the regression lines. The greatest increase in growth over time occurred for cervical vertebrae IV for males and females. Maxilla (Mx) showed the smallest increase in growth for both males and females.

Pearson Correlation Coefficients were calculated for the seven dependent variables against chronological age (Table IV). Low correlations were exhibited for the dependent variables against time for females (r = .115-.263). For males, the correlations increase slightly (r = .446-.670). Comparing the dependent variables against one another, the correlations improve significantly. For example, the correlation between $SN\text{-}CV_{III}$ and $SN\text{-}CV_{II}$ was .995 for females and .993 for males (signigifant at the p .001 level). The correlation between $SN\text{-}CV_{III}$ and SN-Md was .953 for females and .912 for males. $SN\text{-}CV_{II}$ versus SN-Md showed a correlation of .942 for females and .893 for males.

Figures 11 to 15 are graphic illustrations which show mean vertical growth of facial and cervical dimensions outlined and discussed earlier. It should be emphasized that these graphs represent

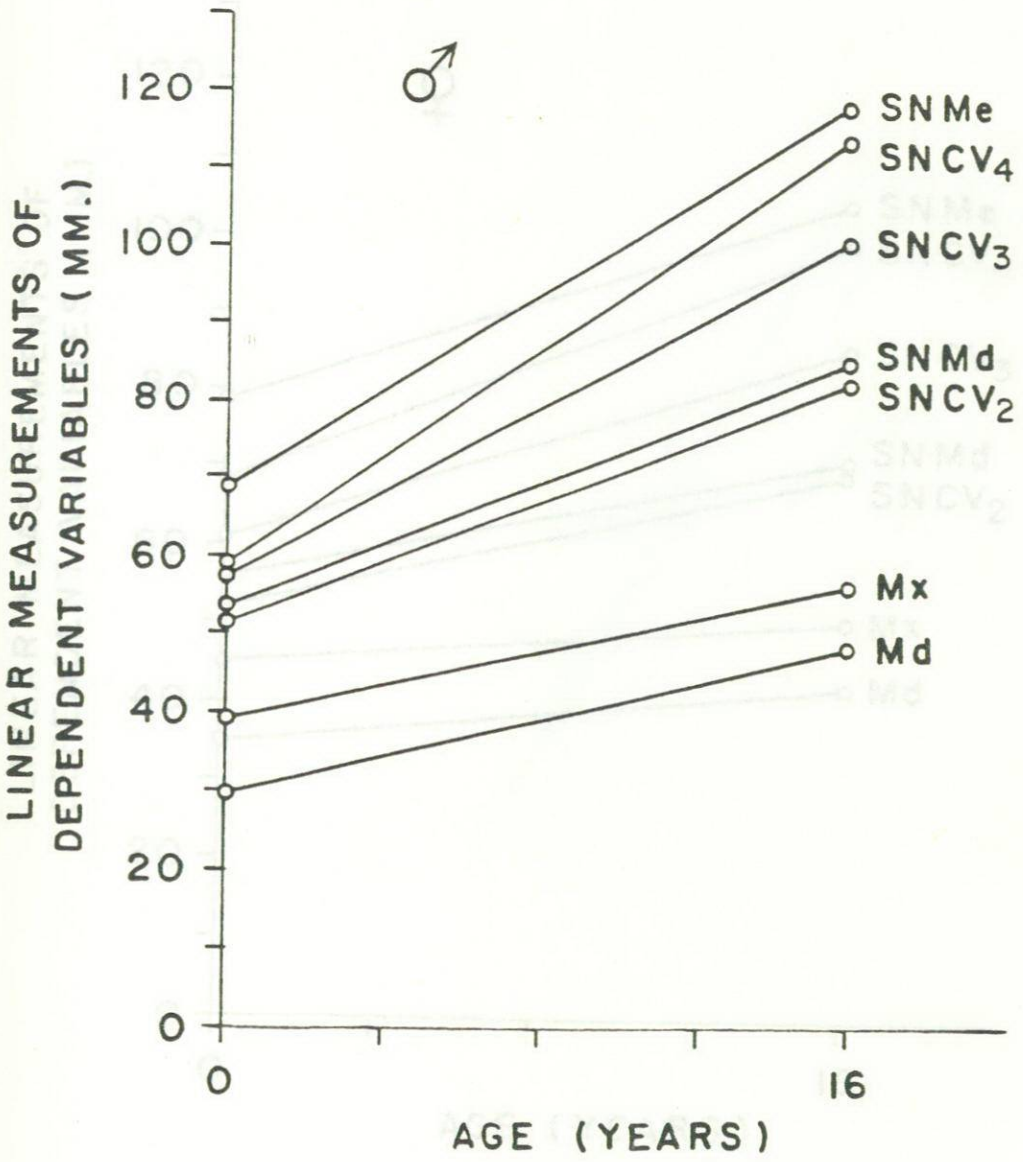

♂
120
100
80
60
40
20
0
0
16
AGE (YEARS)
LINEAR MEASUREMENTS OF DEPENDENT VARIABLES (MM.)
SNMe
SNCV4
SNCV3
SNMd
SNCV2
Mx
Md

Fig. 7

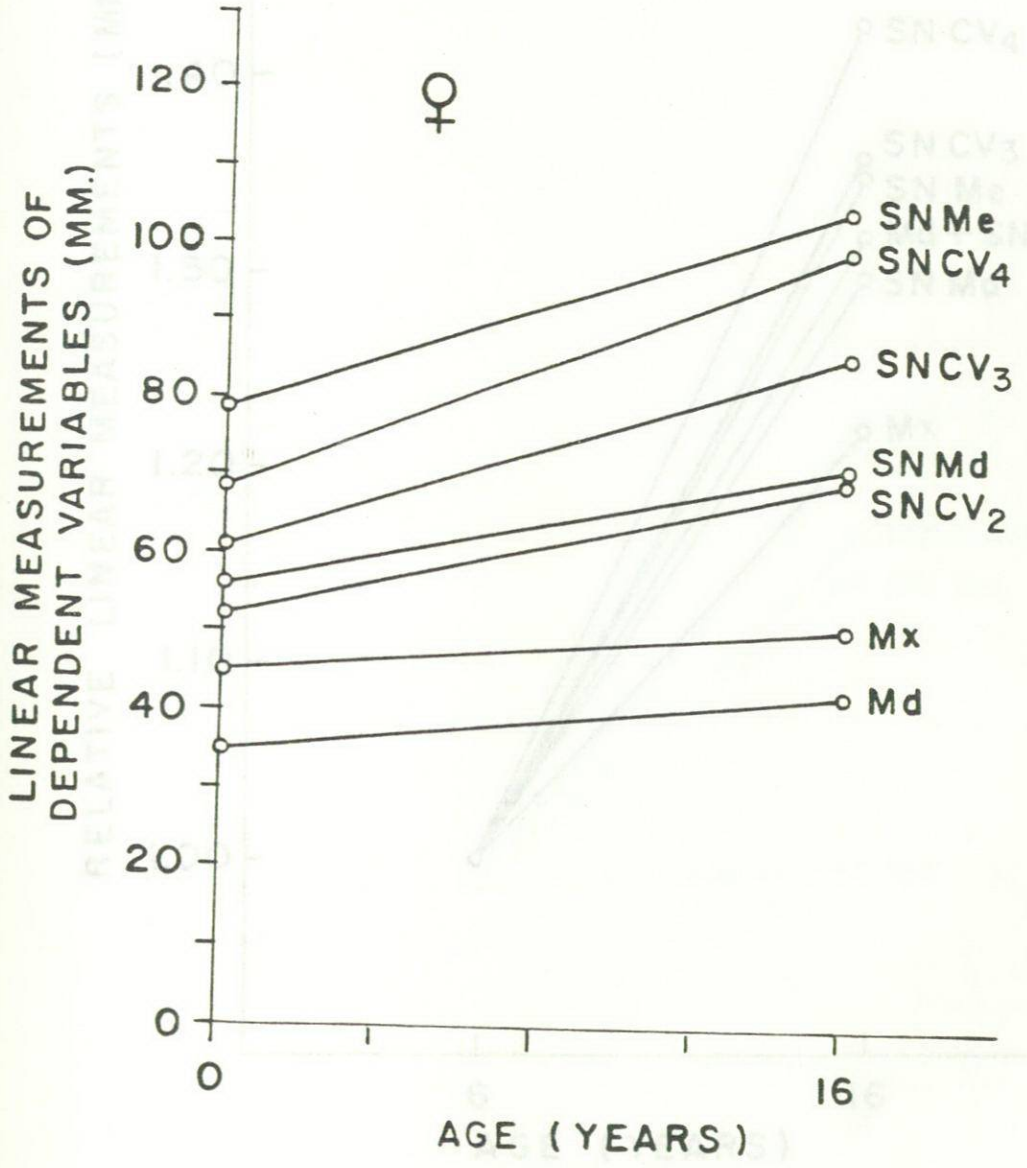

♀
120
100
80
60
40
20
0
0
16
AGE (YEARS)
LINEAR MEASUREMENTS OF DEPENDENT VARIABLES (MM.)
SNMe
SNCV4
SNCV3
SNMd
SNCV2
Mx
Md

Fig. 8

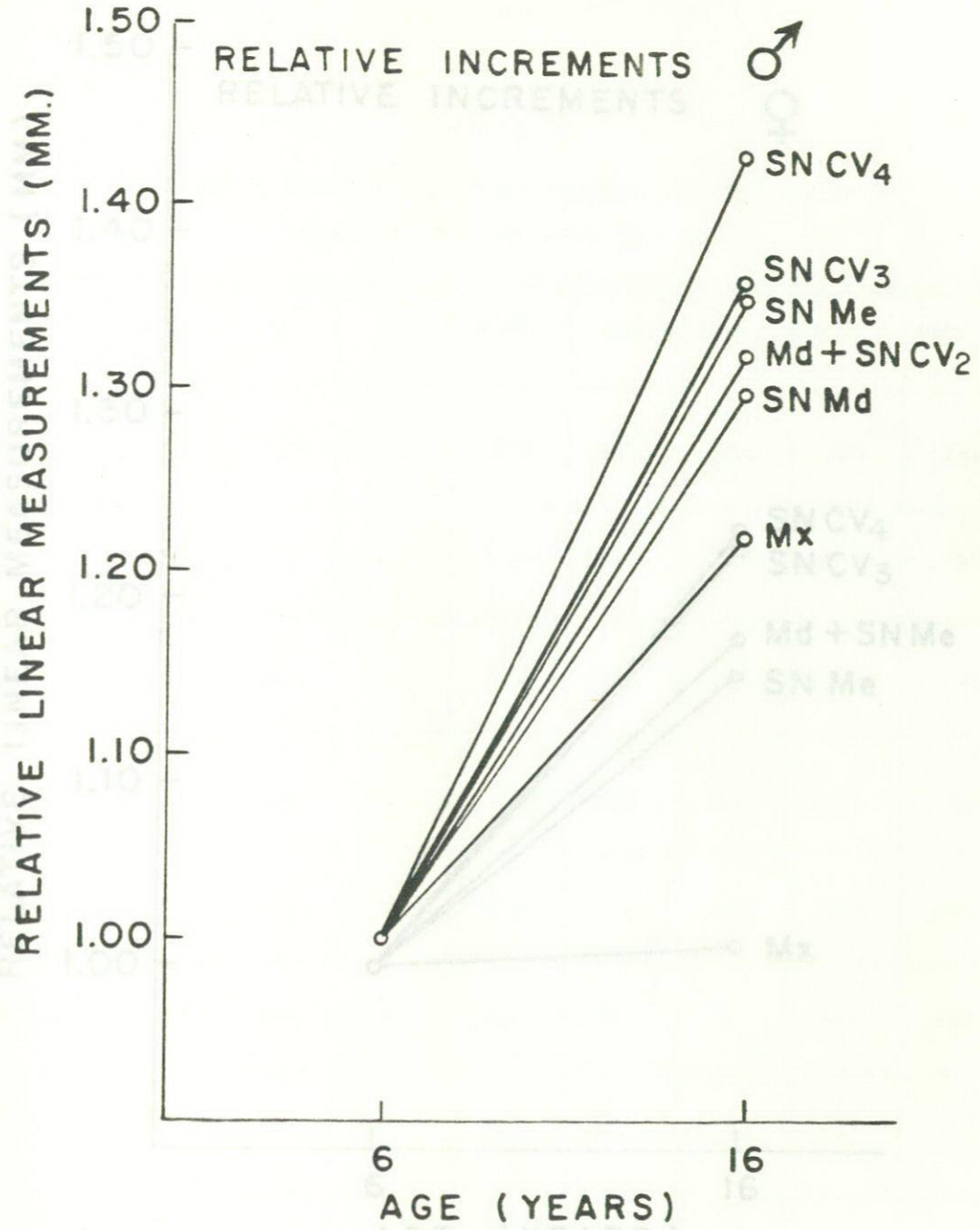

RELATIVE INCREMENTS ♂
RELATIVE LINEAR MEASUREMENTS (MM.)
1.50
1.40
1.30
1.20
1.10
1.00
SN CV4
SN CV3
SN Me
Md + SN CV2
SN Md
Mx
6
16
AGE (YEARS)

Fig. 9

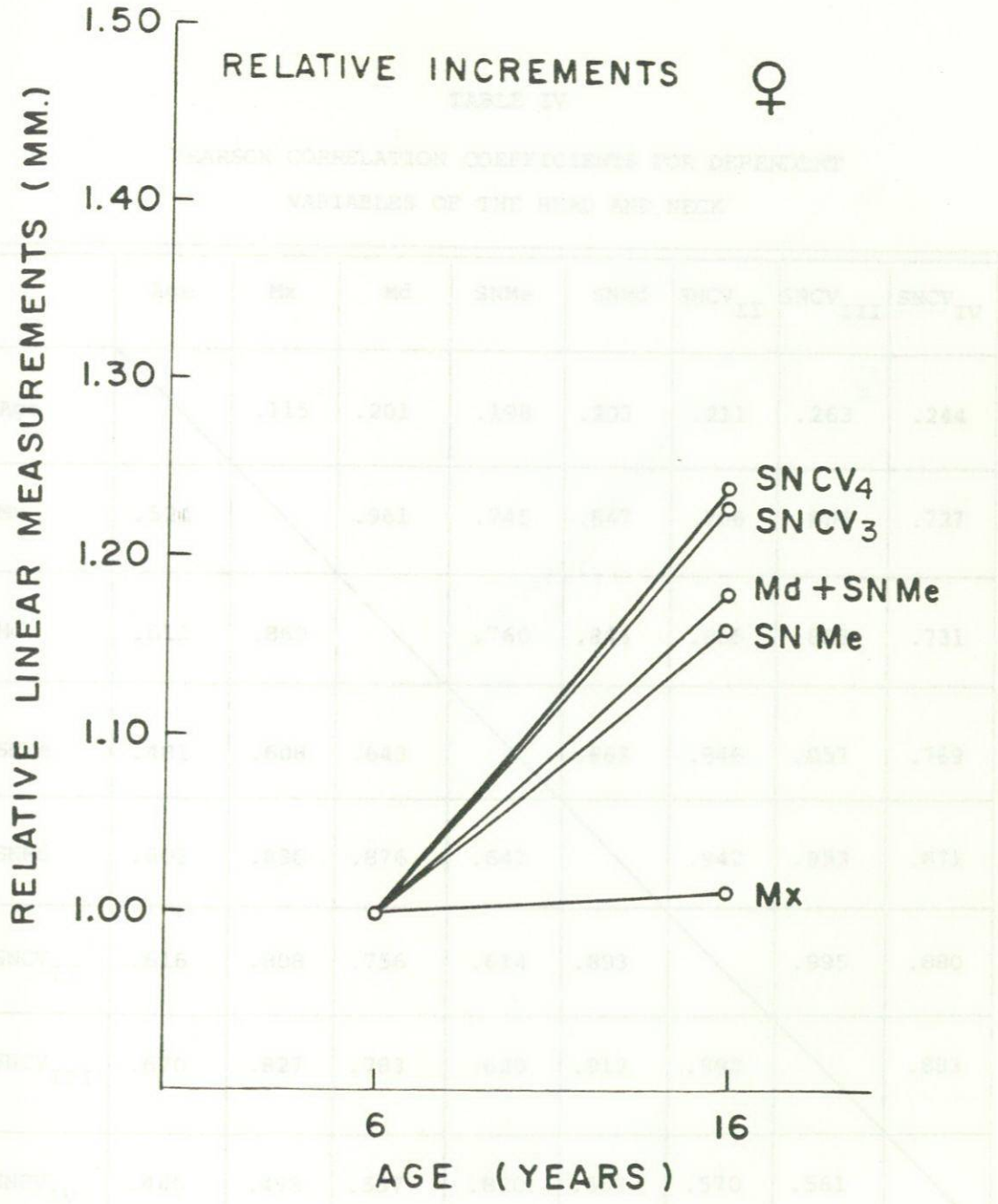

RELATIVE INCREMENTS ♀
RELATIVE LINEAR MEASUREMENTS (MM.)
1.50
1.40
1.30
1.20
1.10
1.00
SN CV4
SN CV3
Md + SN Me
SN Me
Mx
6
16
AGE (YEARS)

Fig. 10

TABLE IV

PEARSON CORRELATION COEFFICIENTS FOR DEPENDENT VARIABLES OF THE HEAD AND NECK

	Age	Mx	Md	SNMe	SNMd	$SNCV_{II}$	$SNCV_{III}$	$SNCV_{IV}$
Age		.115	.201	.198	.203	.211	.263	.244
Mx	.524		.961	.745	.847	.786	.806	.727
Md	.612	.869		.760	.846	.805	.823	.731
SNMe	.481	.608	.643		.863	.846	.857	.769
SNMd	.603	.836	.876	.647		.942	.953	.871
$SNCV_{II}$	.616	.808	.756	.614	.893		.995	.880
$SNCV_{III}$	.670	.827	.783	.620	.912	.993		.883
$SNCV_{IV}$	.446	.498	.537	.820	.553	.570	.561	

Females

Males

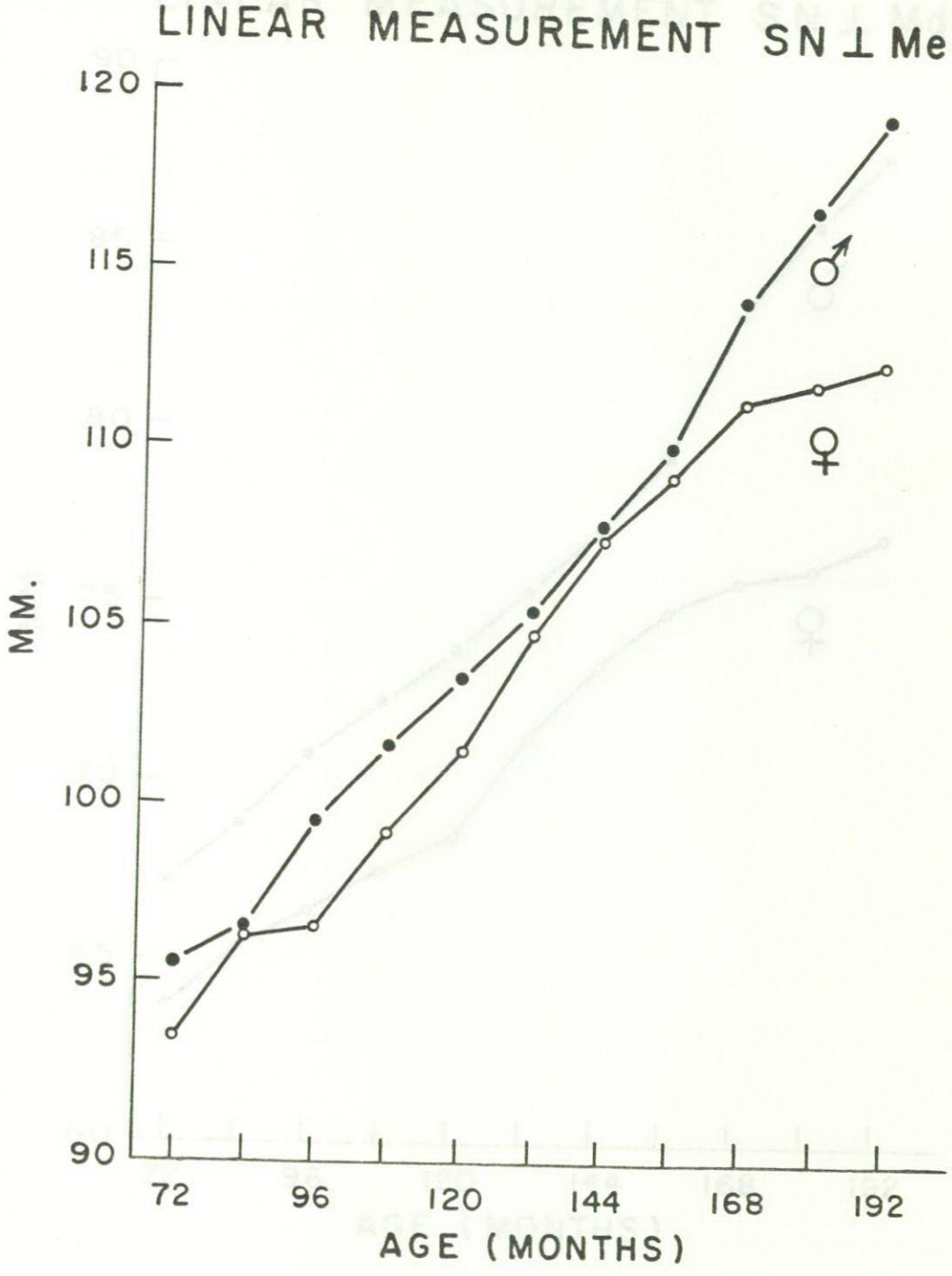

LINEAR MEASUREMENT SN ⊥ Me
120
115
110
105
100
95
90
MM.
♂
♀
72
96
120
144
168
192
AGE (MONTHS)

Fig. 11

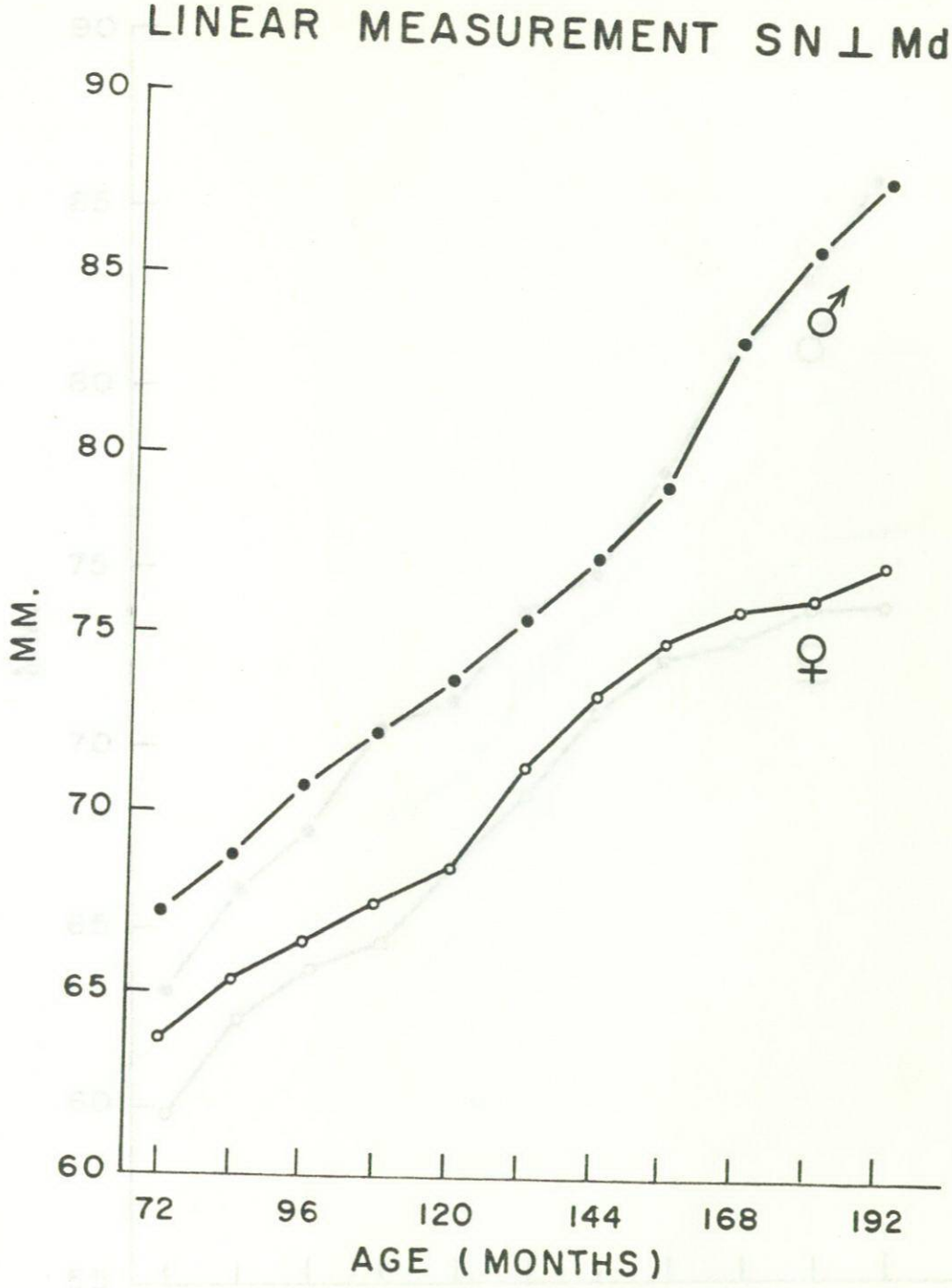

LINEAR MEASUREMENT SN ⊥ Md
90
85
80
75
70
65
60
MM.
♂
♀
72
96
120
144
168
192
AGE (MONTHS)

Fig. 12

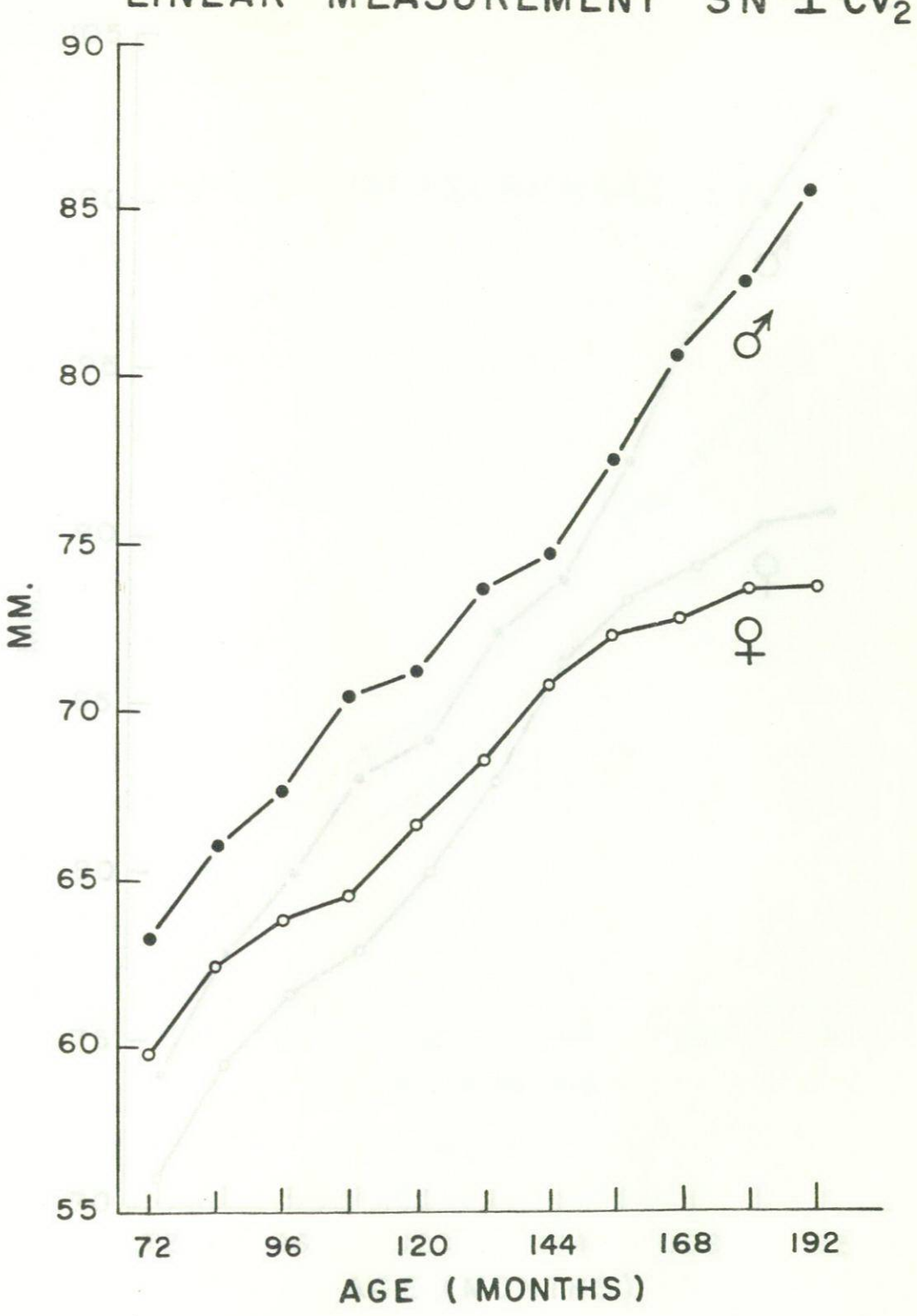

LINEAR MEASUREMENT SN ⊥ CV2
90
85
80
75
70
65
60
55
MM.
♂
♀
72
96
120
144
168
192
AGE (MONTHS)

Fig. 13

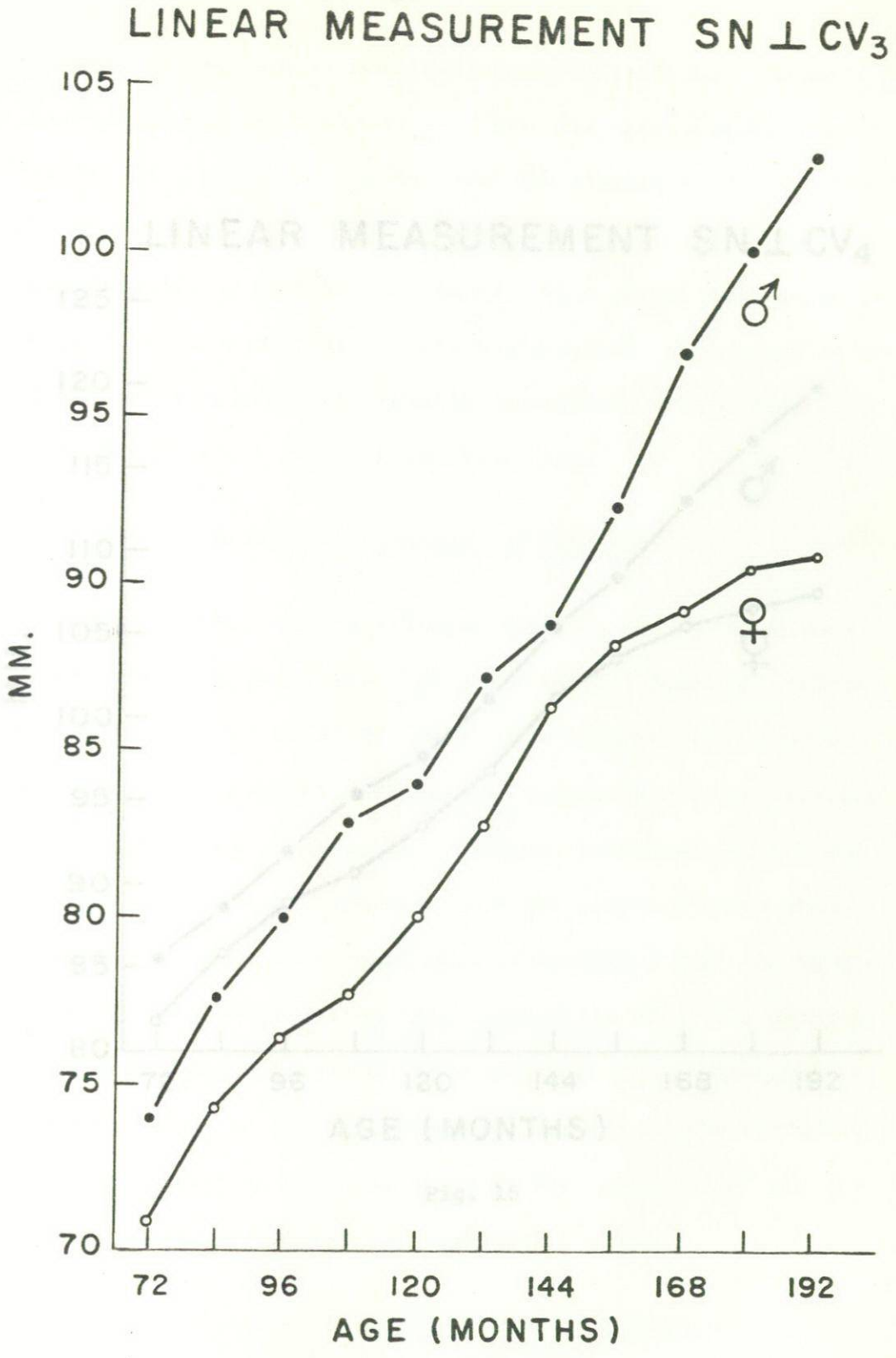

LINEAR MEASUREMENT SN ⊥ CV3
105
100
95
90
85
80
75
70
MM.
♂
♀
72
96
120
144
168
192
AGE (MONTHS)

Fig. 14

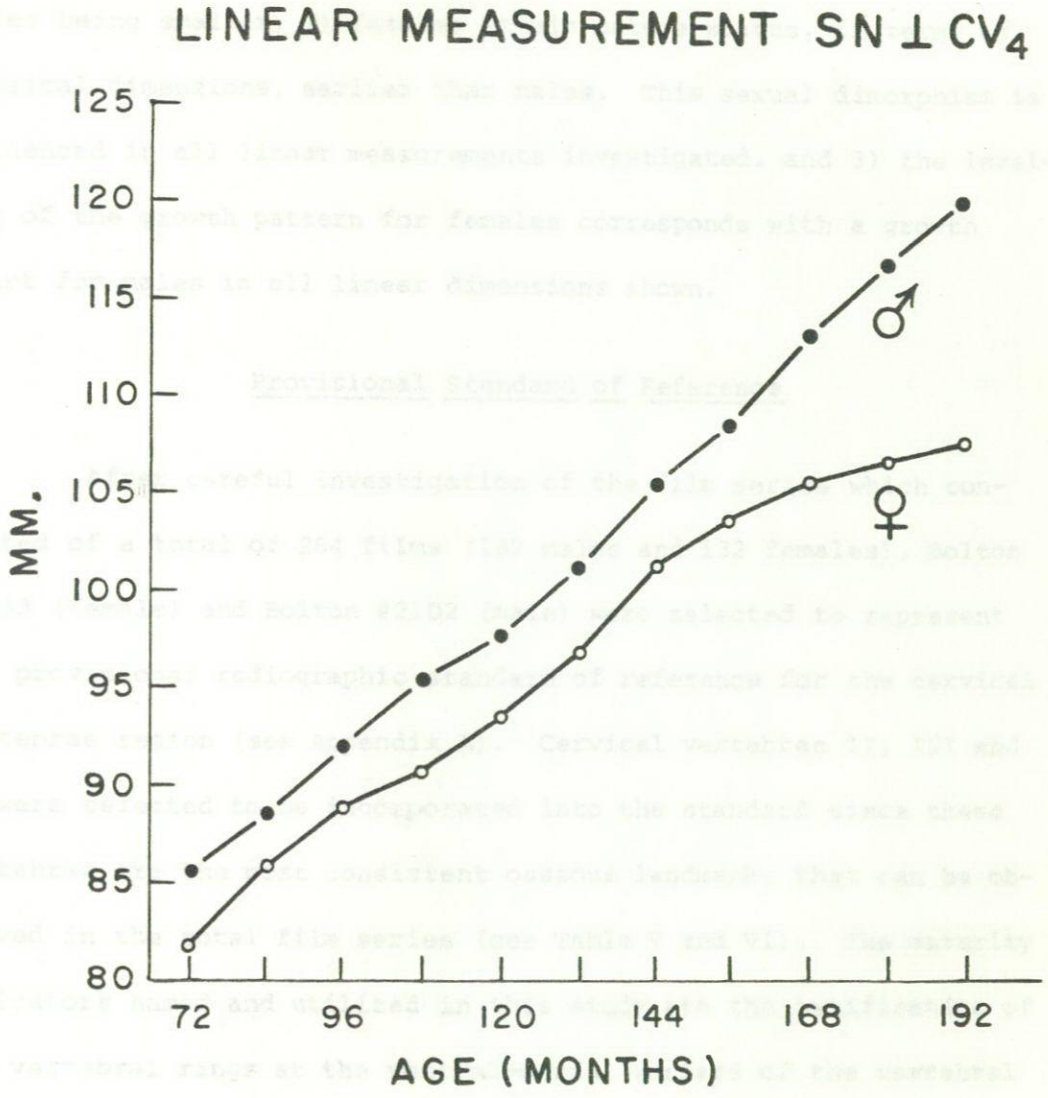

LINEAR MEASUREMENT SN ⊥ CV4
125
120
115
110
105
100
95
90
85
80
MM.
72
96
120
144
168
192
AGE (MONTHS)
♂
♀

Fig. 15

averaged values and tend to mask individual differences. Three characteristics may be observed: 1) there are corresponding increases for both males and females with the dimensions for the females being smaller, 2) females attain mature status, in terms of physical dimensions, earlier than males. This sexual dimorphism is evidenced in all linear measurements investigated, and 3) the leveling of the growth pattern for females corresponds with a growth spurt for males in all linear dimensions shown.

Provisional Standard of Reference

After careful investigation of the film series which consisted of a total of 264 films (132 males and 132 females), Bolton #2033 (female) and Bolton #2102 (male) were selected to represent the provisional radiographic standard of reference for the cervical vertebrae region (see Appendix A). Cervical vertebrae II, III and IV were selected to be incorporated into the standard since these vertebrae are the most consistent osseous landmarks that can be observed in the total film series (see Table V and VI). The maturity indicators named and utilized in this study are the ossification of the vertebral rings at the ventral-caudal surface of the vertebral body and the initiation of a concavity at the epicenter of the caudal surface of the vertebrae body (Lamparski, 1972).

Relationship of Vertebral Ring Ossification with Maximum Facial Growth

An example of the summary graphs utilized in this investigation are shown in Figures 16 and 17. A total of 24 graphs were

TABLE V

NUMBER OF COMPLETE OSSEOUS SHADOWS OF CERVICAL VERTEBRAE (II TO VII) VISIBLE IN THE LATERAL VIEW RADIOGRAPHS OF 12 CLEVELAND MALES AT THE FOLLOWING CHRONOLOGICAL AGES (MONTHS)

Bolton Number	72	84	96	108	120	132	144	156	168	180	192
B113	II,III,IV, V,VI*	II,III,IV	II,III,IV, V	II,III,IV	(119) II,III,IV, V*	II,III,IV	II,III,IV*	II,III	II,III,IV	II,III,IV	II,III,IV
B114	II,III,IV V,VI*	II,III,IV*	(95) II,III,IV, V*	II,III,IV, V,VI*	II,III,IV, V,VI*	II,III,IV, V*	II,III,IV, V	II,III,IV, V*	II,III,IV, V	II,III,IV	II,III,IV, V*
B2013	II,III,IV, V,VI*	II,III,IV, V	II,III,IV, V,VI	II,III,IV, V	II,III,IV, V,VI*	II,III,IV, V	II,III,IV, V*	(157) II,III,IV, V,VI*	(169) II,III,IV, V,VI	II,III,IV, V*	(193) II,III,IV, V,VI*
B2102	II,III,IV, V	II,III,IV	II,III,IV, V*	II,III,IV, V*	II,III,IV, V	II,III,IV, V,VI*	II,III,IV, V*	II,III,IV, V,VI*	II,III,IV, V	II,III,IV, V,VI*	(193) II,III,IV
B2205	II,III,IV, V,VI*	II,III,IV, V*	II,III,IV	II,III,IV, V*	II,III,IV, V,VI*	II,III,IV, V*	II,III,IV, V*	II,III,IV, V*	(169) II,III,IV, V,VI*	(177) II,III,IV, V	II,III,IV, V*
B1168	II,III,IV, V*	II,III,IV, V*	II,III,IV*	II,III,IV, V	II,III,IV	II,III,IV, V*	II,III,IV	II,III,IV	(166) II,III,IV, V*	(179) II,III,IV	II,III,IV*
B2165	II,III,IV	II,III,IV	II,III,IV	II,III,IV	II,III,IV, V	II,III,IV, V*	II,III,IV, V	. .	II,III,IV, V*	II,III,IV	II,III,IV
B2070	II,III,IV, V*	II,III,IV, V,VI	II,III,IV, V	II,III,IV, V*	II,III,IV, V*	II,III,IV, V*	II,III,IV, V,VI*	II,III,IV, V*	(172) II,III,IV, V*	II,III,IV, V,VI*	II,III,IV
B2319	II,III,IV, V	II,III,IV, V,VI	II,III,IV, V,VI*	II,III,IV, V,VI	II,III,IV, V	II,III,IV, V,VI*	II,III,IV, V	II,III,IV, V,VI*	(171) II,III,IV, V,VI*	II,III,IV, V,VI*	II,III,IV, V
B2216	II,III,IV, V	II,III,IV, V	II,III,IV, V,VI*	II,III,IV	II,III,IV	II,III,IV, V	II,III,IV	II,III,IV, V*	II,III,IV, V*	II,III,IV	II,III,IV
B1246	II,III,IV, V	II,III,IV, V*	II,III,IV V*	II,III,IV, V	II,III,IV, V	(134) II,III,IV, V	(143) II,III,IV, V	(155) II,III,IV, V*	(167) II,III,IV, V*	(172) II,III,IV	(188) II,III,IV
B1169	II,III,IV, V*	II,III,IV	II,III,IV, V,VI*	II,III,IV, V	II,III,IV, V*	II,III,IV	II,III,IV	II,III,IV	II,III,IV, V*	II,III,IV	II,III,IV, V*

* Only the cephalic surface of vertebrae is visible in cephalogram.

TABLE VI

NUMBER OF COMPLETE OSSEOUS SHADOWS OF CERVICAL VERTEBRAE (II TO VII) VISIBLE IN THE LATERAL VIEW RADIOGRAPHS OF 12 CLEVELAND FEMALES AT THE FOLLOWING CHRONOLOGICAL AGES (MONTHS)

Bolton Number	72	84	96	108	120	132	144	156	168	180	192
B2243	II,III,IV, V*	II,III,IV, V*	II,III,IV, V,VI*	II,III,IV, V,VI*	II,III,IV, V*	II,III,IV, V	II,III,IV, V,VI*	II,III,IV, V,VI*	(167) II,III,IV, V,VI*	. .	II,III,IV
B2284	II,III,IV, V	II,III,IV, V,VI*	II,III,IV, V	II,III,IV, V	II,III,IV, V	II,III,IV, V*	II,III,IV, V	II,III,IV	II,III,IV, V*	II,III,IV, V*	. .
B1432	II,III,IV, V,VI	II,III,IV, V	II,III,IV	II,III,IV, V*	II,III,IV, V*	II,III,IV, V,VI*	II,III,IV, V*	II,III,IV, V	II,III,IV, V,VI*	(181) II,III,IV, V	(193) II,III,IV, V
B1257	II,III,IV, V	II,III,IV, V,VI	II,III,IV, V,VI	(107) II,III,IV, V,VI*	II,III,IV, V,VI*	II,III,IV, V*	II,III,IV, V	II,III,IV, V	II,III,IV, V	(185) II,III,IV, V	II,III,IV, V*
B2702	II,III,IV, V,VI*	II,III,IV, V,VI*	II,III,IV, V	II,III,IV	II,III,IV, V,VI*	II,III,IV, V	II,III,IV, V	II,III,IV, V	II,III,IV, V	(182) II,III,IV, V*	II,III,IV, V*
B2033	II,III,IV, V,VI*	II,III,IV, V,VI	II,III,IV, V	II,III,IV, V,VI*	II,III,IV, V	II,III,IV	II,III,IV, V	II,III,IV, V	II,III,IV, V,VI*	II,III,IV, V	II,III,IV, V
B2203	II,III,IV, V,VI	II,III,IV, V	II,III,IV, V	II,III,IV, V*	II,III,IV, V	II,III,IV	. .	II,III,IV, V	II,III,IV, V	II,III,IV, V*	II,III,IV, V,VI*
B107	II,III,IV, V*	II,III,IV, V	II,III,IV	II,III,IV, V	II,III,IV, V*	II,III,IV, V	II,III,IV, V	II,III,IV, V*	II,III,IV, V*	II,III,IV, V*	II,III,IV, V*
B110	II,III,IV, V	II,III,IV, V	II,III,IV	II,III,IV, V*	II,III,IV, V*	II,III,IV, V*	II,III,IV	II,III,IV	II,III,IV	II,III,IV*	II,III,IV
B1883	II,III,IV, V	II,III,IV, V*	II,III,IV, V*	II,III,IV	II,III,IV, V*	II,III,IV, V	II,III,IV	II,III,IV, V	II,III,IV	II,III,IV	(194) II,III,IV, V*
B1885	II,III,IV, V,VI*	II,III,IV, V,VI	II,III,IV, V,VI	II,III,IV, V	II,III,IV, V,VI	II,III,IV, V	II,III,IV, V	II,III,IV, V	II,III,IV, V*	II,III,IV, V,VI	. .
B1895	II,III,IV, V	II,III,IV, V*	II,III,IV, V,VI*	II,III,IV, V*	II,III,IV, V*	II,III,IV, V*	(146) II,III,IV, V,VI*	(163) II,III,IV	(170) II,III,IV, V	(181) II,III,IV, V,VI*	(193) II,III,IV, V*

* Only the cephalic surface of vertebrae is visible in cephalogram.

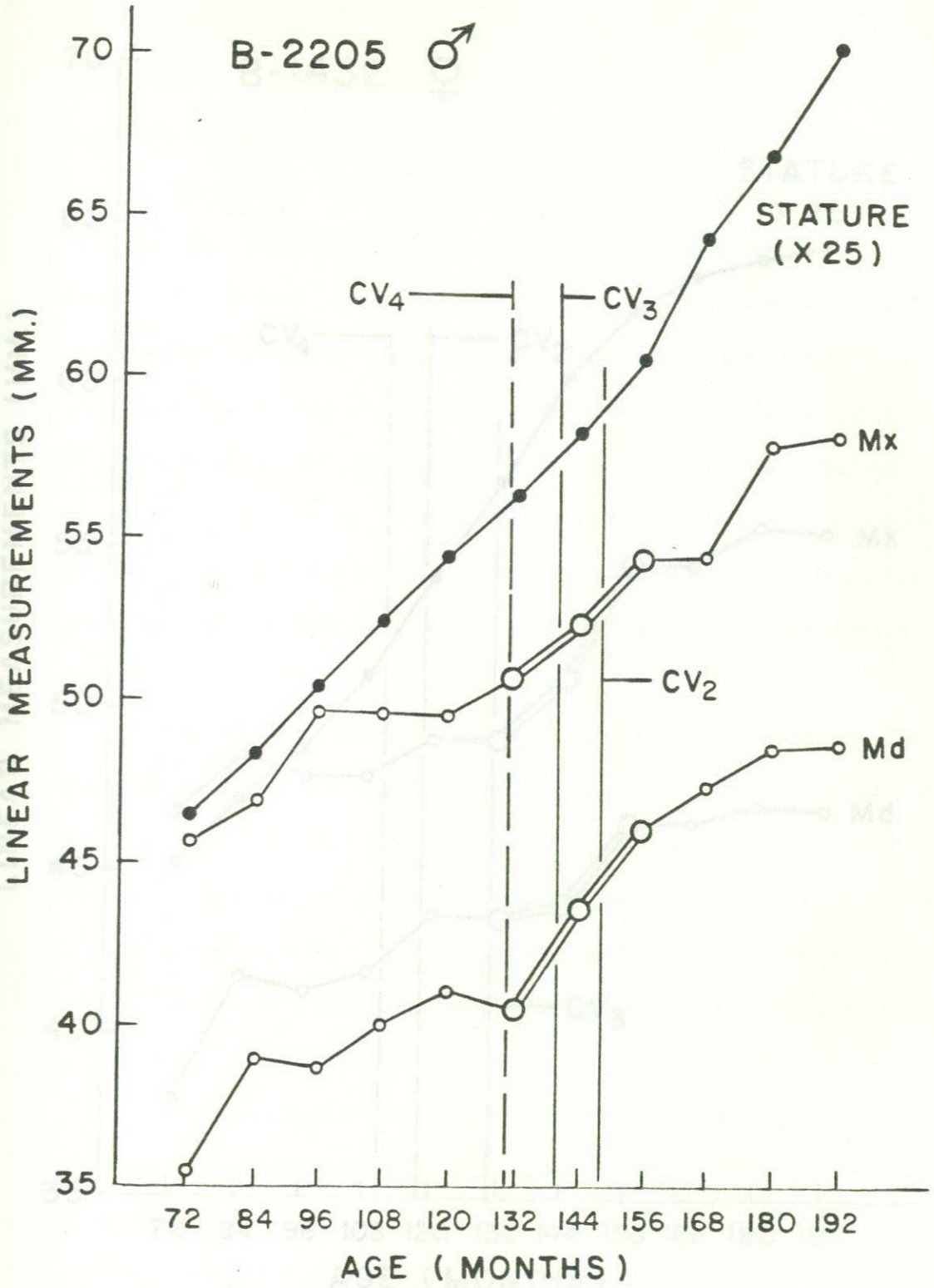

B-2205 ♂
70
65
60
55
50
45
40
35
LINEAR MEASUREMENTS (MM.)
STATURE
(X 25)
CV4
CV3
CV2
Mx
Md
72 84 96 108 120 132 144 156 168 180 192
AGE (MONTHS)

Fig. 16

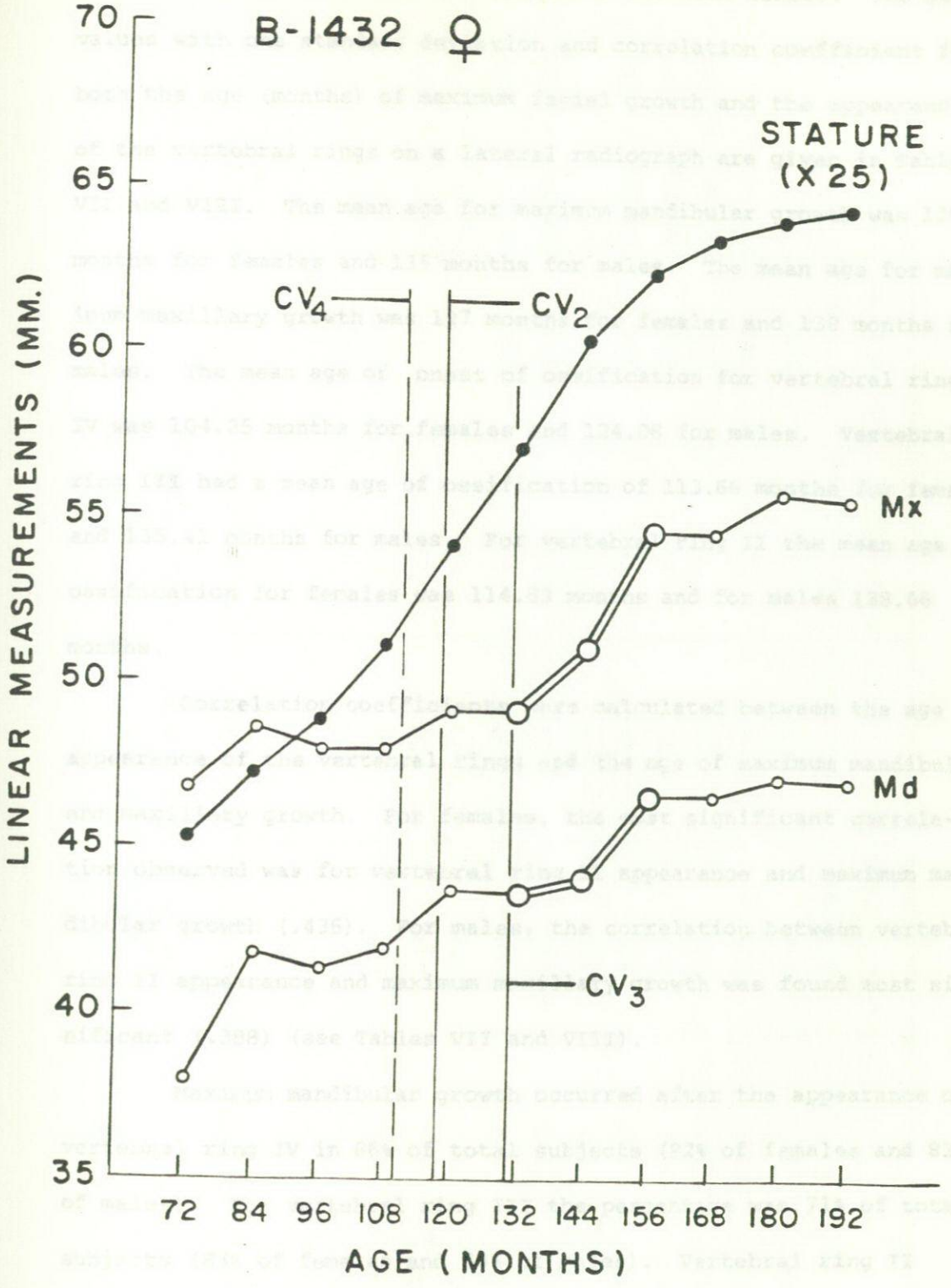

B-1432 ♀
STATURE
(X 25)
CV4
CV2
CV3
Mx
Md
LINEAR MEASUREMENTS (MM.)
70
65
60
55
50
45
40
35
72 84 96 108 120 132 144 156 168 180 192
AGE (MONTHS)

Fig. 17

constructed for each male and female in the film series. The mean values with one standard deviation and correlation coefficient for both the age (months) of maximum facial growth and the appearance of the vertebral rings on a lateral radiograph are given in Tables VII and VIII. The mean age for maximum mandibular growth was 129 months for females and 135 months for males. The mean age for maximum maxillary growth was 127 months for females and 138 months for males. The mean age of onset of ossification for vertebral ring IV was 104.25 months for females and 124.08 for males. Vertebral ring III had a mean age of ossification of 113.66 months for females and 135.41 months for males. For vertebral ring II the mean age of ossification for females was 114.83 months and for males 138.66 months.

Correlation coefficients were calculated between the age of appearance of the vertebral rings and the age of maximum mandibular and maxillary growth. For females, the most significant correlation observed was for vertebral ring II appearance and maximum mandibular growth (.436). For males, the correlation between vertebral ring II appearance and maximum maxillary growth was found most significant (.388) (see Tables VII and VIII).

Maximum mandibular growth occurred after the appearance of vertebral ring IV in 88% of total subjects (92% of females and 83% of males). For vertebral ring III the percentage was 71% of total subjects (83% of females and 58% of males). Vertebral ring II appeared before maximum mandibular growth in 54% of total subjects (75% of females and 33% of males).

TABLE VII

CORRELATION OF ONSET OF MAXIMUM FACIAL GROWTH WITH INITIAL OSSIFICATION OF VERTEBRAL RINGS (MALES)

Bolton Number	Mx	Md	CV_{IV}	CV_{III}	CV_{II}
B1169	144	144	148	151	152
B2216	144	132	134	135	140
B1168	132	132	128	126	140
B2102	132	156	117	148	142
B2070	144	108	106	142	139
B2205	132	132	130	140	148
B113	156	144	118	140	153
B2165	120	120	118	130	136
B2319	144	144	116	138	126
B2013	132	132	130	124	118
B114	144	132	128	126	140
B1240	132	144	116	125	130
	$\bar{X}$ = 138	$\bar{X}$ = 135	$\bar{X}$ = 124.08	$\bar{X}$ = 135.41	$\bar{X}$ = 138.66
	S.D. = 9.57	S.D. = 12.66	S.D. = 11.09	S.D. = 9.23	S.D. = 10.25

	$\underline{r}$
$Mx-CV_{IV}$	= .112
$Mx-CV_{III}$	= .323
$Mx-CV_{II}$	= .388
Mx-Md	= .160
$Md-CV_{IV}$	= .231
$Md-CV_{III}$	= .277
$Md-CV_{II}$	= .129

TABLE VIII

CORRELATION OF ONSET OF MAXIMUM FACIAL GROWTH WITH INITIAL OSSIFICATION OF VERTEBRAL RINGS (FEMALES)

Bolton Number	Mx	Md	CV_{IV}	CV_{III}	CV_{II}
B1257	120	132	142	128	114
B2243	120	96	94	104	100
B2702	132	156	104	106	126
B1432	132	132	112	130	118
B2033	108	108	90	106	116
B1895	120	144	116	130	129
B2284	120	120	105	104	98
B2203	132	132	80	93	100
B107	144	120	104	138	136
B110	144	120	112	114	118
B1883	120	156	112	129	130
B1885	132	132	80	82	93
	$\bar{X}$ = 127	$\bar{X}$ = 129	$\bar{X}$ = 104.25	$\bar{X}$ = 113.66	$\bar{X}$ = 114.83
	S.D. = 10.80	S.D. = 17.82	S.D. = 17.13	S.D. = 17.32	S.D. = 14.22

	$\underline{r}$
$Mx-CV_{IV}$ =	.069
$Mx-CV_{III}$ =	.077
$Mx-CV_{II}$ =	.273
Mx-Md =	.119
$Md-CV_{IV}$ =	.278
$Md-CV_{III}$ =	.216
$Md-CV_{II}$ =	.436

Maximum maxillary growth occurred after the appearance of vertebral ring IV in 92% of total subjects (92% of females and 92% of males). For vertebral ring III the percentage was 71% of total (75% of females and 67% of males). Vertebral ring II occurred before maximum maxillary growth in 67% of total (75% of females and 58% of males).

DISCUSSION

In view of the dearth of information regarding the longitudinal growth of the cervical vertebrae, an attempt was made to investigate the maturational process of cervical vertebrae II, III and IV, as correlated with the growth of the face during the postnatal period from 6 years to 16 years. The results show that the maturation of the vertebrae can provide an index in ascertaining the developmental status of an individual, but its use as an aid in timing treatment to coincide with the circumpubertal facial growth spurt is inadequate. The findings show a lack of sufficient correlations to enable any form of prediction to be made concerning peak facial growth at adolescence as indicated by the onset of ossification of the vertebral rings of cervical vertebrae II, III or IV. The most significant finding is that prior to ossification of vertebral ring IV (e.g., ring has yet to appear in headfilms) 92% of females and 83% of males in this sample still had maximum increment of mandibular growth yet to occur and 92% of males and females still had maximum increment of maxillary growth yet to appear.

Investigation of the growth of the cervical vertebrae with the vertical growth of the face showed a significant sexual difference of growth over time. This finding substantiates many past investigations by Simmons and Todd (1938), Meredith (1953), and Tanner (1955) showing distinct sexual differences in the timing, magnitude

and morphology of growth of various parts of the body during adolescence. Of particular interest is the fact that the cervical and facial mean dimensions attained by males were consistently larger than those of females, and the rates of growth were greater for males compared to females as evidenced by the relative increments of the slopes of regression lines. This sexual difference in growth patterns seems to occur in response to the sexual differences in respiratory needs that occur at adolescence. Bosma (1963) contends that the development of head and neck posture is functionally related to maintenance of a patent pharyngeal airway. Studies by Ferris and Smith (1953) and Morse et al. (1952) have shown that the pattern of respiratory needs changes at puberty, with males showing an increased respiratory volume and vital capacity. This leads to larger lung size and consequently broader shoulders and chest size to accommodate the difference. From the findings obtained in this investigation, it is concluded that the vertical development of the face and cervical vertebrae have growth patterns analogous in development with the respiratory needs of males and females.

Graphic illustrations of the rate of progress of mean vertical growth for both the head and neck demonstrate a growth spurt for males with a corresponding leveling of growth for females. This sexual change in the pattern of growth demonstrates a developmental basis explaining the sexual dimorphic character of vertical development of the head and neck. That is, if a portion of the male body continues to grow for a longer amount of time, it should then show relatively larger dimensions for males compared to females at the

cessation of their respective growth periods.

In establishing a base of reference for the normal growth and development of the cervical vertebral region, the assumptions of Gruelich and Pyle (1959) regarding the progress of ossification in any growing bone were taken into account. They concluded these assumptions were a pre-requisite to formulating a radiographic standard of reference design. These parallel assumptions were:

1. There are transitional, ossifying features in the bodies of the cervical vertebrae which are the same for both sexes.
2. The chronological intervals between transitional features of any cervical vertebrae are not uniform.
3. The process of ossification and development occurs more slowly in males than in females who are on the same developmental schedule.

In the present investigation, it was found these assumptions are correct for the vertebral rings and the concavities at the caudal surfaces of the vertebral bodies. Mean onset age of ossification for the vertebral rings showed females at an advanced (earlier) pattern of development compared to males for all three vertebral rings in question. The sequence of ossification showed that the vertebral ring of cervical vertebrae IV ossifies first, vertebral ring III begins to ossify second, and vertebral ring II ossifies last. Females developed concavities at the caudal surfaces of cervical vertebrae II, III and IV earlier than males.

In contrast to Lamparski's (1972) standard of reference, which was based on cross-sectional data, this provisional standard of reference was constructed so as to utilize longitudinal

radiographic data, thus allowing for a near-complete and regularly spaced sequence of developmental data for each sex. Upon viewing the sequential changes of the osseous shadows, the female standard was found to be more advanced developmentally as compared with Lamparski's data in regard to the initiation of concavities at the caudal surfaces of the vertebral bodies. This difference could be explained by the nature of the population samples utilized in our respective investigations.

A significant finding resulting from this investigation was the high degree of correlation among certain variables of cervical vertebral development as compared with the vertical development of the face. These relationships appear to demonstrate a biologic continuity of development which could be used as an index for normal vertical facial growth. Further investigation in this area is warranted to (1) determine if vertical dysplasia of facial growth patterns can be predicted early in one's developmental scheme, and (2) to develop precise quantitative standards for identifying "long" and "short" faces.

SUMMARY AND CONCLUSIONS

1. The purpose of this study was to study the relationship between the normal maturation of cervical vertebrae II, III and IV and the maximum rate of facial growth at adolescence.

2. The sample consisted of 12 males and 12 females taken from the Bolton-Brush Growth Study collection. Longitudinal data were obtained from records and lateral cephalograms of Cleveland children taken annually, for the ages 6 years to 16 years.

3. Peak facial growth was determined from composite time series graphs of the facial dimensions that expressed the maxillary and mandibular alveolar lengths.

4. The age of appearance of the "vertebral rings" were determined by inspection of the annual cephalometric radiographs.

5. It is concluded that the maturation of cervical vertebrae II, III and IV can provide a reliable index for the developmental status of an individual (Appendix A).

6. Onset of ossification in the vertebral rings and the development of concavities at the caudal surfaces of vertebral bodies were found to occur later in males than in females.

7. The vertebral ring of cervical vertebrae IV started to ossify first before the others for both males and females, with vertebral ring of CV_{II} the last to begin its ossification.

8. There is a sexual difference between the vertical growth of cervical vertebrae II, III and IV and the horizontal and vertical growth of the face. This sexual difference appears to relate to corresponding differences in the respiratory needs of males as compared with females at adolescence.

9. Results show a lack of sufficient correlations that would permit any form of clinical prediction to be made regarding peak facial growth at adolescence with maturation of cervical vertebrae II, III or IV or the ossification of its vertebral rings.

10. Significantly high correlations were found to exist between the vertical development of the neck and the vertical development of the face. It is suggested that these correlations demonstrate the existence of a biologic continuity between them, and that an index could be constructed that would allow an assessment of the status of vertical facial development utilizing the cervical vertebrae.

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APPENDIX A

PROVISIONAL RADIOGRAPHIC STANDARD OF REFERENCE FOR CERVICAL VERTEBRAE II, III, IV FOR MALES AND FEMALES

PLATE I

SKELETAL AGE EQUIVALENCE--72 MONTHS (FEMALE)

CV_{II}: Caudal surfaces are relatively flat and osseous corners are rounded. Vertebral ring is entirely cartilaginous (radiotranslucent on radiograph).

CV_{III}: Caudal surfaces are flat with osseous corners more defined than CV_{II}. Vertebral ring is entirely cartilaginous (radiotranslucent).

CV_{IV}: Caudal surfaces are flat with osseous corners more defined than CV_{III}. Vertebral ring is cartilaginous.



PLATE II

SKELETAL AGE EQUIVALENCE--84 MONTHS (FEMALE)

CV_{II}: Caudal surfaces are relatively flat and osseous corners are rounded. Vertebral ring is entirely cartilaginous (radiotranslucent on radiograph).

CV_{III}: Caudal surfaces are flat with osseous corners more defined than CV_{II}. Vertebral ring is entirely cartilaginous (radiotranslucent).

CV_{IV}: Caudal surfaces are flat with osseous corners more defined than CV_{III}. Vertebral ring is cartilaginous.



PLATE III

SKELETAL AGE EQUIVALENCE--96 MONTHS (FEMALE)

CV_{II}: Caudal surface is relatively flat with osseous corners showing more definition at lateral border. Vertebral ring is still entirely cartilaginous.

CV_{III}: Caudal surface is flat with well-defined osseous corners. Vertebral ring is cartilaginous.

CV_{IV}: Caudal surface is flat and corners are sharp. An osseous dot has appeared at the ventral-caudal surface of the body. Onset age--90 months.

NOTE: Onset age is subjective determination at which initial ossification occurs utilizing inspectional technique first advocated by Todd (1929).

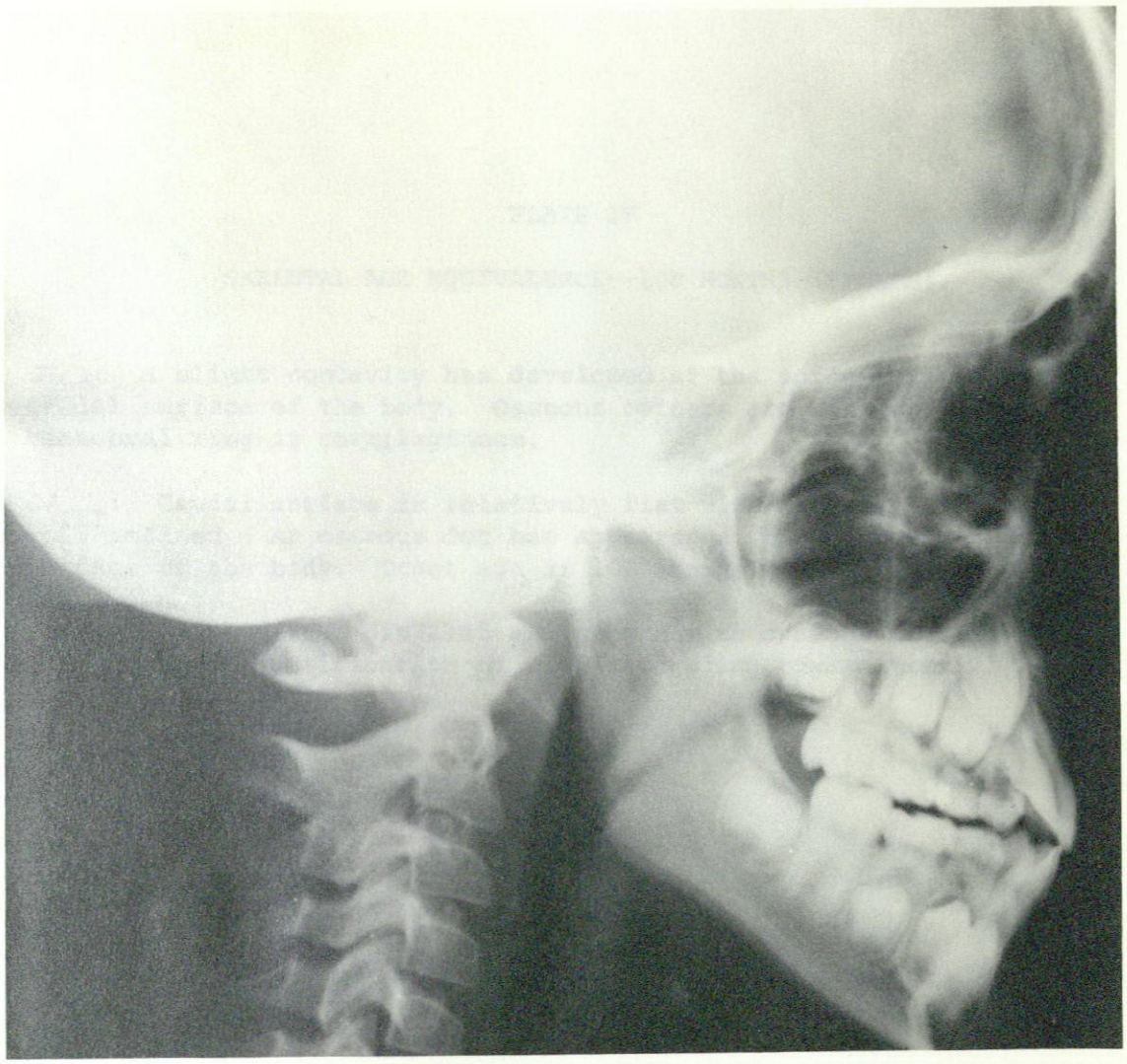


PLATE IV

SKELETAL AGE EQUIVALENCE--108 MONTHS (FEMALE)

CV_{II}: A slight concavity has developed at the epicenter of the caudal surface of the body. Osseous corners are more defined. Vertebral ring is cartilaginous.

CV_{III}: Caudal surface is relatively flat with osseous corners well defined. An osseous dot has appeared at the ventral-caudal surface of the body. Onset age is 106 months.

CV_{IV}: Caudal surface is flat and smooth with osseous corners well defined. Ossification of ring proceeding toward ventral border of body.



PLATE V

SKELETAL AGE EQUIVALENCE--120 MONTHS (FEMALE)

CV_{II}: Concavity at caudal surface has slightly deepened. An osseous dot is evident at ventral-caudal surface. Onset age is 116 months.

CV_{III}: A concavity has developed at the epicenter of the caudal surface of body. Ossification of vertebral ring is proceeding towards ventral border.

CV_{IV}: Caudal surface is flat with ossification of ring proceeding from epicenter of body to ventral border.

NOTE: Ventral vertical heights of CV_{III} and CV_{IV} have increased.



PLATE VI

SKELETAL AGE EQUIVALENCE--132 MONTHS (FEMALE)

CV_{II}: Concavity has deepened at caudal surface of body. Ossification of ring proceeding toward ventral side of body. Note dorsal ring ossification.

CV_{III}: Concavity has slightly deepened with ossification of ring proceeding.

CV_{IV}: A concavity has developed at the epicenter of the caudal surface of the body. Ossification of ring proceeding from epicenter of body.

NOTE: Vertical heights at epicenter of vertebrae III and IV have increased more than 1 mm from preceding year.

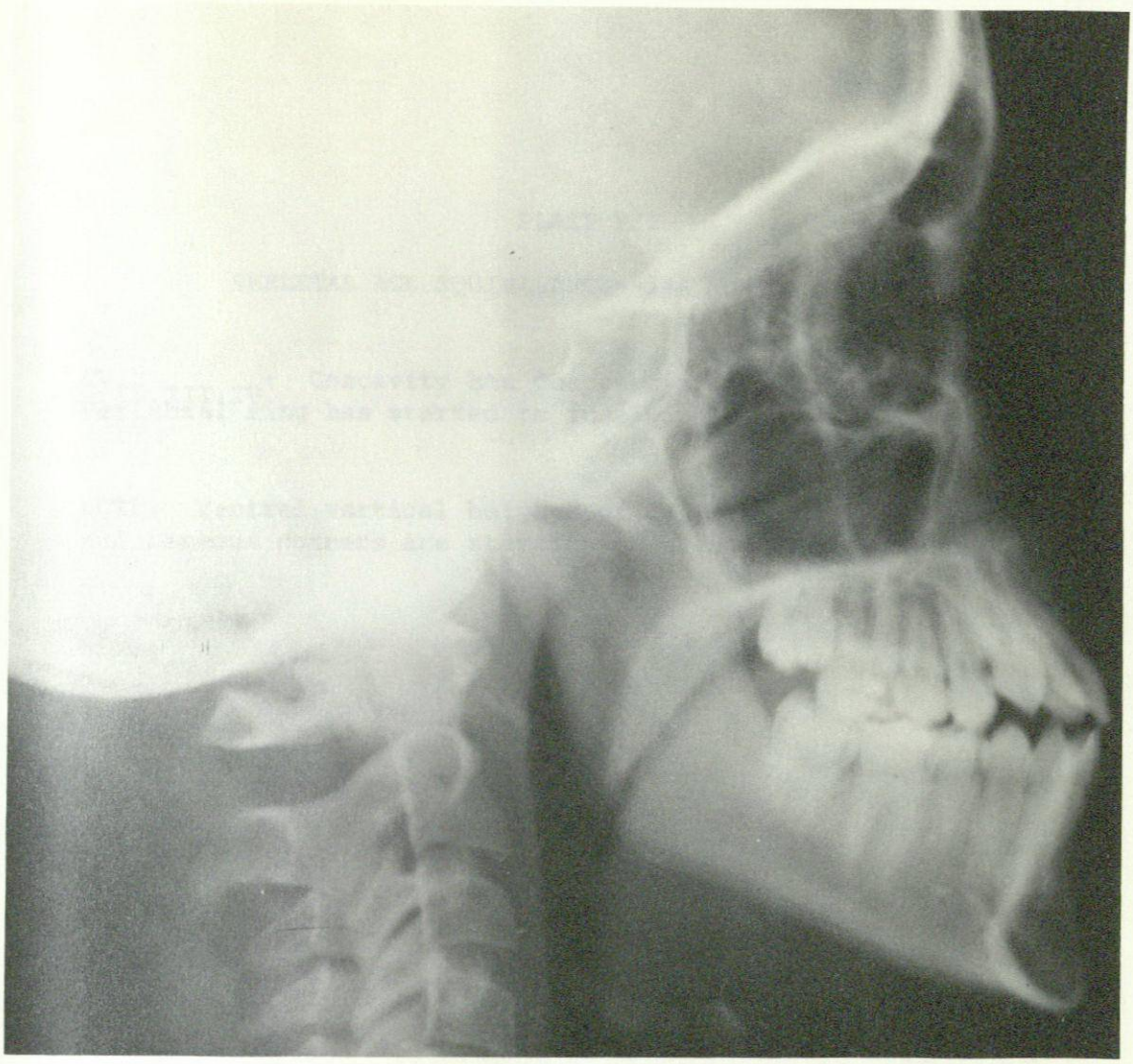


PLATE VII

SKELETAL AGE EQUIVALENCE--144 MONTHS (FEMALE)

$CV_{II, III, IV}$: Concavity has deepened at caudal surfaces. Vertebral ring has started to fuse with body at epicenter.

NOTE: Ventral vertical heights of CV_{III} and CV_{IV} are increasing and osseous corners are starting to become less defined.

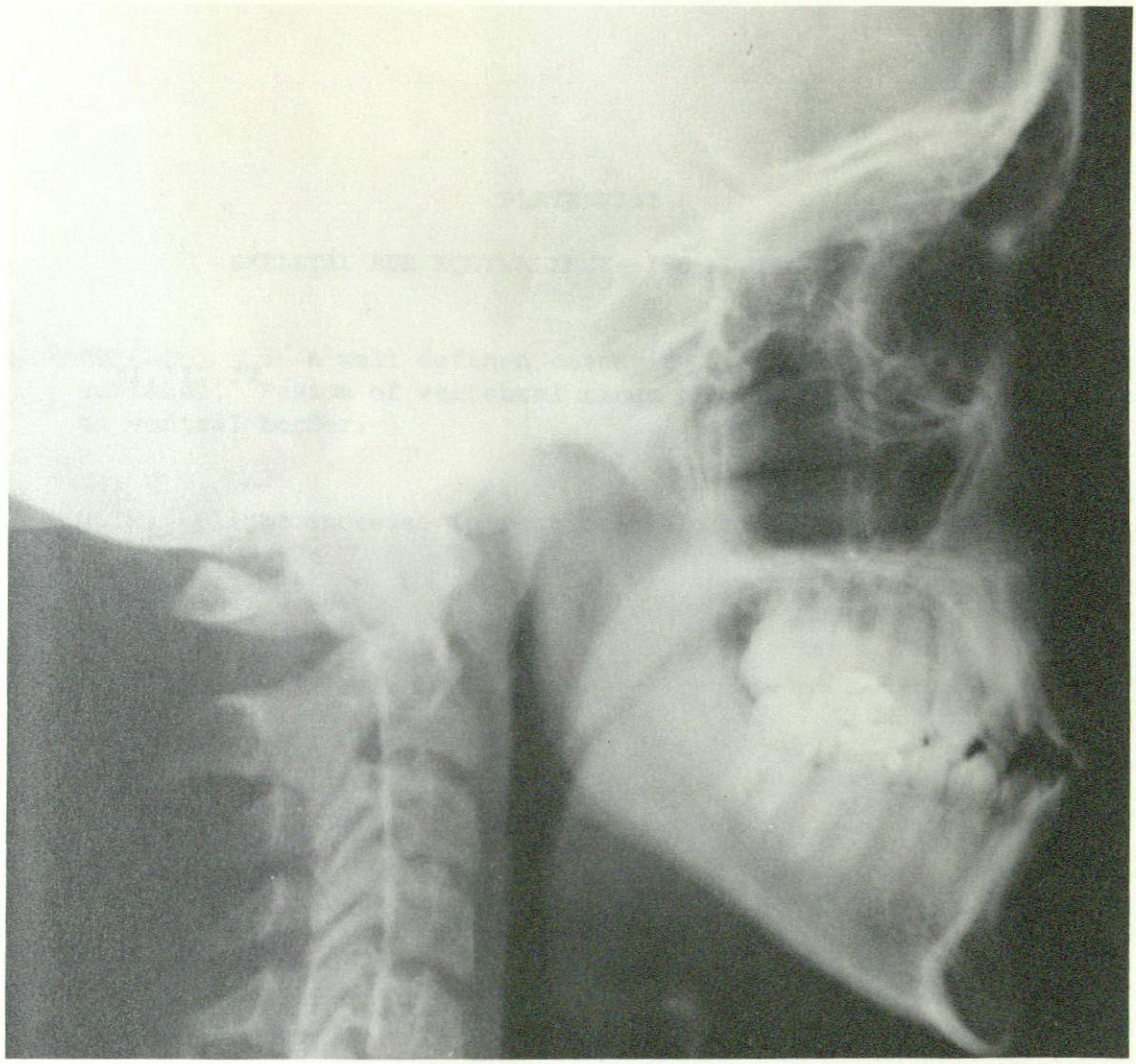


PLATE VIII

SKELETAL AGE EQUIVALENCE--156 MONTHS (FEMALE)

$CV_{II,III,IV}$: A well defined concavity is exhibited at caudal surfaces. Fusion of vertebral rings proceeding from epicenter to ventral border.

NOTE: Slight increase in vertical heights of CV_{III} and CV_{IV}.



PLATE IX

SKELETAL AGE EQUIVALENCE--168 MONTHS (FEMALE)

$CV_{II, III, IV}$: A well-pronounced concavity is exhibited at caudal surface of all three vertebral bodies. Fusion of vertebral rings near completion.

NOTE: Slight increase of vertical heights.



PLATE X

SKELETAL AGE EQUIVALENCE--180 MONTHS (FEMALE)

$CV_{II,III,IV}$: A well pronounced concavity is demonstrated at caudal surfaces. Fusion of vertebral rings has occurred at caudal surfaces adding to pronounced concavity. Fusion age--180 months.



PLATE XI

SKELETAL AGE EQUIVALENCE--192 MONTHS (FEMALE)

$CV_{II,III,IV}$: Mature cervical vertebrae with pronounced concavity at caudal surface. Vertebral rings have fused with the bodies of the vertebrae.