TIMING AND MAGNITUDE OF THE FEMALE CIRCUMPUBERAL GROWTH ACCELERATION OF HEIGHT, WEIGHT, AND SEVERAL FACIAL DIMENSIONS.

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INTRODUCTION

Orthodontists have long strived for better, more stable, results of their therapy. In the early period dominated by Edward Angle emphasis was on appliance design and manipulation for effective tooth movement. We now have several versions of such appliances and although progress continues, there is increasing interest in the individual facial growth and maturation of the patient. This is well justified in light of the negligible permanent effect orthodontic therapy has on the facial skeleton[1,2,3,4,5,6] and that in spite of effective mechanics, orthodontists are not able to produce uniformly successful results.

As part of their interest in facial growth orthodontists have expressed a need for prediction and manipulation of the period of rapid mandibular growth during the circumpuberal period[7,8,9,10,11]. Most orthodontists use some criteria to determine when this period of rapid growth occurs, even if it is only the patient's chronologic age. Additional criteria often used include rapid increase in height, appearance of secondary sex characteristics and menarche, and sometimes an assessment of skeletal maturation based on hand and wrist radiographs.

Of the numerous proposals for prediction of circumpuberal facial growth, including those of Hixon[1,12], Johnston[13], Singh et al[14,15], Bergersen[16], Maj and Luzi[17], Meredith[18], Helm et al[19], Karasparek[20], Bjork and Helm[21], and Ricketts[22,23,23], none has proven to be particularly successful[1,15,16,25]. One question that has not been directly addressed is whether the circumpuberal acceleration in mandibular growth is of sufficient intensity to justify the effort being expended in its prediction.

It is the purpose of this investigation to explore the literature concerning the circumpuberal acceleration of facial growth, and to examine on a longitudinal sample of females the timing and magnitude of the circumpuberal acceleration in stature, weight and selected facial measurements, and to relate the findings to those of previous investigators, with an aim towards determining clinical utility.

LITERATURE REVIEW

The classic description of human annual growth velocity in height is a steadily decreasing curve from birth until mid-childhood, where it levels off, and then increases to a pubertal peak followed by a rapid decline with growth essentially complete by the second decade[26]. This classic description is nicely exhibited by the first longitudinal growth study recorded, that of Count Gueneau de Montbeillard on his son between 1759 and 1777[27]. (Figure 1) Recent studies, however, have shown that many individuals do not follow this classic growth pattern[28,29].

The early vital staining studies of Hunter[30] and Brash[31] and the wire implants of Humphrey[31] showed that the mandible grows by remodeling, especially of the ramus, by an increase in alveolar height, and that the condyle is an active growth site.

The introduction of standardized cephalometric techniques by Broadbent[32] in 1931 resulted in a myriad of roentgenographic investigations of facial growth in general and mandibular growth in particular. These cephalometric investigations reached their zenith with Bjork's metallic implant study in humans which defined the direction and variability of mandibular growth, and also that it, like stature, experienced a circumpuberal acceleration in growth velocity[33,34,35,36].

In spite of numerous investigations, the relationship between facial growth and general body growth remains unclear. A definitive association between the development of various body components might allow precise predictions of the timing, direction, and amount of facial changes.

Timing of the Facial Growth Spurt

Howard[37], in 1936, reported that with retarded development of jaws and arches skeletal growth also showed general retardation. Lindegard[38] and Hrdlicka[39] showed "significant association" between mandibular growth and facial and body growth.

In his implant studies, Bjork[33,34,35] reported that, on the average, the circumpuberal growth spurt at the condyles and facial sutures occurs at the same time or slightly later than the growth spurt in body height.

Nanda[40], in a longitudinal sample of ten males and five females, measured the rate of growth of height and seven facial dimensions. He found that the various facial dimensions had different rates of growth and that the circumpuberal maximums of growth in height and facial dimensions were closely related, but that the facial growth velocity tended to reach its maximum nine to twelve months after that of body height.

Bambha[41], in a similar study but with the sample enlarged to twenty-five males and twenty-five females, generally concurred with Nanda's findings. He found that 80 percent of the subjects had their peak circumpuberal facial growth within nine months of their peak growth in stature, and that 66 percent had their facial growth peak after the peak in body height. These findings indicated the possible prediction of mandibular growth acceleration based on peak statural growth.

The findings of Hunter[42] disputed those of Bambha and Nanda in that in general he did not find that the maximum increments of various facial dimensions occurred after the peak in height. In Hunter's sample of twenty-five males and thirty-four females 39 subjects had the majority of the facial dimensional peaks occurring coincident with the peak growth in height, and in only 10 of the 59 did a majority of the facial growth velocity peaks occur after the peak growth velocity of height.

In a cross-sectional study of mandibular growth in females, Ludwick[43] found a "close association" between incremental growth of the mandible and of stature during the circumpuberal period.

Singh et al[15] reported that the maximum adolescent increase in scalp and cranial dimensions occurred at the same time or a "trifle earlier" than peak adolescent height growth velocity.

Fukuhara and Matsumoto[44] compared facial growth increments, represented by sella-gnathion (S-Gn), to growth in height during adolescence. They rejected from their sample of Japanese children all subjects more than one standard deviation from the average as indicated by height and weight tables. In the remaining "average" sample they found that in 25 out of 27 females the peak growth of

S-Gn was coincident with or occurred after the peak growth in height. This was in general agreement with Nanda and Bambha. However, the males were split, with 9 of 24 having the facial growth peak before, 10 of 24 having it after the peak growth in height. They concluded that in female patients the maximum growth in height may be a clinically useful tool to indicate the growth spurt of sella-gnathion.

In a cross-sectional study, Rose[45,46] reported that stature and body weight were better indicators of facial growth during the circumpuberal period than was chronologic age.

Brown et al[47] studied adolescent facial growth in a longitudinal sample of Australian aborigines; sixty-one males and thirty-four females. They found no significant differences between the ages at which peak growth velocity in body height and in any of five facial dimensions occurred. The average of peak growth velocity in height for boys was 13.7 years, and for the five facial dimensions ranged from 13.0 to 13.8 years. The average age of peak growth in height for girls was 12.0 years, and for facial dimensions ranged from

11.7 to 12.2 years. The correlation between the ages of peak growth velocity in height and mandibular length (articulare-pogonion) was .78 for males, .79 for females.

Bergersen[16] in a longitudinal study of twenty-three white males found a high correlation, .87, between the age of onset of the circumpuberal growth spurt of the mandible (articulare-gnathion) and that of height. He defined the onset of the circumpuberal growth spurt as "the beginning of the two-year period of greatest intensity of growth during adolescence".

In a longitudinal study of twenty Angle Class I females, Tofani[48] found a positive, but low, association between the age of maximum incremental growth of mandibular length (articulare-pogonion), corpus length (gonion-pogonion) and stature: r = .43 and r = .49 respectively.

Thompson et al[49] reported statistically significant, but very low correlations (.21 to .28) between the ages of maximum growth velocity in mandibular length, stature and weight. Unlike Nanda[40], Fukuhara et al[44], and Tofani[48], they found no significant difference between the mean ages at which the maximum increments of stature and mandibular length occurred, agreeing with the findings of Bergersen[16], Bjork and Helm[21], Hunter[42] and Brown et al[47].

In addition, several investigators have shown that there is less variation in the timing of the circumpuberal spurt in facial growth when assessed by height rather than chronologic age[42,46,50].

Despite the accumulation of evidence that general body growth and facial growth are closely related, Bjork warns that mandibular growth patterns show wide variations as to timing, direction, and amount, and this makes direct comparisons between statural growth and facial growth hazardous[35,36]. Tallgren[51] and others[36,41,52,53] feel that facial growth continues after growth in height is essentially complete.

Krogman[54] states that the upper face, cranial vault, orbit and cranial base mainly follow the neural growth curve, while the lower face (including the mandible) follows the body growth curve. Irie et al[55] feel that the mandible, as an "endochondral" bone, has a different manner of growth from that of the other facial membranous bones. Roche[56] differentiates between skeletal growth and skeletal maturation, and feels that they are interrelated, but not synonymous. And that facial growth resulting from cartilaginous based structures will show a direct relationship to the adolescent growth in height, but facial growth not so directly related to cartilaginous derived bone growth will not show the same close relationship.

Magnitude of Facial Growth

Numerous investigators have found only a low association between general body growth and facial growth[1,12,18,28,57,58]. Bushra[59] in a 1949 cross-sectional study of one hundred male and one hundred female adults, found that the association between adult size in stature and that of five cranial-facial dimensions did not exceed r = .42. Hunter[42] reported that of the facial dimensions studied, gain in mandibular length (Ar-Po) exhibited the most consistent relationship with gain in height, r = .76. Maj and Luzi[17] studied growth of the mandible body (gonion-menton) and growth in height in a longitudinal sample of twelve males and sixteen females between the ages of 9 and 13 years. They reported a correlation of .13 between relative increments in length of mandibular body and increments in height. Thompson et al[49] in a recent longitudinal study of one hundred and eleven girls, age 4 to 14 years, reported correlations between size of maximum increments of mandibular length and stature and weight as being statistically significant but low, (.20 to .37). Singh et al[14] studied a longitudinal sample of thirty-three girls, ages 6 to 14 years, and found that of six mandibular and maxillary facial dimensions only mandibular length (gonion-pogonion) showed a significant correlation (.41 to .69) with body measurements at each age. They concluded that the size and growth of general body physique and face are not closely interrelated and that "it is possible for a child to be large in body and relatively small in face and vice versa." Bowden[60] essentially agreed with this conclusion and feels that peak facial growth does not always correspond with peak statural growth.

In summary, it would appear that the circumpuberal acceleration in general body growth and mandibular growth are related, but the high association needed for precise prediction is lacking. Many investigators regard the lack of high association between the timing of peak facial and general body growth to be the result of using chronologic age, which states precisely how long an individual has lived, but is oftentimes not a particularly good measure of an individual's progress towards maturity.

Factors Affecting Timing and Magnitude of Growth

Growth and development is dependent on time, but also nutrition, environment and genes[61]. The most obvious variation in timing and amount of growth and development is exhibited by sex differences. It is generally reported that females erupt teeth earlier[62,63,64,65,66,67,68,69,70], have their peak circumpuberal growth about two years before males, and are generally smaller[26,28,43,47,50,70,71,72,73,74,75,76,77]. It is also generally accepted that within-sex variability of growth and ultimate size of facial components is predominately genetically controlled[78,79,80,81,82,83,84] although Dudas and Sassouni[85] found that of fifteen facial dimensions observed in a longitudinal twin study, only four were highly genetically determined during the active growth period.

Growth and maturation may also be affected by racial differences[62,64,79,86,87,88] although some of the differences may be related to nutrition and environment. Grave and Brown[89] recently reported that in a longitudinal sample of Aborigines the ossification ages, age of peak circumpuberal growth in stature and facial dimensions were all within the norms for whites.

Chronic malnutrition appears to delay skeletal maturation but not alter the sequence of appearance of ossification centers[61,90,91,92,93]. Cheraskin et al[94,95] reported delayed skeletal and dental maturation in children with vitamin C deficiency.

Acute illnesses and some mild chronic diseases have little or no effect on circumpuberal growth[96,97,98] but certain chronic diseases and metabolic and endocrine disorders can markedly delay or accelerate general body growth and development, and to a lesser degree, dental eruption[61,97,99,100].

Garn has found that fatter children tend to be advanced in both skeletal maturation and dental eruption[79,101]. And there is a general concensus of opinion that body somatype has a significant role in the growth process, that is, endomorphic girls mature earlier than ectomorphic types[26,61,101,102] and that early maturers have more weight per height[26,74,103,104,105,106].

Frisch and Revelle[105,107], in a review of data from three longitudinal growth studies, suggest that in females a critical weight may trigger menarche and the adolescent growth spurt. They contend that when a girl reaches a weight of about 31 kg there is a change to a critical metabolic level and increased output of ACTH and/or growth hormone, causing the adolescent growth spurt. This would explain the secular trend to an earlier menarch as it is known that with increased food supplies children are reaching this "critical weight" earlier[104,105,106].

Anderson et al[103] recently tested this hypothesis and did not find it true for their longitudinal sample of one hundred and eleven Canadian females. Meredith[18] and Singh et al[14] warn that body build and maturation are not consistently related, and that one cannot conclude that endomorphic girls have advanced facial growth in size or maturation.

Methods for Determining Developmental Status

Extensive criticism[10,16,20,21,45,67,71,89,99,108,109] for using chronologic age and/or stature as indications of the circumpuberal growth spurt has resulted in various methods being proposed to more precisely determine the timing of circumpuberal growth. Orthodontists have long used the appearance of secondary sex characteristics to indicate the adolescent period. Most, such as appearance of hair, acne, and breast development, are too vague to be of much clinical value. Menarche has been well studied, and although it is considered to be better correlated with peak growth than is chronologic age, it mostly occurs after the age of peak circumpuberal growth velocity and so is useful only as an indication that peak growth has passed[21,26,48,60,104,110].

The most valuable and widely used method of assessing a child's progress towards maturity is skeletal aging, that is, the appearance and development of ossification centers[61]. Several methods of assessing skeletal age have been advanced[71,108,111,112,113,114].

Most make use of a hand and wrist radiograph although many more areas may be included. Numerous workers have reported success in reducing the variability of the timing of the circumpuberal growth spurt by relating it to skeletal age[10,16,42,89,115,116]. Conversely, Tanner[26] has warned that the assessment of skeletal age does not provide a definite indication of growth stages of individuals, and numerous investigators have reported that skeletal age assessment did not reduce the variance of the circumpuberal growth spurt compared to chronologic age[42,46,49,77,117].

Bean[62], in 1914, suggested that teeth may be of greater value in determining physiologic age than stature, body weight, bone growth, or secondary sex characteristics. Attempts to reduce the variance of adolescent growth by defining it in terms of dental age has met with mixed success. Many early studies used the dental development/eruption standards popularized by Schour and Massler[118,119] and distributed by the American Dental Association. Their standards were essentially derived from Logan and Kronfeld's[120] small sample of the remains of sick children. These standards have been severely criticized as being too narrow and inaccurate[121,122,123]. Although some studies have found a "high" association between dental eruption and adolescent growth[124,125] most investigations have reported low or no correlation between the eruption of teeth and growth during adolescence[11,21,63,75,79,87,126,127,128,129,130,131,132]. Many researchers feel that the time of eruption of teeth is unsatisfactory due to extrinsic influences that can alter eruption time[66,67,113,121,122,130,133,134,135]. Gleiser and Hunt[69] remark that calcification/development of teeth is a better measure because it can be assessed at any time during the span of active growth, whereas eruption is a fleeting event whose exact time of occurrence is often impossible to determine. Most of the studies of tooth calcification/development have described several "stages" of crown calcification and root formation, even though it is a continuous event[65,69,113,136,137,138].

Several studies have found high association (r = .75 to r = .94) between ages of dental calcification stages and skeletal age[113,135,137,139] but others[21,79,100,122,129,130,135,140] report little or no association between the age of stages of dental development and skeletal development, stature and weight.

The use of certain ossification events, instead of an assessment of a skeletal age, has been advocated for use in prediction of the circumpuberal growth spurt. As early as 1928 Hellman[141] correlated the ages of ossification and fusion of certain bones with chronologic age and maximum increments of growth during adolescence.

Deming[142] reported a high association (r = .9) between fusion of the capitellum of the humerus and peak statural growth when fitted to a Gompertz curve.

The ulnar sesamoid bone of the metacarpophalangeal joint of the thumb has been widely studied because it is easily indentified and begins ossification early in adolescence[71,143]. Bjork[21], Bowden[60] and Grave et al[89], among others[21,144,145], have reported correlations of .57 to .87 for initial appearance of the ulnar sesamoid and peak circumpuberal growth in height. Several researchers[16,20,47,48,146] have reported use of the age of appearance of the ulnar sesamoid and the age of specific stages of fusion of the phalanges to predict the age of peak mandibular growth during adolescence, but Pileski et al[28] found the association between the age of the appearance of the sesamoid and the age of maximum mandibular growth velocity in females to be r = .43, and that 20 percent of his sample did not show sesamoid bone appearance until after peak mandibular growth velocity had passed. Their findings led them to believe that events that follow appearance of sesamoid, such as maximum height velocity, would be even less well-correlated and that these would not greatly improve the prediction of the timing of maximum mandibular growth.

In summary, the literature relating to the circumpuberal mandibular growth spurt is profuse, yet often vague and conflicting. Many of the studies were cross-sectional in nature so as to obscure individual variation, or were longitudinal in nature but with small sample size.

The purpose of this longitudinal investigation is to add to the body of information relating to the female circumpuberal growth spurt in height, weight, and several facial measurements, and to report on the degree of association between these variables as to magnitude and age at peak growth velocity.

METHODS AND MATERIALS

The materials for this study were records of 80 females from the longitudinal growth study conducted by the Child Study Clinic at the University of Oregon Dental School. The girls were clinically healthy, white, predominently Northwest European ancestry, and of middle socio-economic status. The main criteria for acceptance into this study was completeness of records, although those with obvious serious illness or physical abnormalities were excluded. Some siblings were included, but no twins or girls who had undergone orthodontic treatment were accepted.

The age distribution of the sample used in this study is in Figure 2. The records utilized were from age eight for 91% of the sample, the remainder at age 9, and the final records examined were when growth in height had passed its circumpuberal acceleration and had experienced a marked decrease in growth velocity, usually by age 15, but in no case earlier than age 14.

Records used in this study consisted of the recorded height and weight, and lateral closed and open-mouth cephalograms. The roentgenograms were taken with the patient's head oriented to the Frankfort plane in a Broadbent-Bolton Cephalometer. Height, weight and lateral cephalograms were taken bi-annually as close as possible to the patients birthdate and six months later until age fourteen, annually thereafter. The open-mouth lateral cephalograms were taken annually.

Each lateral cephalogram was traced on .003" matte acetate to reveal the landmarks articulare, nasion, pogonion and sella. Each annual open-mouth lateral cephalogram was traced to reveal the mandibular condyle(s) and pogonion. Measurements and landmarks are shown in Figure 3.

Because pogonion is relatively unstable due to remodeling of the anterior mandible, it was located on "middle" cephalogram (usually age 11-12) and transferred to the other serial cephalograms for that patient by superimposition. After pogonion was located, condylion was located as the most distant point from pogonion on the outline of the mandibular condyle. In many cephalograms, due to asymmetry of the facial skeleton or vertical or lateral tipping of the head in the cephalostat, the right and left images of the structure were not exactly superimposed. When this occurred both images were traced and the measurement point was taken as the midpoint between the two landmarks.

Due to the difficulty in tracing the outline of condyle in normal lateral cephalograms it was traced only on the annual open-mouth lateral cephalograms. Tracing of all structures within a set of serial cephalograms on the same individual is somewhat easier than on a single cephalogram because of the advantage of "before" and "after" comparisons.

Measurements were taken for the variables Ar-Po, S-Po, N-Po, and C-Po on the tracings with a dial caliper to the nearest .1 mm. Height was measured to the nearest millimeter, weight to the nearest ¼ pound and then converted to kg. Since some of the records were not taken exactly every six or twelve months, the continuous data was interpolated to conform to bi-annual and annual intervals. In the case of C-Po, which was measured only annually, or the very few cases of missing or defective records, bi-annual increments were interpolated.

The experimental error in determining the mandibular variables can be categorized as:

1. The error in landmark location, i.e., S, Ar, N, and Po. These errors do not occur randomly but tend to follow bony contours, and are larger for some landmarks than others[147,148,149]. For example, an error in location of pogonion on a flattened anterior mandible is apt to be mostly a vertical error and hence would affect the measurement N-Po much more than C-Po or Ar-Po.

2. The error in determining actual length of the mandibular measurements, or the difference between the true value and the measured value.

3. Alterations in magnification. All the cephalograms were enlarged about eight percent, but this is assumed to be constant and no correction was made. However, if a person's head was not positioned in the head holder exactly the same each time, either rotated laterally in a horizontal plane or at non-uniform distance from the x-ray source,

the magnification would vary slightly.

To minimize the extent of error in this study the following procedures were performed. All landmark locations, tracings and measurements were performed by the same individual. Bony contours were carefully located and traced in a darkened room under ideal conditions. Measurements were done with the same instrument throughout the study. All cephalograms, and the recording of height and weight were carefully taken by an experienced radiographer.

Any serial cephalometric study will exhibit difficulty in estimating growth increments in individuals due to the smallness of the increments between time intervals. This difficulty is compounded when the increments are small, as in slow growing females, and when the intervals are only six months.

Ten longitudinal series of the total sample were randomly selected and retraced and remeasured a separate time. The results of the error determinations are shown in Table I. The standard error of measure revealed the lowest error was for Ar-Po (.26), while Co-Po had the largest, (.53). The paired "t" test similarly showed the differences of the means were not significantly different at the 1% level.

The data obtained from each serial record were transferred to computer punch cards, and utilizing a computer program: (1) converted dates of all records to ages in decimal years and (2) interpolated the continuous data to years and half years, (3) calculated bi-annual increments for the continuous data: height, weight, Ar-Po, N-Po, S-Po and Co-Po. (4) Calculated percent increments of growth for the mandibular variables according to the formula from Nanda[40]

$$\% \text{ rate change} = \frac{y_2 - y_1}{\frac{y_2 + y_1}{2}} \quad \text{X } 100$$

(5) Did three-point smoothing once and twice for bi-annual increments and the percent increments, according to the formulas from Hildebrand[150]

left end point $y\text{-}1 = y_6 \; (5f\text{-}1 + 2f_0 + f_1)$

middle points $y_0 = 1/3 \; (f\text{-}1 + f_0 + f_1)$

right end point $y_1 = y_6 \; (-f\text{-}1 + 2f_0 + 5f_1)$

(6) Plotted graphs for 3, 4, and 5.

For each individual, the age at which peak growth velocity occurred was determined for height, weight and the four facial measurements. The peak growth velocity is defined here as the largest increment of growth between two consecutive ages from the unsmoothed data. The age of peak growth velocity was taken as the midpoint of the two consecutive ages between which the maximum increment occurred. In several cases no one clear peak was evident from the unsmoothed data. In these cases the once and twice smoothed data were used to help identify the age of maximum growth velocity. For the entire sample, means and standard deviations were calculated for the ages and the magnitude of peak growth increments for each of the variables.

For the variable Ar-Po, the increments of growth one and two years before, and one and two years after the peak were calculated and recorded. The total weight of an individual at the age of peak growth velocity of Ar-Po was recorded.

Finally the associations between the variables, expressed as correlation coefficients, were calculated and recorded.

FINDINGS

Examination of the computer plots of individual growth increments revealed considerable variation from de Montbeillard's son's classic growth curve. Approximately thirty percent of all the unsmoothed incremental growth curves of height, Ar-Po, S-Po N-Po and C-Po showed two or more distinct circumpuberal peaks (Figure 4) or no peak greater than the standard error of the measure for that dimension. (Figure 5) The four facial dimensions exhibited this somewhat more often than did height. The weight curves were the most variable and the only ones exhibiting a negative change.

The effect of three point smoothing on an incremental growth curve is shown in Figure 6.

Timing of Maximum Growth Velocity

The means, standard deviation, and ranges for the ages at the midpoint of the maximum six month growth velocity are shown in Table II. The mean ages of maximum growth velocity for the six variables ranged from 11.53 to 11.91 years. The earliest age of maximum growth for Ar-Po was 9.75 years, while the latest was 13.75 years, and the mean 11.8 $\pm$ 1.0 years. The mean for age of maximum height growth was 11.5 $\pm$ 1.0 years. Figures 7-12 show the frequency distribution of the ages of maximum growth increment for each of the six variables. The variation, as indicated by the standard deviation, is readily apparent from these histograms. Table III shows the correlation coefficients for ages of maximum growth velocity of height and weight and the four facial dimensions. The correlations ranged from .56 to .84 and all were significant at the .01 level. The highest correlation was .84 between age of maximum growth velocity of height and of Ar-Po.

When judged from the plots of incremental percentage rate smoothed twice, using Nanda's formula, the age of maximum growth velocity of mandibular length (Ar-Po) and that of height were coincident in 24 of 80 individuals, and were within $\pm$ six months in 60 out of 80 subjects. (see Figure 13) While 68 individuals had their maximum height increment at the same time or before that of Ar-Po. Figure 14 shows the distribution of the difference between age at maximum increment of height and age of maximum increment of Ar-Po derived from the unsmoothed data. In 30 out of 80 the ages of maximum increment of height and Ar-Po were coincident, and 62 of 80 were within ± six months. The age of maximum increment of height occurred coincident or before that of Ar-Po in 68 of 80 individuals.

The distribution of the difference between the age of maximum increment of weight and the age of maximum increment of Ar-Po is shown in Figure 15. Sixteen of eighty individuals had the ages of maximum increment of weight and Ar-Po coincident. While 25 had maximum increment of weight earlier, 39 had it later, than the maximum increment of Ar-Po.

The ages of the maximum growth increments of several of the variables were subjected to the Student's "t" test, the results of which are shown in Table IV. The difference between the mean ages of the maximum increments of height and weight are significant at the .025 level, while the difference in ages of height and

Ar-Po maximum increments were significant at the .05 level. There was no significant difference between ages of maximum increments of weight and Ar-Po or between C-Po and Ar-Po.

Magnitude of the Maximum Six Month Growth Increment

The means, standard deviation, and ranges of the magnitudes of the maximum six month growth increments for the six variables are shown in Table V. Mandibular length, Ar-Po, grew on the average 1.98 ± .54 mm during the maximum six month period, with a range of .54 mm to 3.2 mm. Figures 16-21 show the distribution of individuals according to the magnitude of their maximum six month increment for each of the six variables. For Ar-Po, over one-half the sample grew 2.0 mm ± .4 mm during the maximum six month period.

Correlation coefficients for magnitude of maximum growth increments of height and weight and the four facial dimensions are shown in Table VI. The magnitude of increments of height were significantly correlated with those of S-Po (.33) and C-Po (.38) at the .01 level. Magnitude of height increments were not significantly correlated with those of Ar-Po (.16), nor were weight increments with Ar-Po (-.05).

Growth of mandibular length, (Ar-Po) during the circumpuberal period is summarized in Table VII. The mean six month maximum increment of Ar-Po was 1.98 mm, or an annual rate of 3.96 mm. The mean growth of Ar-Po during the first year before and first year after the six month period of maximum growth was 2.29 mm and 2.33 mm respectively. During the second year before and after the six month maximum period the mean growth was 1.71 mm and 1.41mm. All the periods showed wide ranges of magnitude of growth of Ar-Po. The size of the mandible (Ar-Po) at the beginning of the four and one-half year growth period ranged from 87.2 to 103.3 mm with the mean of 95.4 mm. The total growth of Ar-Po during the period ranged from 5.38 to 14.98 mm with a mean of 9.80 mm. Figures 22-26 are histograms showing the distribution of growth increments of Ar-Po during the first and second year before and after and during the six month period of maximum growth. A summary of the distribution of growth increments during this four and one-half year period is shown in Table VIII.

The correlation coefficient for mandibular length (Ar-Po) at the beginning of the four and one-half year adolescent growth period and the total increments of growth during this period was .14 (see scattergram Figure 27), which is not significant at the .05 level.

Some Associations Between Height, Weight and Ar-Po

The total weight of individuals at the age of maximum growth of Ar-Po ranged from 24.7 kg to 62.4 kg, and 27 of 80 individuals weighed 44 kg $\pm$ 3 kg at this age. (See Figure 28) The correlation coefficient for the age of maximum Ar-Po growth velocity and the individuals total weight at that age was .001. (See scattergram Figure 29)

The correlation coefficient for the age of maximum Ar-Po growth velocity and the individuals weight to height ratio at that age was -.085. (See scattergram Figure 30)

The correlation coefficient for the age of maximum Ar-Po growth velocity and the magnitude of the maximum six month increment was found to be -.181, and is illustrated by the scattergram

Figure 31. None of these correlation coefficients are significant at the .05 level.

The number of individuals in this sample with the age of maximum Ar-Po growth velocity $\leq$ 10.75 years was seventeen (21%) and these were arbitrarily considered "early maturers". Those who experienced maximum Ar-Po growth velocity $\geq$ age 12.75 years, twenty-one, (26%) were considered "late maturers". In Table IX the early and late maturers are compared in terms of their weight and weight to height ratio at the age of maximum mandibular growth rate.

The mean total weight at the age of maximum Ar-Po growth was 42.9 $\pm$ 9.2 kg for the early maturers, and 43.6 $\pm$ 8.9 kg for the late maturers. These means were not significantly different (t = .24). The weight to height ratio at the age of maximum Ar-Po growth velocity was 29.3 for the early maturers and 28.6 for the late maturers. This difference was not significant (t = .41). The magnitude of the maximum six month Ar-Po growth for the early maturers was 2.1 $\pm$ .55 mm, and for the late maturers it was 1.9 $\pm$ .6 mm.

Again the difference was not significant, ($t = 1.1$).

The association between the magnitude of the maximum six month increment of Ar-Po and the individuals weight to height ratio, calculated at the age of maximum Ar-Po growth velocity, was found to be $r = .27$ (see Figure 32), which is significant at the .01 level.

DISCUSSION

In order to describe the circumpuberal growth spurt one must first determine if such a spurt exists. Because we are dealing with a continuous biologic process any definitions or descriptions will necessarily be somewhat arbitrary. That other investigators have and will choose different guidelines for other perfectly valid reasons is here acknowledged and accepted. Approximately 500 total incremental growth curves for the six variable have been examined and in some respects they show remarkable consistency. Almost all of them show a rise in growth velocity from age 8 to a maximum and then a decrease, in many cases almost to zero, by age 14 or 15. The magnitude of the increments varied of course, but not greatly. Human females do not vary nearly as much as do, for instance, dogs if one were plotting growth increments of a dachshund and a St. Bernard.

For the purpose of this investigation a circumpuberal peak was simply defined as the greatest six month increment of growth, and if that peak was greater than the immediately adjacent increment points by more than the standard error for that measure, then it was considered a real growth spurt. A very few plots (Figure 5) showed no such peak and thus did not have an age of maximum increment.

To a greater or lesser degree all of the variables displayed multiple peaks or spurts during the circumpuberal period studied. Weight curves were by far the most variable, probably because weight is unique in that it can have negative changes due to weight loss over a period of time, and because weight is, at least partially, under control of the individual. For these reasons, weight changes may not be as useful as other measures.

Boyd[151] noted post-puberal maximums when she studied growth of shoulder, chest, and hip width, and Nanda[40], described "secondary maximums" of incremental growth of facial dimensions that he often saw before, but also after the circumpuberal cycle. He was of the opinion that these were due to an actual temporary growth acceleration in that individual. Woodside[29] also described multiple "peaks" of mandibular incremental growth during the circumpuberal period. He acknowledges that the definition of a "peak" is "purely qualitative" but in his longitudinal sample of females he reported only 35 out of 104 exhibiting one peak, while 64 showed two peaks and five showed three. He, like Nanda, felt these multiple peaks were real growth accelerations and not artifacts. One explanation of the multiple growth peaks is indeed that they represent true temporary growth accelerations, and in light of their prevalance in this and other studies this may well be the case. Some investigators have related these temporary growth accelerations to climatic and seasonal conditions[152,153] and Tanner[26] states that magnitude of growth in height during March, April, and May is twice what it is during September, October, and November. Since the increments for this study were generally measured at six month intervals, this seasonal variation in growth could explain some of the multiple peaks of growth increments, (see Figure 33). Investigations that have recorded only annual measurements would lose this seasonal variation.

Other possible explanations for multiple growth increment peaks of facial dimensions are measurement errors and the teeth of the subjects not being in occlusion during exposure of the cephalogram. Measurement error is especially suspect if the normal growth increments are small and approach the standard error of the measure in magnitude; conversely measurement error would be of little import if the increments were very large. If the mouth is open during cephalogram exposure all dimensions that involve the mandible and some other point will be adversely affected. Intra-mandibular dimensions, like condyle-pogonion, would not be affected save for any change in magnification. When the teeth are completely discluded it is easily seen on the cephalogram and any facial-mandibular dimension on that film can be disregarded. If the teeth are just barely discluded it is not easily apparent and the result might well be a "temporary growth acceleration" on the incremental growth curve. Serial data or mean's from longitudinal data will tend not to show multiple peaks. Individual longitudinal curves that have been smoothed will minimize them or render them unnoticeable.

Despite the admitted difficulties and shortcomings of selecting a single peak for each incremental growth curve, this was done and the ages recorded. One cannot help but wonder as to the relative lack of discussion of this problem in the literature. To go further and arbitarily define a beginning and end of the circumpuberal growth spurt was beyond the scope of this investigation, although others[16,42,77,105,145] have done so using a variety of definitions based mainly on means, or time span.

Timing of the Circumpuberal Maximum Growth Increment

The mean age of maximum height increment for this sample was 11.5 ± 1.0 years, and for weight the mean maximum increment was at age 11.9 ± 1.1 years. See Table X for comparison with previous investigations. Mandibular length, as defined by Ar-Po, had a mean age of maximum increment of 11.8 ± 1.0 years, and comparison with other studies is seen in Table XI.

Much has been made in the literature of relationship of the timing of peak circumpuberal growth of height and facial dimensions. In this study Ar-Po was compared to height and it was found that they were closely related as to timing (Figure 14). Thirty of eighty (37.5%) individuals had their age of maximum growth increments of height and Ar-Po coincident, in sixty-two (77.5%) these ages were within six months of each other. There was some tendency for the age of the Ar-Po maximum increment to occur later than that of height: thirty-eight individuals (47.5%) had their Ar-Po maximum later than height, while only twelve individuals (15%) had their Ar-Po maximum increment before that of height. The differences in the mean age of maximum increment for height and Ar-Po were statistically significant. Nanda[40] reported that 28% of his sample had maximum facial and height growth increments at the same age, and 57% had facial maximum after height maximum and 15% had height maximum earlier. Bambha[41] reported 66% had facial growth maximum later than height growth maximum, and 80% of the ages of facial and height maximum increments were within nine months of each other. The findings of Bjork[21,33,34], Ludwick[43], Fukuhara[44], Brown[47] and Tofani[48] agree with these general findings, while Grave[89], Bergersen[76], Thompson[49] and Hunter[42] reported no significant differences between the ages of maximum growth of facial dimension and that of height. Kasparek[20], on the other hand, reported that the ages of peak facial and height growth were coincident, or facial growth maximums preceeded height growth maximums. The difference in these values could be attributed to 1. differing criteria for the definition of the age of maximum circumpuberal growth increment and 2. whether the incremental values had been smoothed, how often and by what method, and 3. sample differences. Nanda's values were reported for % increment change, three-point smoothed twice. When that technique was applied to these data the distribution becomes twenty-four of eighty (30%) ages of maximum Ar-Po and height increments coincident. Forty-four of eighty (53%) with age of maximum increment Ar-Po later than that of height and twelve of eighty (15%) Ar-Po before height. These are almost identical to the findings of Nanda.

The distribution of the ages of maximum increment of weight relative to the age of maximim increment of Ar-Po is shown in Figure 15. The differences between the mean ages of the maximum increment were not significantly different. The age of maximum increment of height and weight are significantly different, with the maximum increment of height preceeding that of weight by four and one-half months on the average.

Magnitude of the Circumpuberal Growth Increments

The mean magnitude of the maximum six month increment in height was 4.40 ± 1.01 cm. Thompson et al[49] reported a mean maximum annual height increment for their sample of girls to be 8.39 ± 1.63 cm, very close to the mean annual rate for this sample. They reported the mean maximum annual weight increment of 7.64 ± 2.06 kg which compared to the 4.48 ± 1.62 kg mean six month maximum increment reported here. Tracy and Savara[154] among others[16,29,42,43,49,103] have reported magnitudes of annual mandibular length growth increments of females during the circumpuberal period. Comparison of the reported dimensions is hazardous because only Tracy and Savara have corrected for distortion and enlargement[154,155]. They found the maximum mean annual circumpuberal increment for C-Po to be 3.6 ± 1.0 mm. Most other reported annual mandibular increments during the circumpuberal period are 2 to 4 mm. The magnitude of the mean maximum six month increment of Ar-Po for this sample was 1.98 ± .54 mm (uncorrected for magnification and distortion). In the first year prior to the six month period of maximum Ar-Po growth the mean Ar-Po growth increment was 2.29 ± .78 mm, and the second year prior to the six month peak the mean Ar-Po increment was 1.71 ± .62 mm. The first and second years after the six month peak, the growth increment was 2.33 ± .74 mm and 1.41 ± .59 mm respectively. The total four and one-half year Ar-Po growth increment was 9.80 ± 1.98 mm with a range of 5.38 to 14.98 mm. Some individuals grew more in one year than others did in the entire four and one-half year period.

In examining circumpuberal growth from the point of view of clinical significance one might take a hypothetical case having mandibular growth equivalent to the mean. See Table VII. If orthodontic treatment was carried out for 24 months during the period of greatest possible growth (the 6 month period of maximum increment, 1.98 mm, plus the increment for the first year after the peak, 2.33 mm, plus one/half the annual increment prior to the peak, $\frac{2.29}{2}$ = 1.15 mm) the Ar-Po increment would be 5.46 mm. While the minimum circumpuberal increment for Ar-Po would be 3.74 mm (the increment for the entire first year after the six month peak, 2.33 mm, plus that for the second year, 1.41 mm)

The difference between treating at the most favorable time and the least favorable time is about 1.75 mm. This is not a staggering amount, yet if it were translated into orthodontic treatment effect it could be of considerable significance. The Ar-Po maximum growth increment compared to the incremental growth for the years before and after the peak is probably of significant magnitude to justify its attempted prediction. Purely in terms of taking maximum advantage of growth it would be beneficial to start before the peak, however treatment commenced slightly after the peak can still make use of relatively large amounts of growth, on the average.

Influence of Sex and Race on Circumpuberal Height and Mandibular Growth.

When compared to previously published reports of male incremental growth it is apparent that, on the average, females in this sample had smaller increments of growth, and experienced maximum growth earlier.

Recent investigations[16,21,28,42] have reported that the mean white male age of maximum increment in height occurs between 13.9 to 14.1 years compared to 11.5 years for this female sample, a difference of over two years. Mean age of peak mandibular growth for males has been reported as 13.6[72], 13.9[28], and 14.2[16] years, compared to 11.8 for the females of this study, a difference of approximately two years.

Comparison of the average amount of mandibular growth is limited because different mandibular dimensions have been measured, (Ar-Po, Co-Po, Co- Symphysis point, etc.) and because some of the measurements were corrected for magnification and/or distortion. The mean peak six month growth increment of Ar-Po for this sample of girls was 1.98 mm, which was not corrected for magnification or distortion. Reports of mean maximum annual mandibular length growth increment for male samples includes 4.8 mm by Harris[70] and 4.6 mm by Savara et al[72].

When compared to the mean reported values of other ethnic or racial groups the age of maximum height increment for this study, 11.5 years, was slightly earlier. Three investigations from the Burlington Study in Toronto on Canadian females report 11.4[49], 11.6[103], and 12.0[29] years as the age of maximum height increase. The means reported for a sample of female Australian Aborigines were 11.8[146] and 12.0[47], and for Danish[21], Finnish[156] and English[26] females, about 12.5 years.

The mean ages of maximum growth of mandibular length for Canadian girls was reported as 11.4[49], and 12.0[28,29] years, for Aborigines as 12.0[47] years and for "average" Japanese as 11.5[44] years, which compares to 11.8 years for this study. It is not known whether these relatively small differences in mean ages were real or due to methodological artifact. Magnitude of annual circumpuberal height increase for other ethnic groups was 8.3 cm[47] and 8.5 cm[146] for female Aborigines and 8.4 cm[49] for Canadian girls, compared to 4.4 cm per six months for this sample. It is interesting how little difference in magnitude of maximum height increase there is between these groups of diverse geographical and genetic background.

Associations Between Mandibular Growth and Height, Weight and Mandibular Length.

Height

An individuals height at a given point in time has proved to be a poor indicator of future growth[1,71]. During the circumpuberal period a person who is average height at one given age can be:

1. a small person who is experiencing early growth acceleration
2. an average size person with average growth or 3. a large person with retarded growth acceleration. The relation of height to future mandibular growth is even more tenuous, especially in view of the low association reported between various body parts[2,14] which implies that large individuals can have small mandibles and vice versa.

Size of the Mandible to Predict Future Size

Specifically the size of the mandible at a given age has been found to have only a low correlation (.15[157], -.09[158]) to future increments of mandibular growth. This was also found to be the case in this study; the association between mandibular length and future growth was r = .14. Mandibular length two years before the six month growth peak for each individual (so usually about age 9.5 years) was compared to the total growth increment four and one-half years hence (usually about age 14.0 years). This very low association precludes use of size of the mandible to predict future mandibular growth increments.

Weight Relationships for Prediction

Recent reports[105,107] have suggested that when a "critical weight" of 30-31 kg is reached in females the adolescent growth spurt is triggered, and with release of increased amounts of ACTH and growth hormone, growth is accelerated and the circumpuberal growth spurt follows. If this "invariant critical weight" hypothesis were correct it could be of value in prediction of the timing of the circumpuberal mandibular length growth acceleration. For this sample the mean weight at the age of maximum increase of mandibular length was found to be 43.2 $\pm$ 7.6 kg - hardly an "invariant" absolute weight. The distribution of individuals weight at age of maximum mandibular length increase is shown on the histogram Figure 28 and plotted on the scattergram Figure 29. It would appear that the "critical weight" hypothesis is of no immediate value in prediction of the mandibular growth spurt.

To test the hypothesis that heavier girls; those with more weight per height, have their growth peak sooner, the weight to height ratio was calculated at the age of maximum mandibular length growth velocity. The association was found to be -.09. (see scattergram Figure 30) Also the sample was divided into "early" and "late" maturers, that is, those who reached peak Ar-Po growth velocity before age 10.76 years and after 12.74 years, which is approximately one S.D. before and after the mean age of maximum Ar-Po growth. For the early and late groups the weight determined at the age of maximum Ar-Po growth was not found to be significantly different. (See Table IX) These findings are in agreement with those of Singh et al[14] Meredith[18] and Anderson et al[103] who warn that body build is not consistently related to maturation. The relationship between weight to height ratio and magnitude of maximum Ar-Po growth increment was found to be low, r = .28, but statistically significant at the .01 level. (Figure 32)

Increments of height and of weight were found to be poorly correlated with growth increments of mandibular length during the circumpuberal period; r = -.05 to .16. This agreed with the findings of Maj and Luzi[17] who reported a correlation of .13, Thompson et al[49] who reported .20 to .37, and Singh et al[14] and Bowden[60] who reported low associations between height and weight increments and mandibular growth increments.

Ages of Maximum Growth Increments of Height and Mandibular Length

The association between the age of maximum height velocity and age of maximum mandibular growth has been reported by Brown[47] r = .79, Thompson et al[49], r = .21, Tofani[48], r = .43, Hunter[42], r = .76 and Bergersen[16] r = .87. For this sample the correlation was .84 for Ar-Po, .72 for C-Po. Different methods of selecting ages of peak growth may account for some of these differences, i.e. whether the data was smoothed or raw, or sample differences. The age of the maximum weight change and age of maximum mandibular length increment were also significantly correlated, r = .57. Thompson[49] reported r = .28 for these two variables.

To test the hypothesis that early maturers, those with peak mandibular growth occurring before age 10.76 years, have a greater intensity of mandibular growth than late maturers, those with peak mandibular growth occurring after age 12.74 years, the magnitude of the maximum six month growth increment for the two groups was compared but was not found to be significantly different.

It is apparent that meaningful relationships needed for clinically useful growth prediction are few and far between. Statistically significant associations are not necessarily clinically useful. Facial growth can best be described as resulting from polygenic hereditary determinants modified by complex environmental influences, which results in wide variation among individuals as to timing, magnitude and direction of mandibular growth. Growth prediction based on means is dependent on two shaky premises: 1. That the individual being predicted will behave as the mean of a sample population of which he is not a member, and 2. That size, shape and past growth of the mandible (or other body parts) is a meaningful clue for future growth of that part. Both of these assumptions are not supported by this, and many other, studies. Mean curves of incremental growth widen the age of the peak growth period by averaging many shorter individual periods of peak growth into one large peak, effectively obscuring individual variation, such as the numerous multiple growth peaks reported in this study. The same "averaging" result is obtained from cross-sectional data.

It is possible that individual variation of growth can be reduced by use of other maturational criteria such as; skeletal age, specific ossification events, dental eruption and/or development, hormone and endocrine blood levels and genetic background, to eventually provide meaningful relationships for growth prediction. It could well be, however, that even if such an association or combination were to be found, its delineation might be so complex and time consuming so as to be clinically useless.

It is, more-over, simplistic to assume that precise prediction of timing and magnitude of growth of a facial part is going to be translated into clinical utility. Direction of growth is just as important a variable, although it has not been addressed here. Bjork[33,34,52] defined the direction of mandibular growth as varying with a range of 22°, and that two of nineteen individuals were "backward rotators". In these individuals no amount of mandibular growth is going to project the chin or lower incisors forward.

The most prevalent single finding of this study is wide individual variation exhibited as to absolute size, magnitude of growth increments, and timing of growth acceleration. No meaningful ($r \geq .8$) association was found except that the age of maximum growth increment of height and mandibular length are highly correlated ($r = .84$) and in 85% of the sample peak height growth occurred coincident or before peak mandibular growth.

Associations between increments of mandibular growth and height and weight were very low, and the use of height, or weight, or weight to height ratio, or mandibular length to predict the age or amount of growth was not possible. Girls with more weight per height tended to have higher magnitudes of maximum mandibular growth, and this association, $r = .27$, although statistically significant is too low to be of clinical value.

SUMMARY AND CONCLUSIONS

The purpose of this study was to analyze the timing and magnitude of the circumpuberal growth acceleration of height, weight, mandibular length, and two other facial dimensions in a sample of girls and to relate these findings to each other and to the findings of previous investigators.

All raw data were obtained from longitudinal records of eighty girls enrolled in the Child Study Clinic, University of Oregon Dental School. Most records were from age eight to fifteen and included bi-annual cephalograms and recordings of height and weight. The raw data was converted by computer to bi-annual growth increments which were plotted for each variable, and smoothed once and twice. Percent increments of growth were calculated, smoothed twice and plotted for each variable.

Analysis of the data was by visual inspection of the incremental growth curves and calculations of means, S.D. correlation coefficients and t tests.

The conclusions drawn from the findings of this investigation are:

1. The incremental growth curves showed considerable variation as to magnitude and timing of the circumpuberal growth acceleration, although the existence of a circumpuberal acceleration was an almost universal finding.

2. The mean ages of peak height, weight and Ar-Po growth were 11.5 $\pm$ 1, 11.9 $\pm$ 1.1 and 11.8 $\pm$ 1.0 respectively, and compared closely to those reported by other investigators.

3. The age of peak growth velocity of mandibular length was significantly later than that of height, although 62 individuals had their peak growth increment for these two variables within $\pm$ 6 months.

4. The age of peak growth velocity of height and mandibular length were highly correlated, .84.

5. The associations between magnitude of increments of height, weight, weight to height, and facial dimensions was found to be low, all r $\leq$ .27.

6. "Early" and "late" maturers were not found to be significantly

different as to weight, weight to height or magnitude of peak Ar-Po growth increment.

7. Circumpuberal growth of the mandible showed only a low association, r = .14, with its size at the beginning of the circumpuberal spurt.

8. Mandibular length increased by a meaningful amount during the circumpuberal growth period, while growth increments one and two years before and one and two years after the peak period, although of a lesser amount, were nevertheless significant. More detailed serial investigation of the circumpuberal growth period is needed to determine whether individuals who exhibit large increments of growth early continue with this trend, and vice versa.

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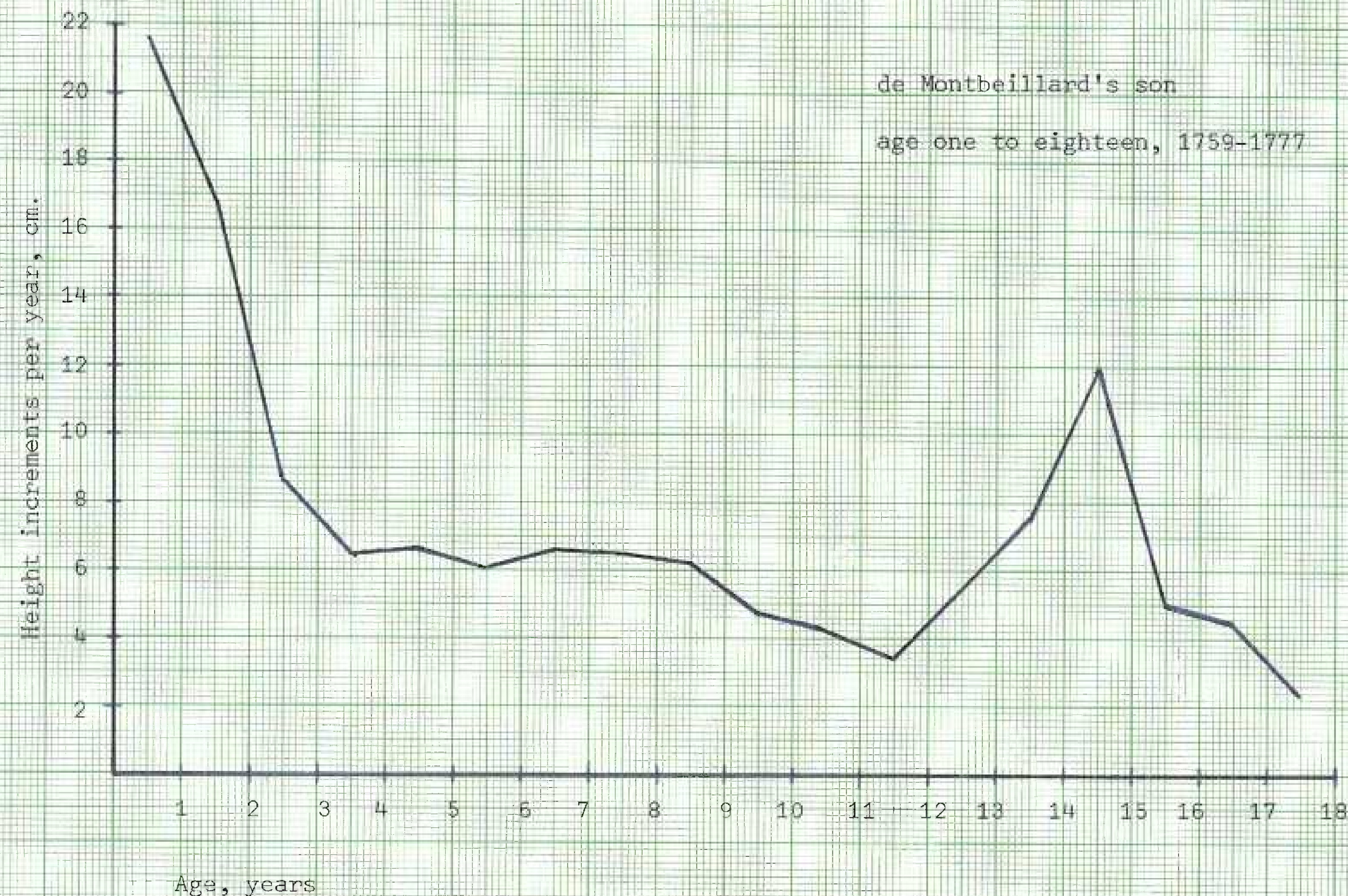


Figure 1. Growth increments in height of de Montbeillard's son, 1759-1777. From Tanner[26]

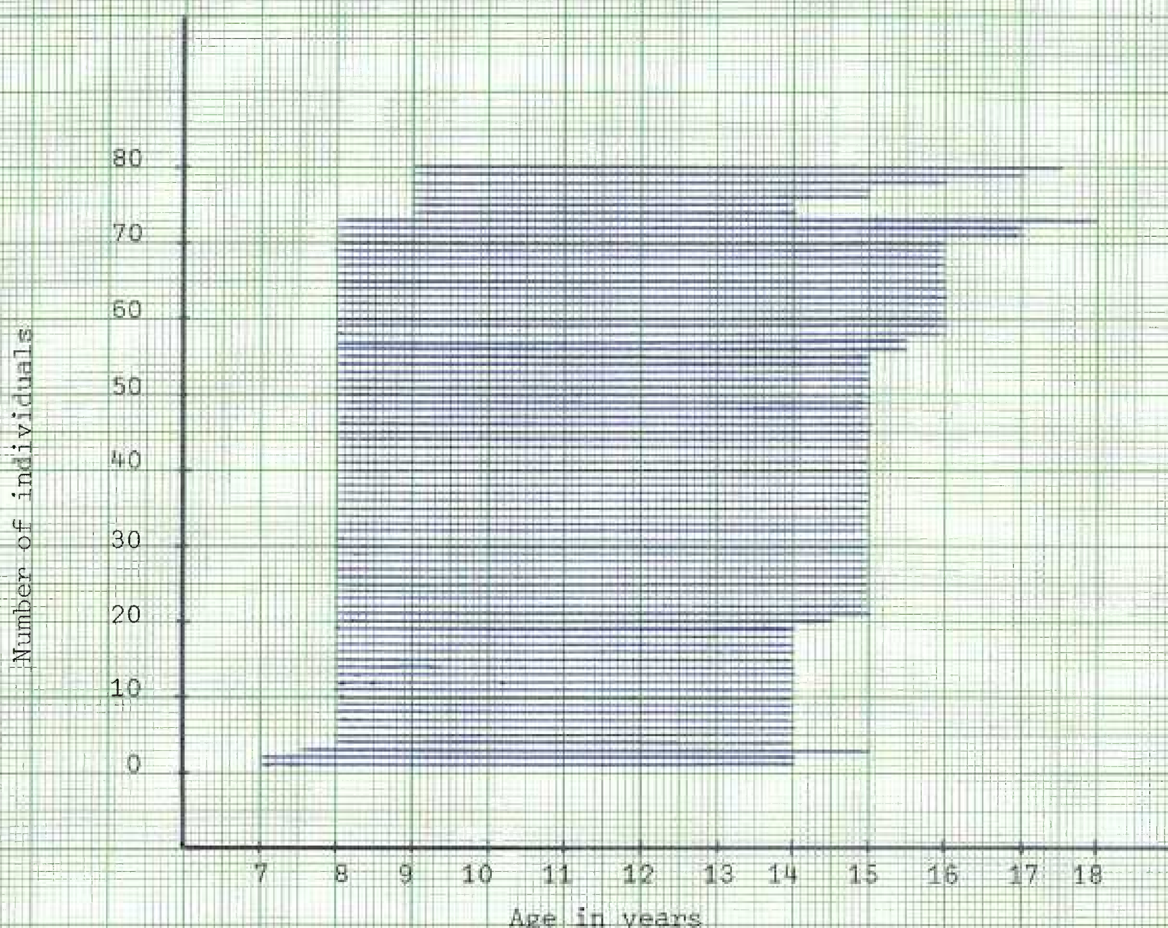
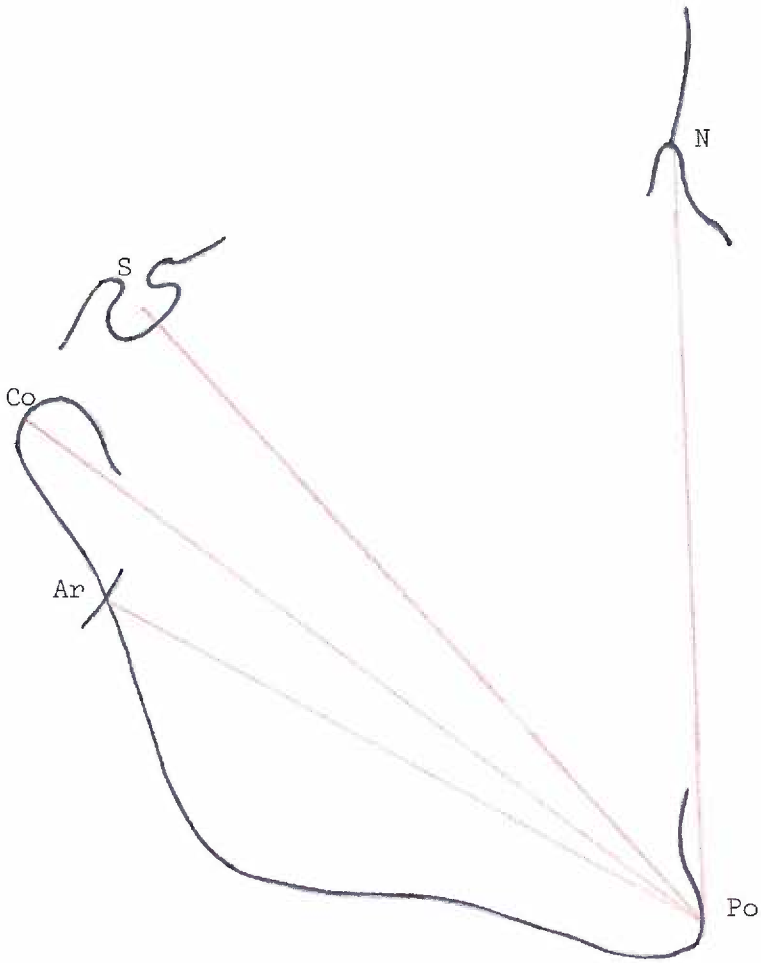


Figure 2. Sample distribution, 80 females



N - junction of frontal and nasal bones

S - center of sella turcica

Co - most distant point on outline of condyle from pogonion

Ar - intersection of the posterior border of the ramus and the temporal bone

Po - most anterior point on the body of the mandible

Figure 3. Landmarks and measurements.

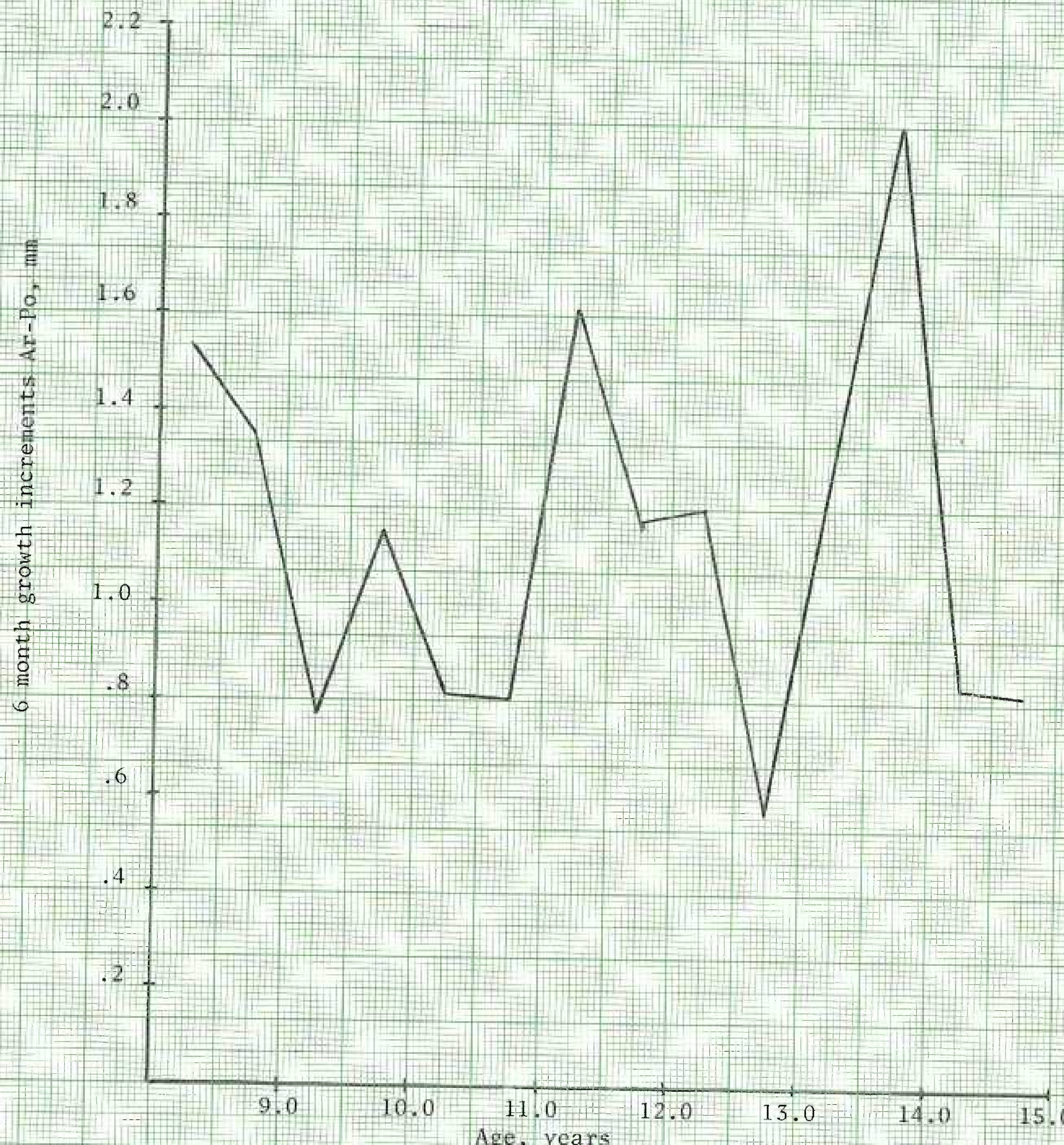


Figure 4, Example of two circumpuberal "peaks" of growth of Ar-Po, case #75

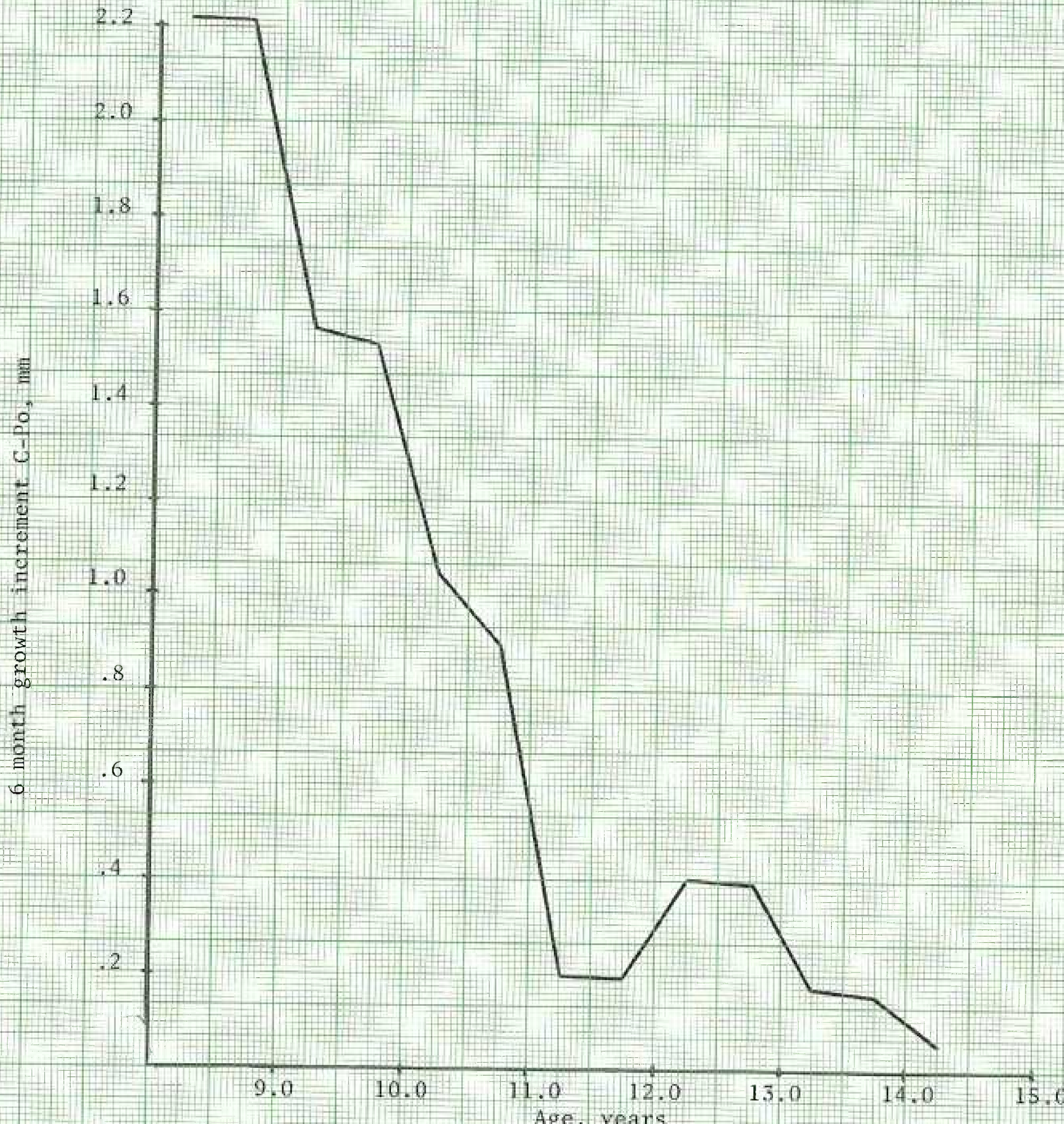
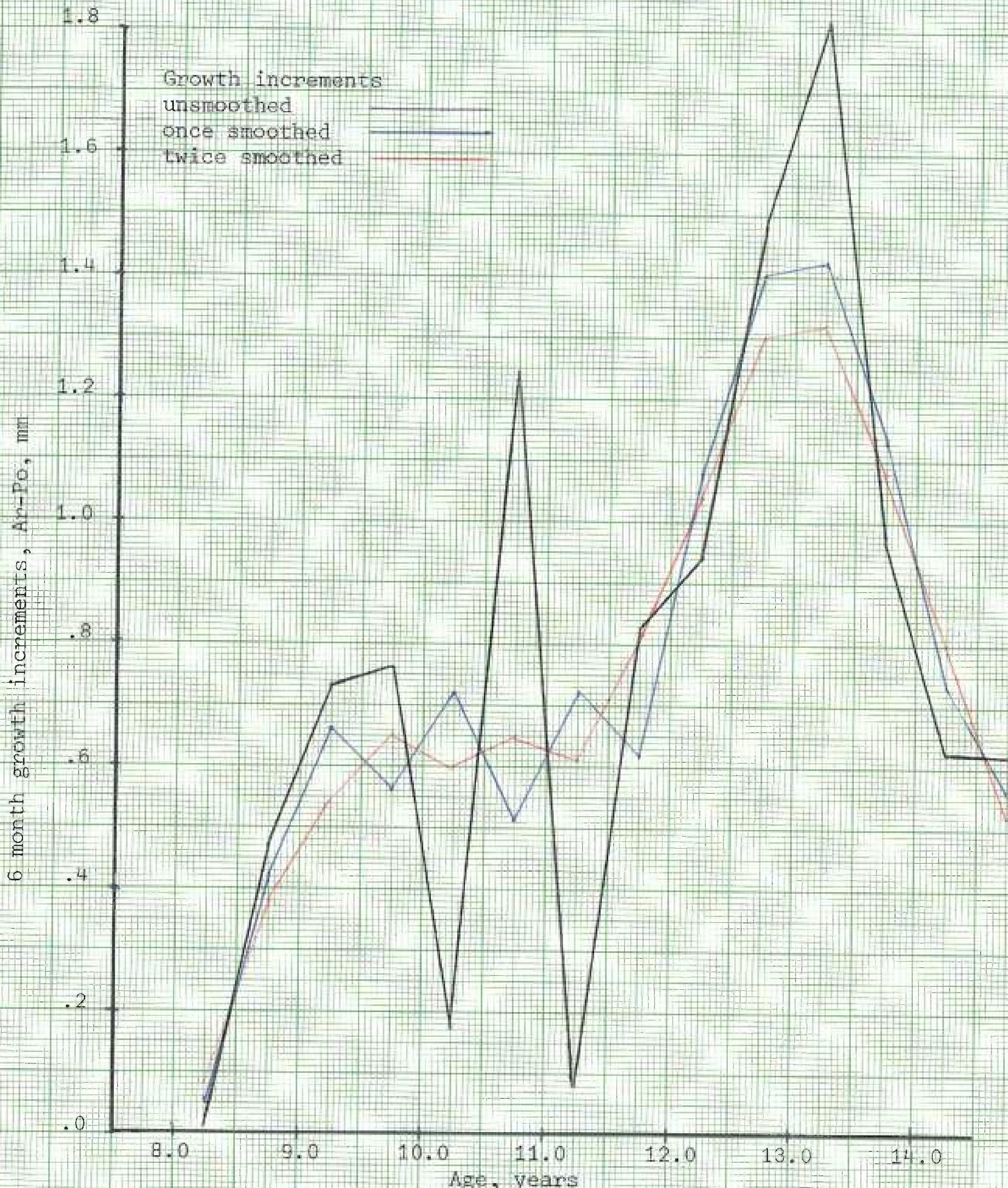


Figure 5, Example of no definite growth peak, C-Po case # 221



Computer smoothed according to the formulas from Hildebrand.[150]

left end: $y_{-1} + \frac{1}{6}(5f_{-1} + 2f_o - f_1)$

middle points: $y_o + \frac{1}{3}(f_{-1} + f_o + f_1)$

right end: $y_1 = \frac{1}{6}(-f_{-1} + 2f_o + 5f_1)$

Figure 6, Effect of three point smoothing, case no. 93, Ar-Po

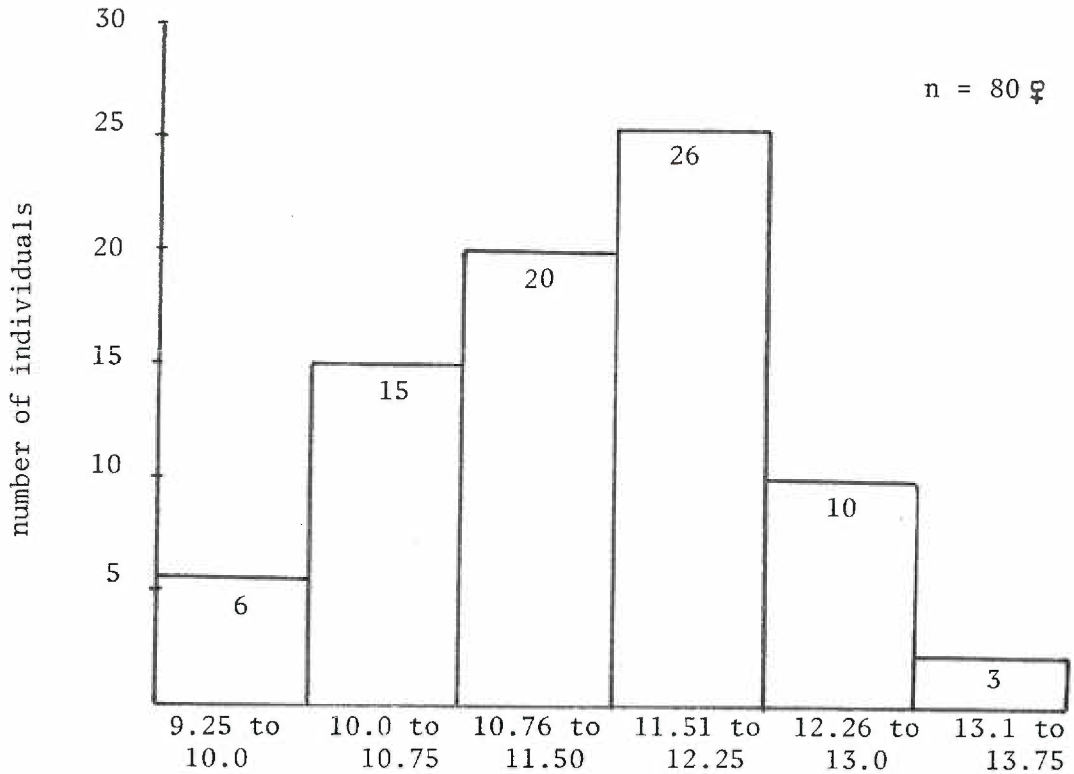


Figure 7, Distribution of ages of maximum growth increment, height.

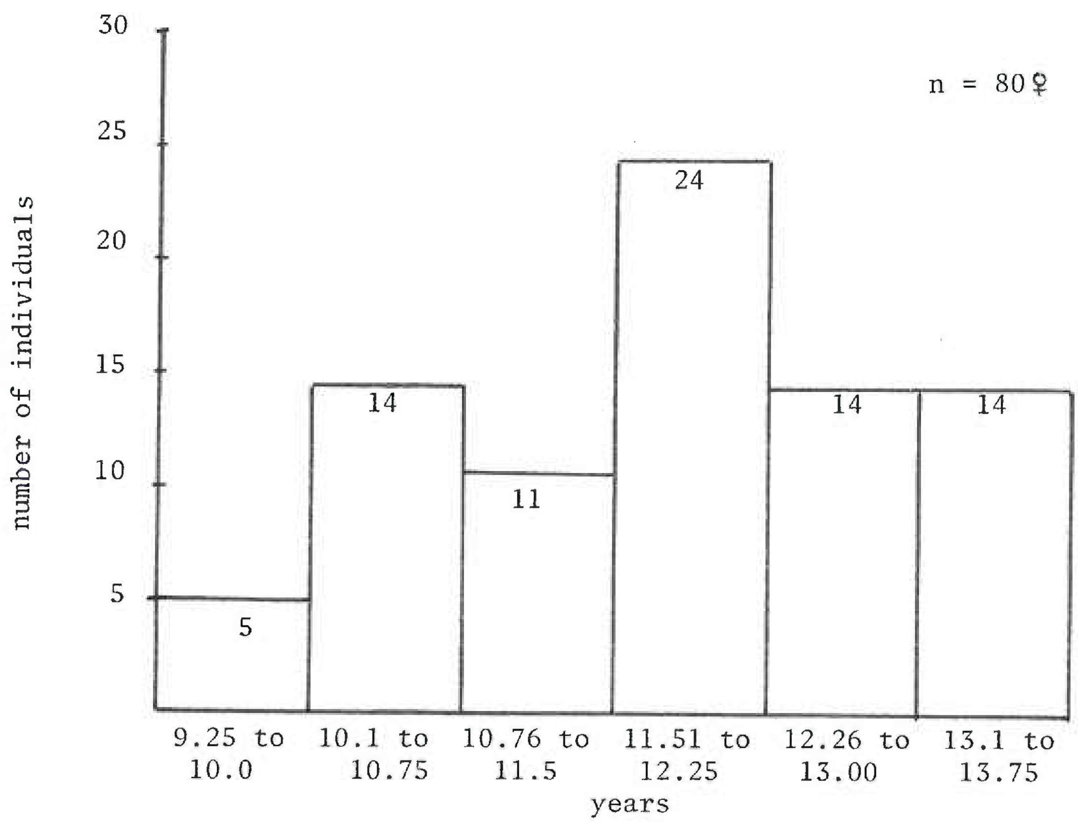


Figure 8, Distribution of ages of maximum growth increment, weight.

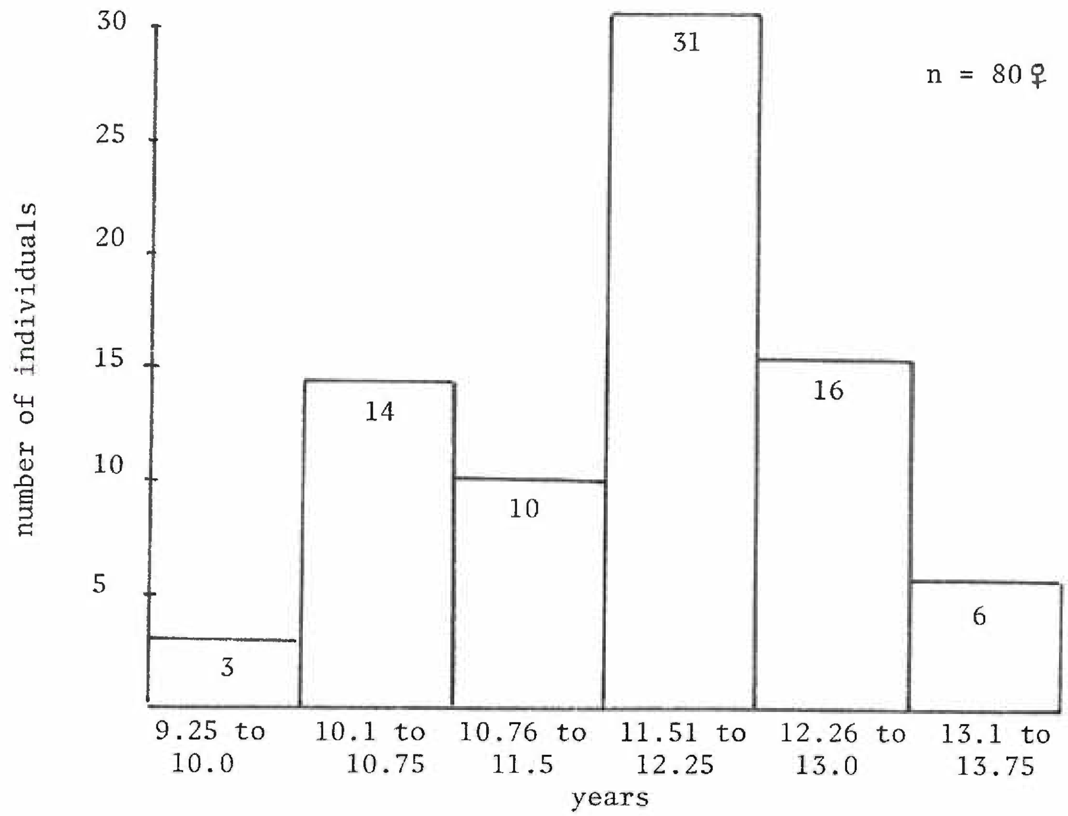


Figure 9, Distribution of ages of maximum growth increment, Ar-Po

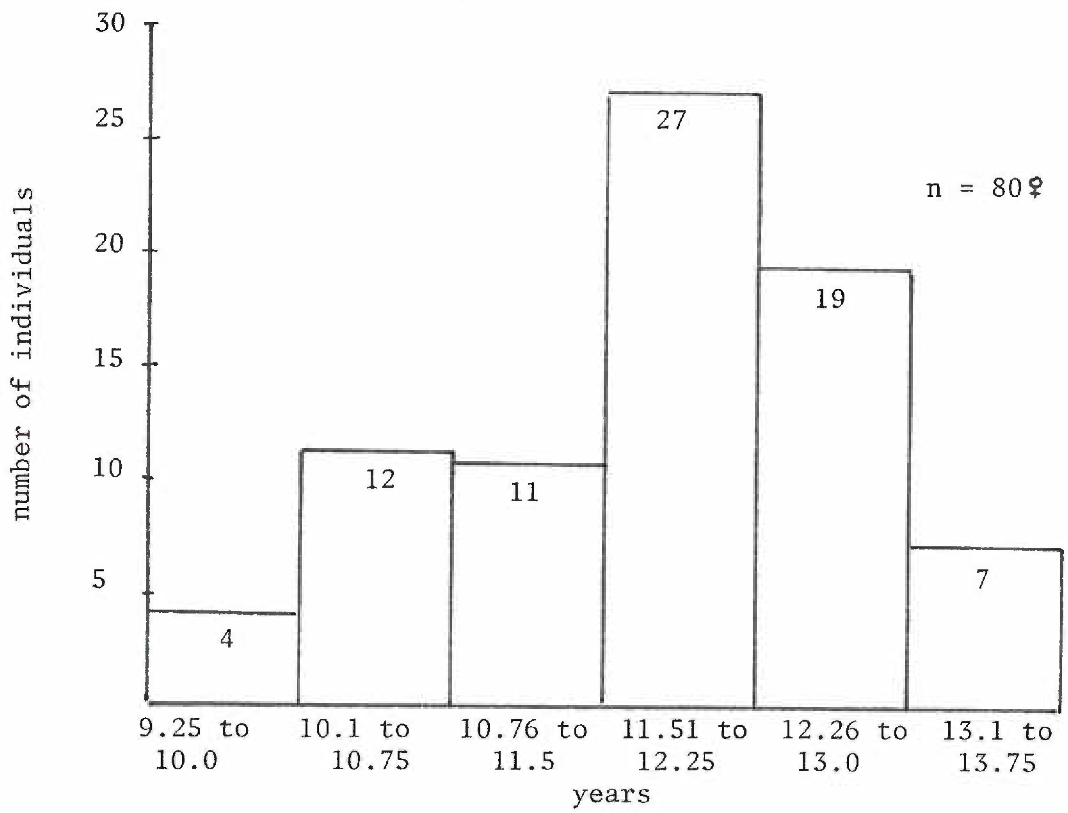


Figure 10, Distribution of ages of maximum growth increment, S-Po

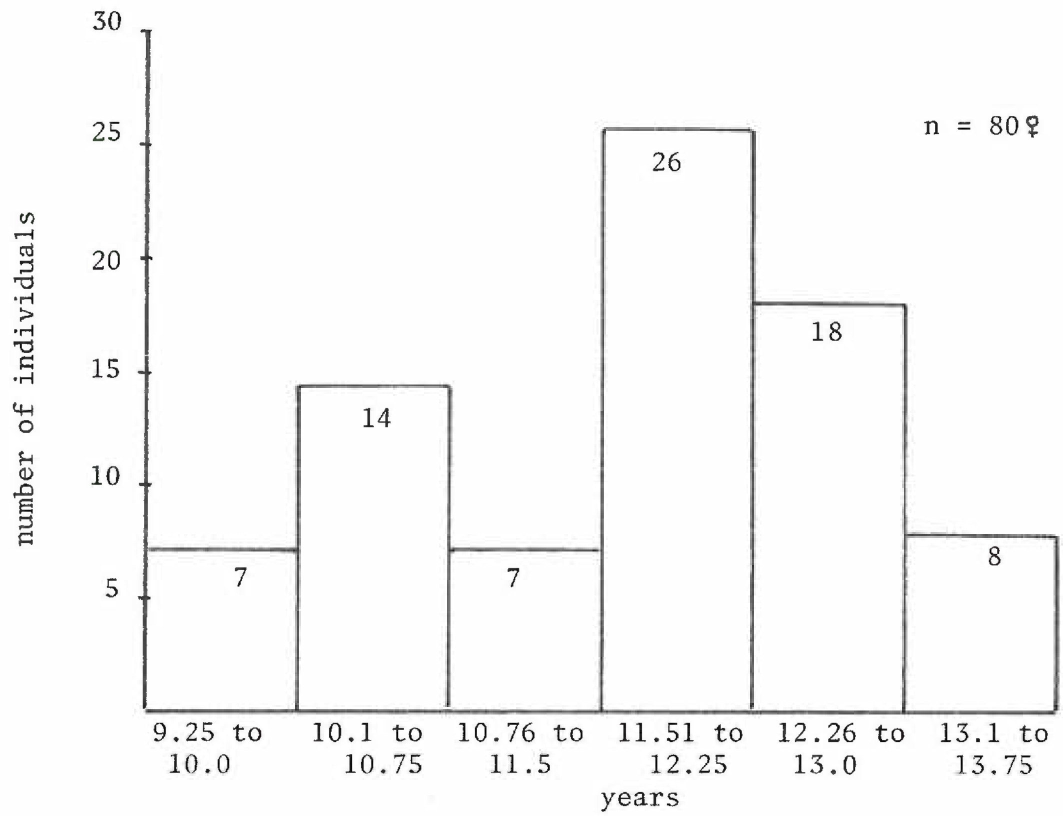


Figure 11, Distribution of ages of maximum growth increment N-Po

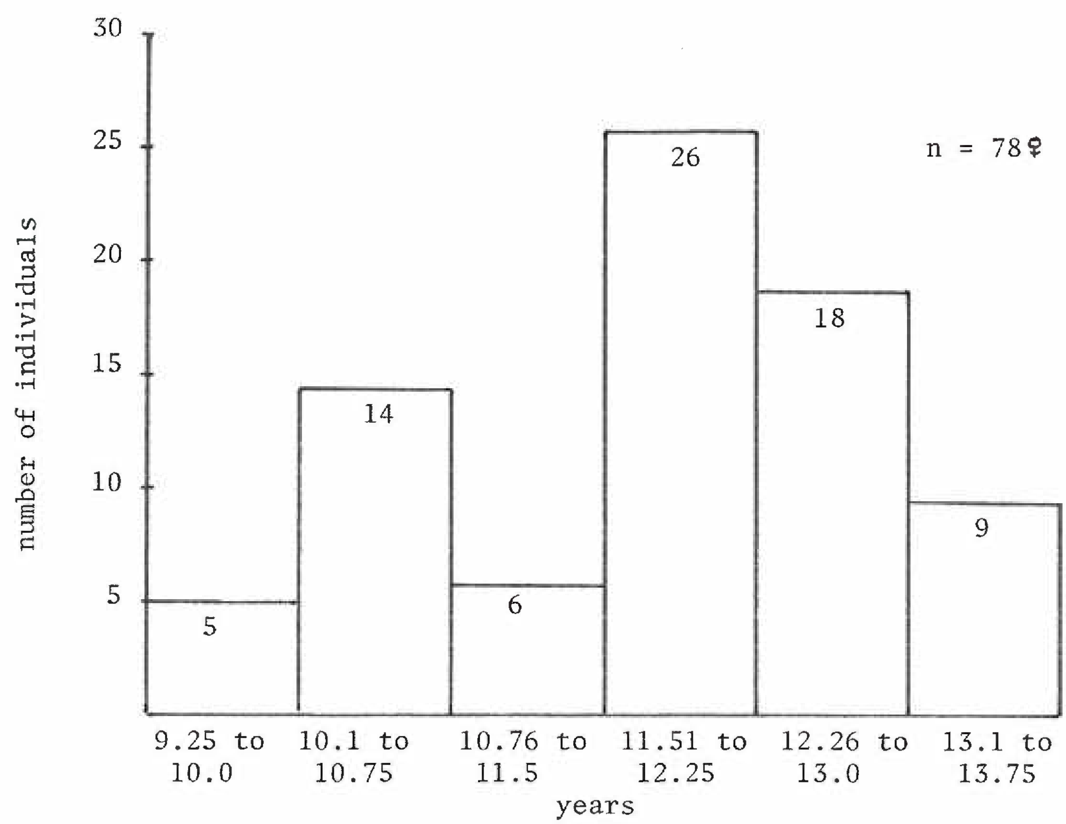


Figure 12, Distribution of ages of maximum growth increment, C-Po

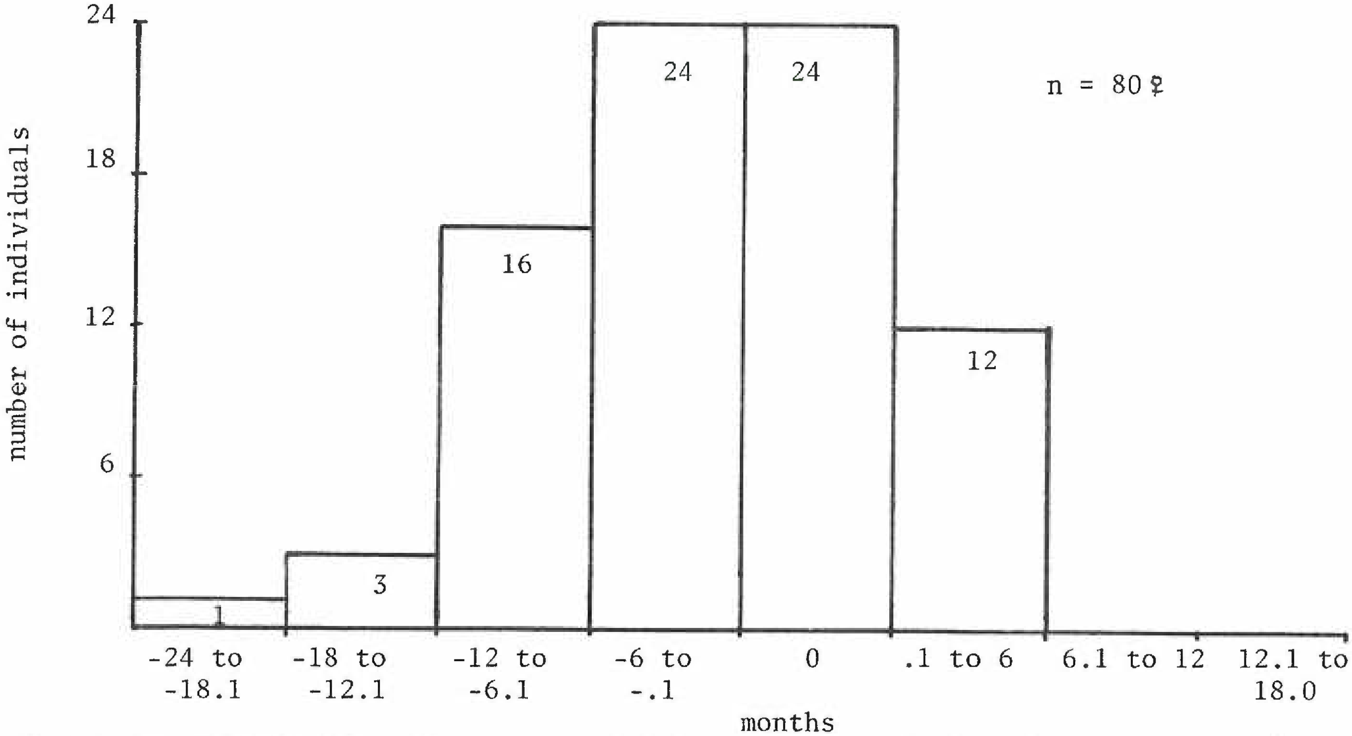


Figure 13, Distribution of age at peak height growth velocity minus age at peak mandibular (Ar-Po) growth velocity using percentage rate smoothed twice.

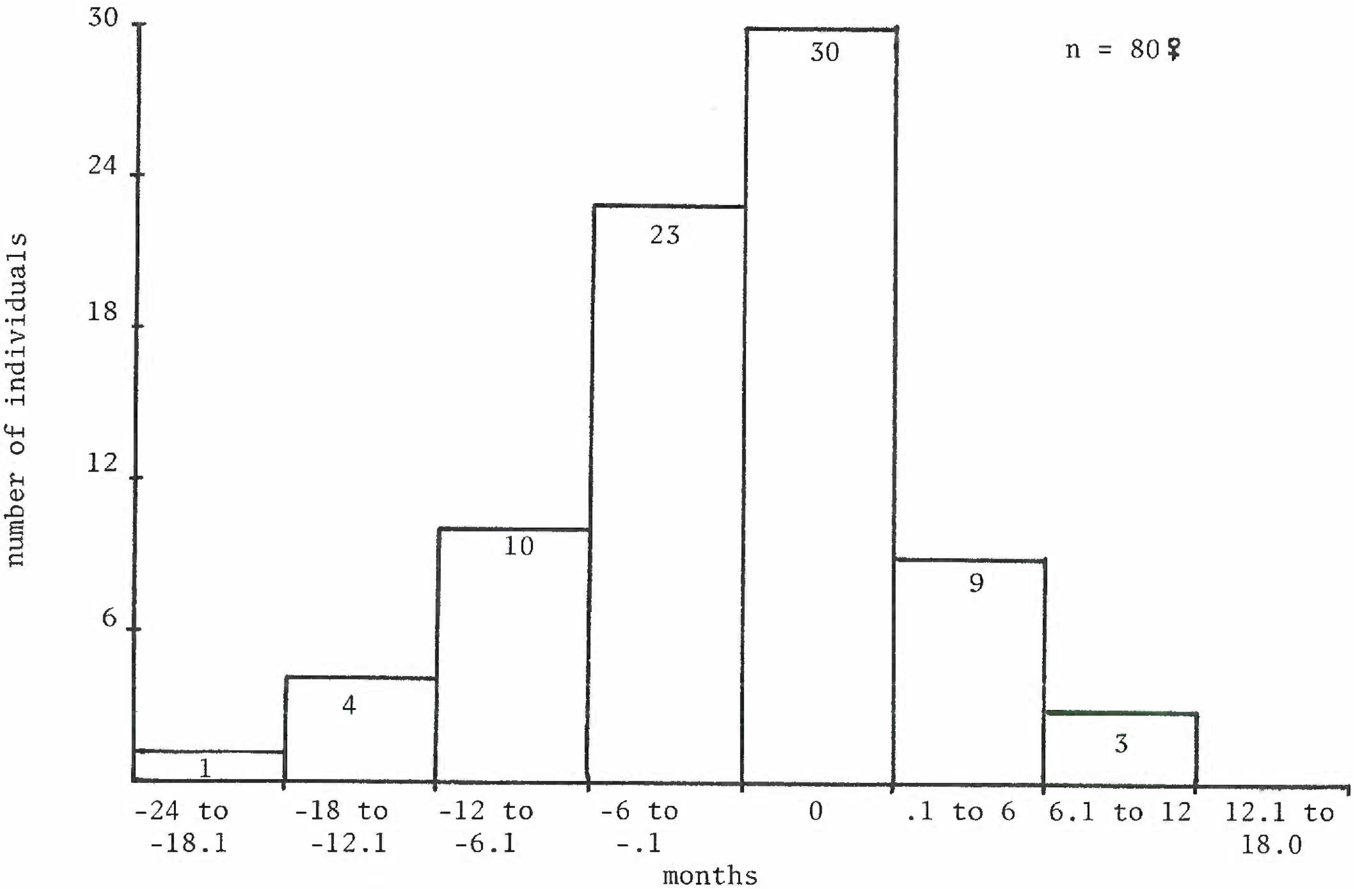


Figure 14, Distribution of age of maximum height growth velocity minus age of maximum mandibular (Ar-Po) growth velocity, using unsmoothed data.

All negative values = peak mand. length growth velocity occurred after that of height

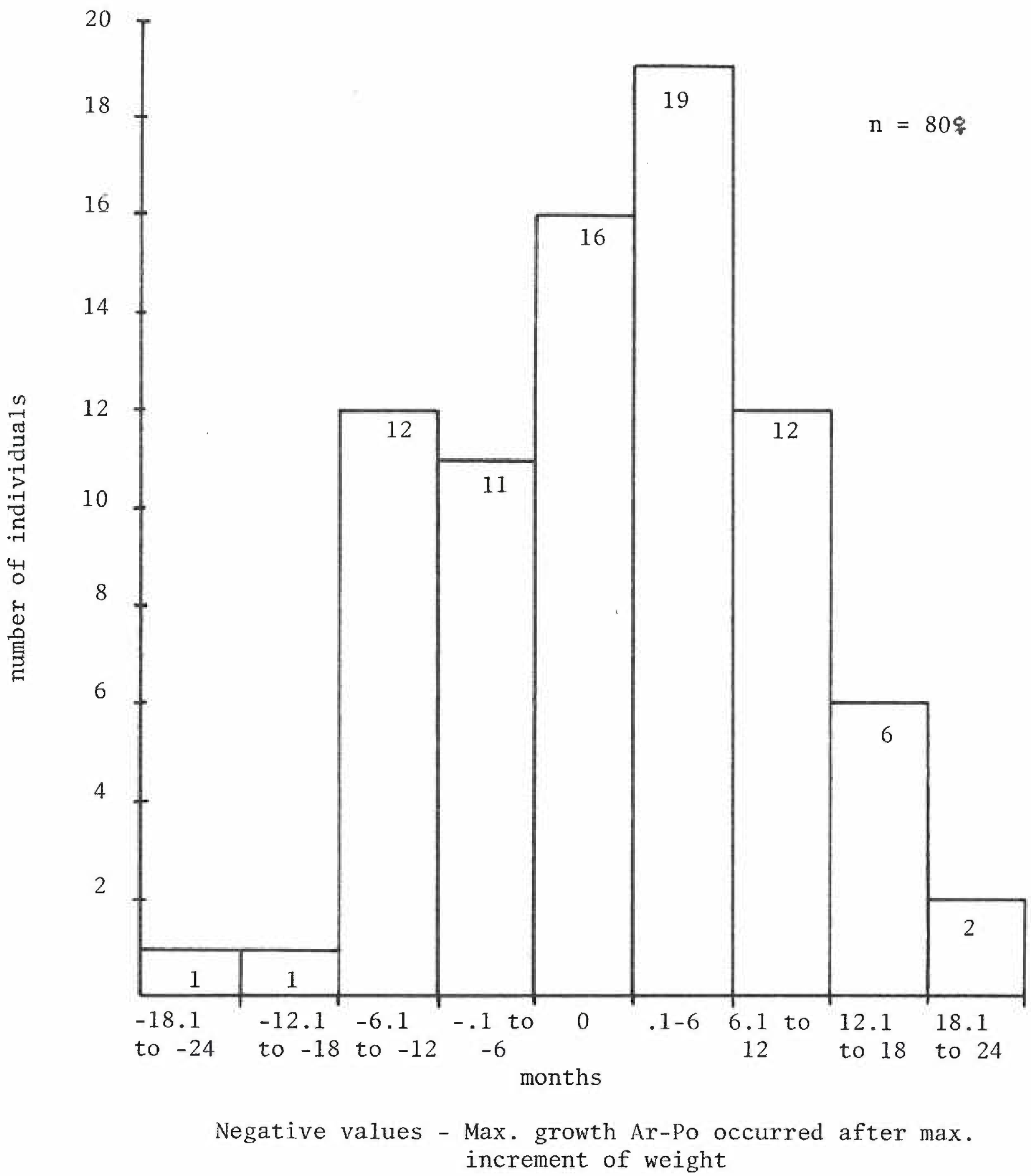


Figure 15, Distribution of age of peak weight increment minus age of peak Ar-Po increment.

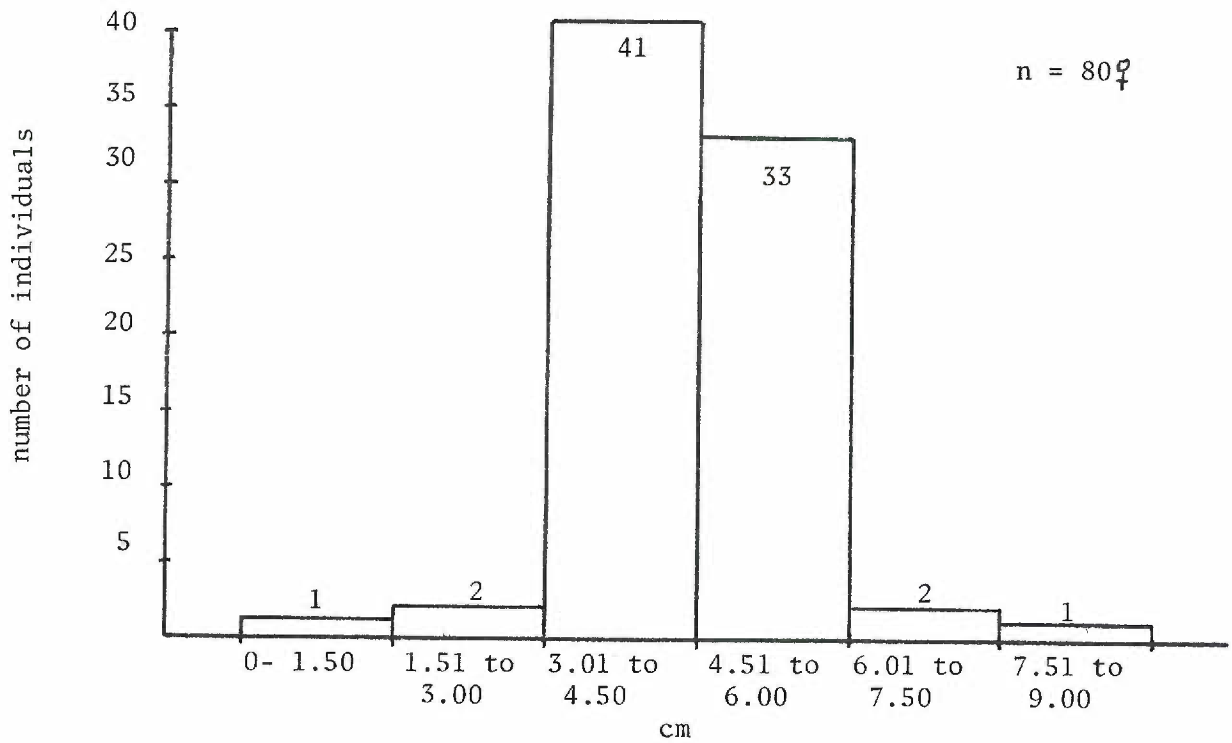


Figure 16, Distribution of magnitude of peak six month growth; Height

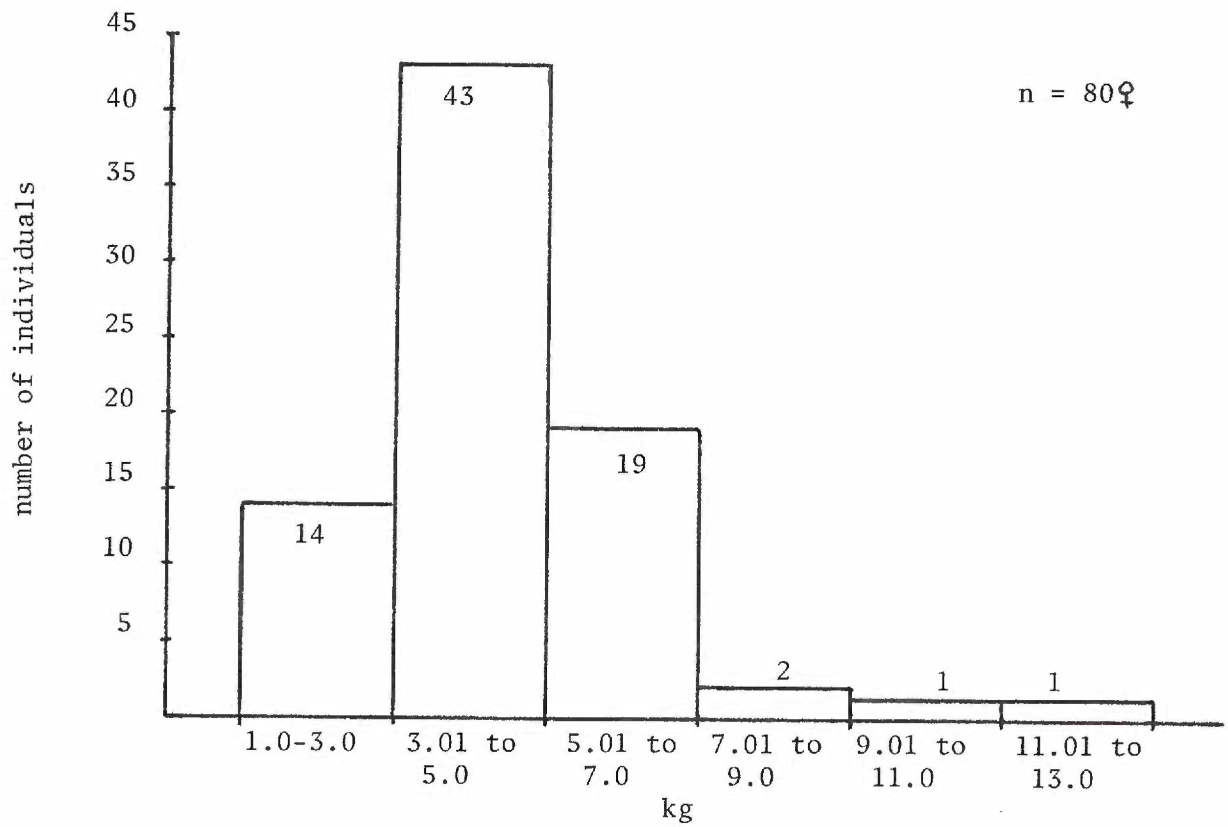


Figure 17, Distribution of magnitude of peak six month growth; Weight

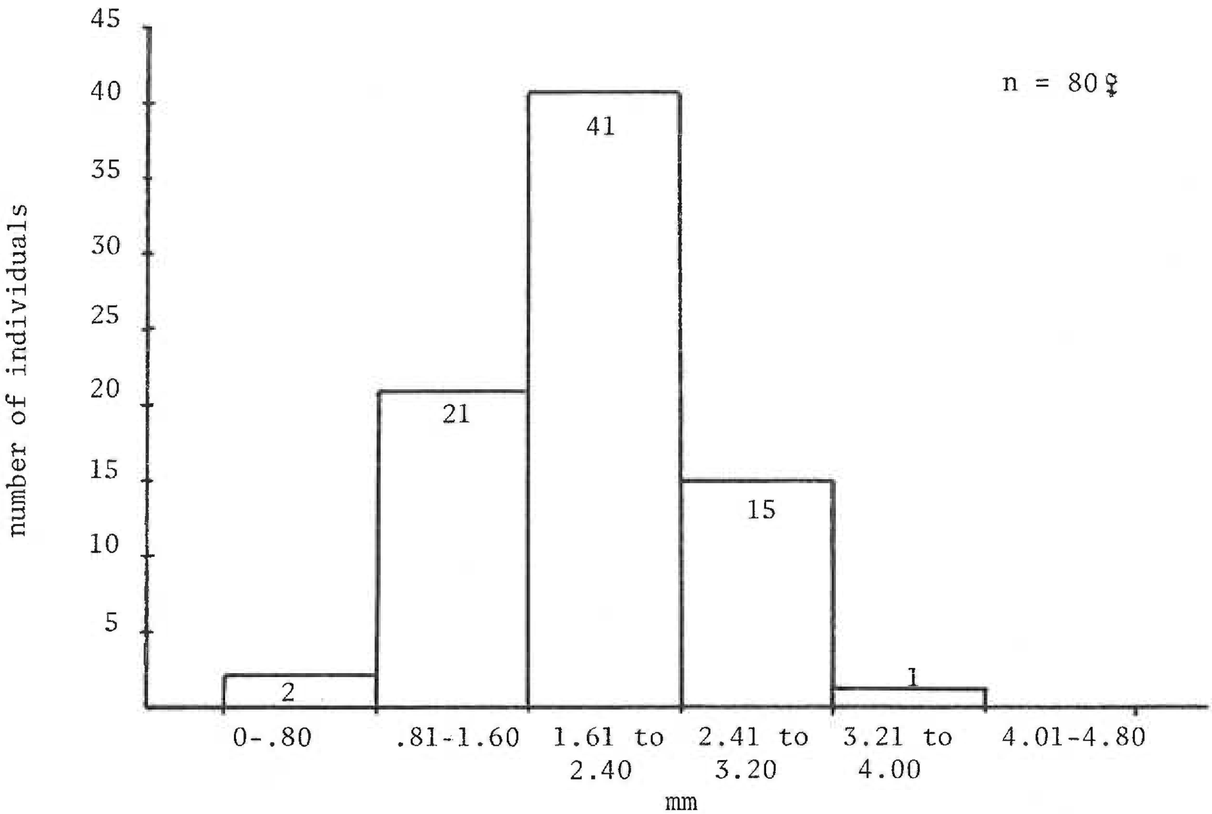


Figure 18, Distribution of magnitude of peak six month growth, Ar-Po

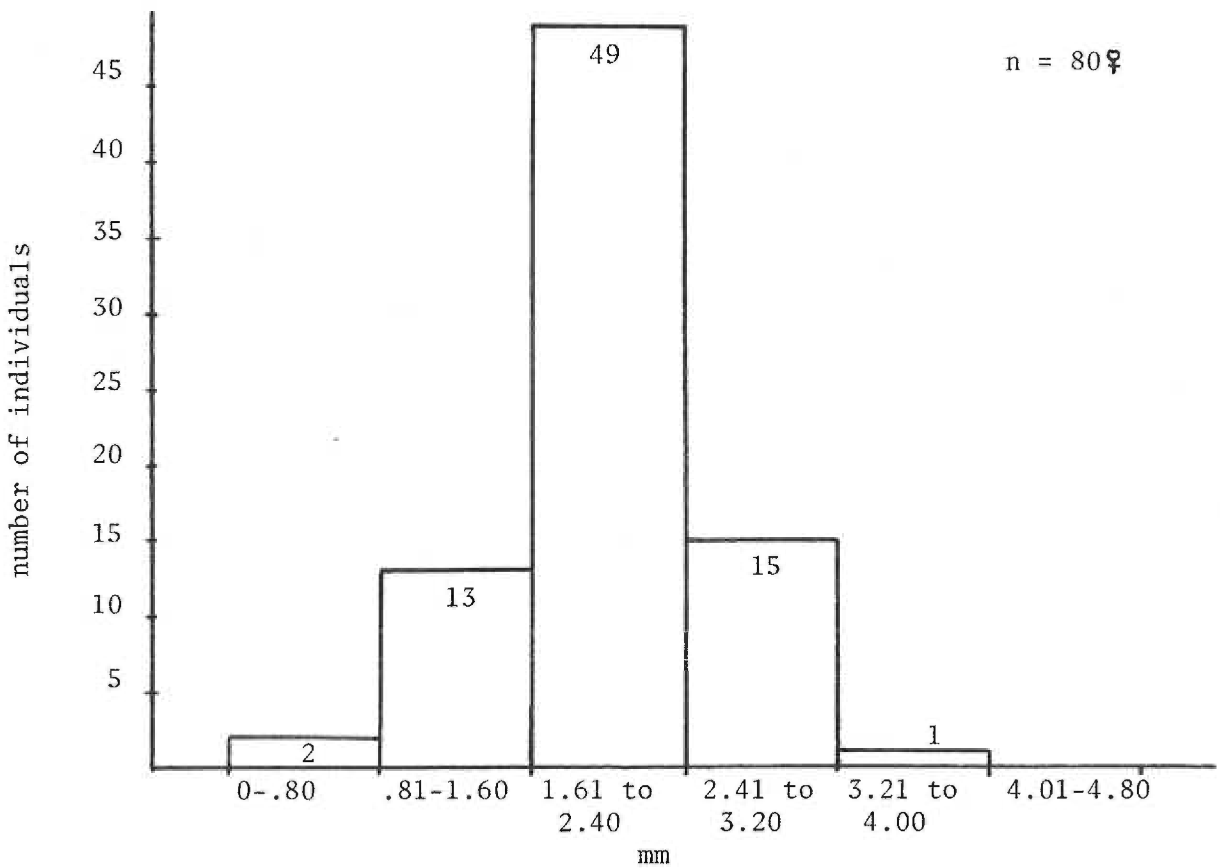


Figure 19, Distribution of magnitude of peak six month growth, S-Po

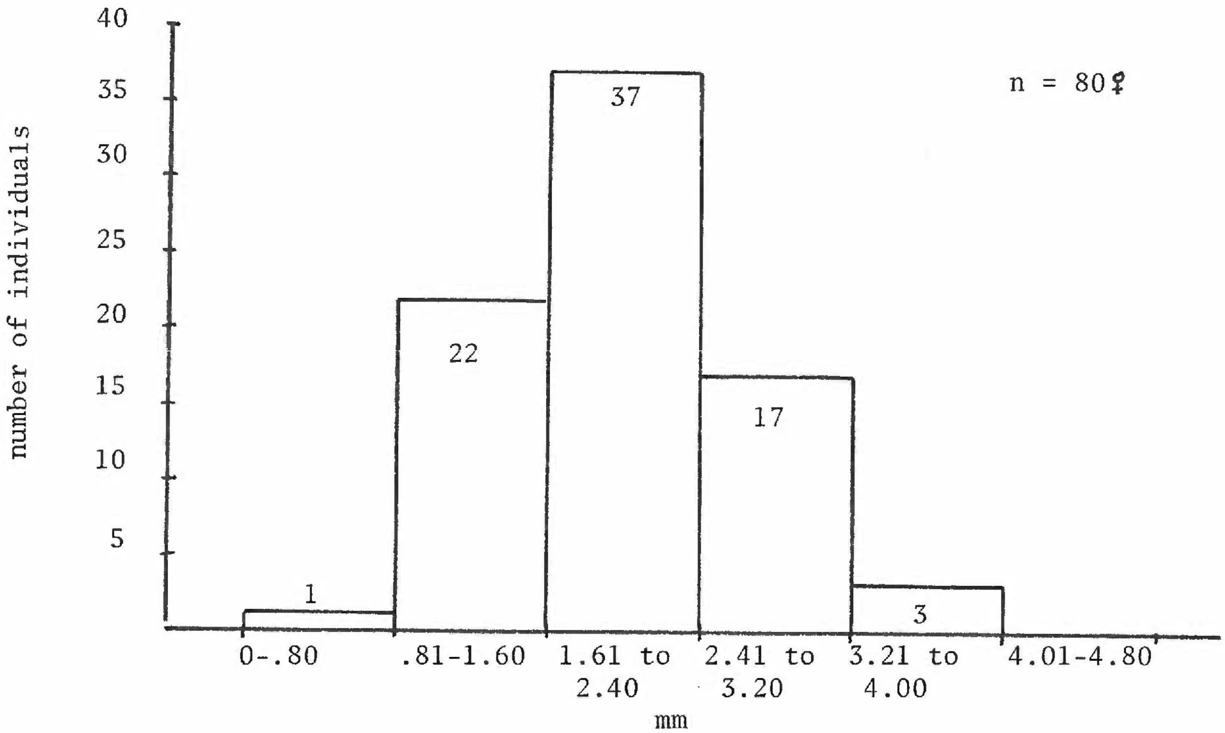


Figure 20, Distribution of magnitude of peak growth N-Po

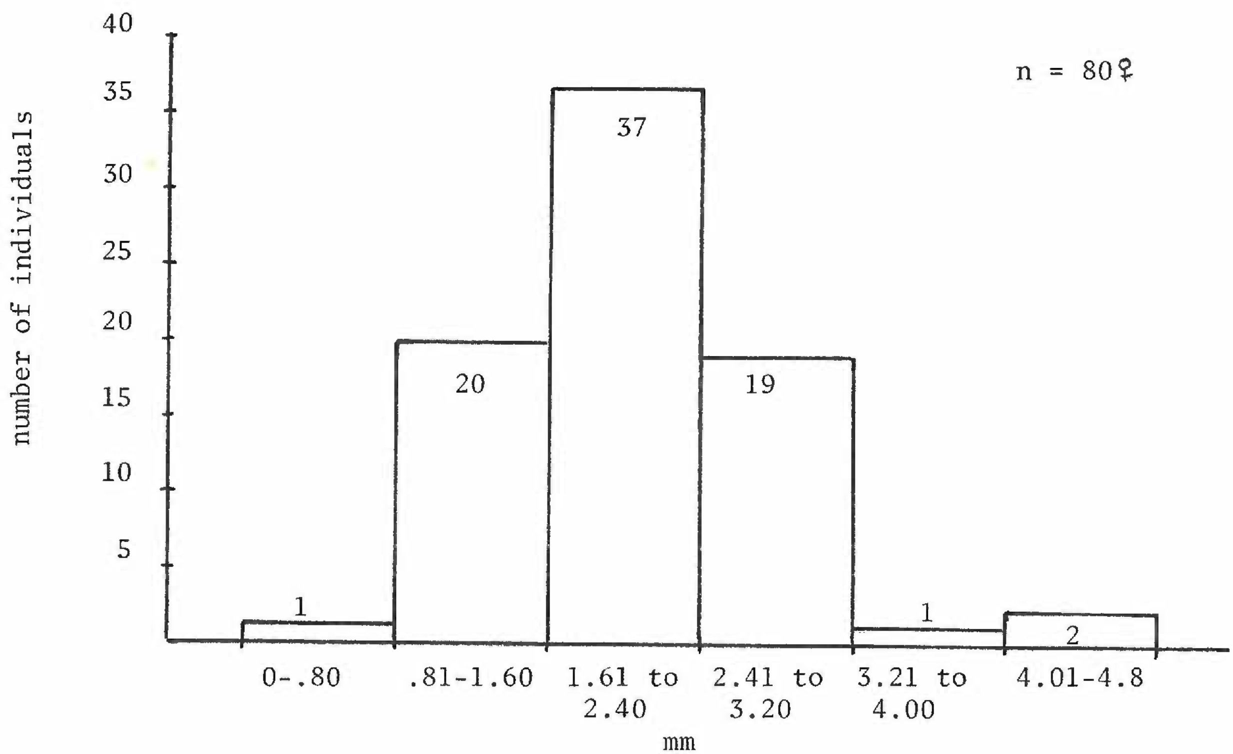


Figure 21, Distribution of magnitude of peak growth C-Po

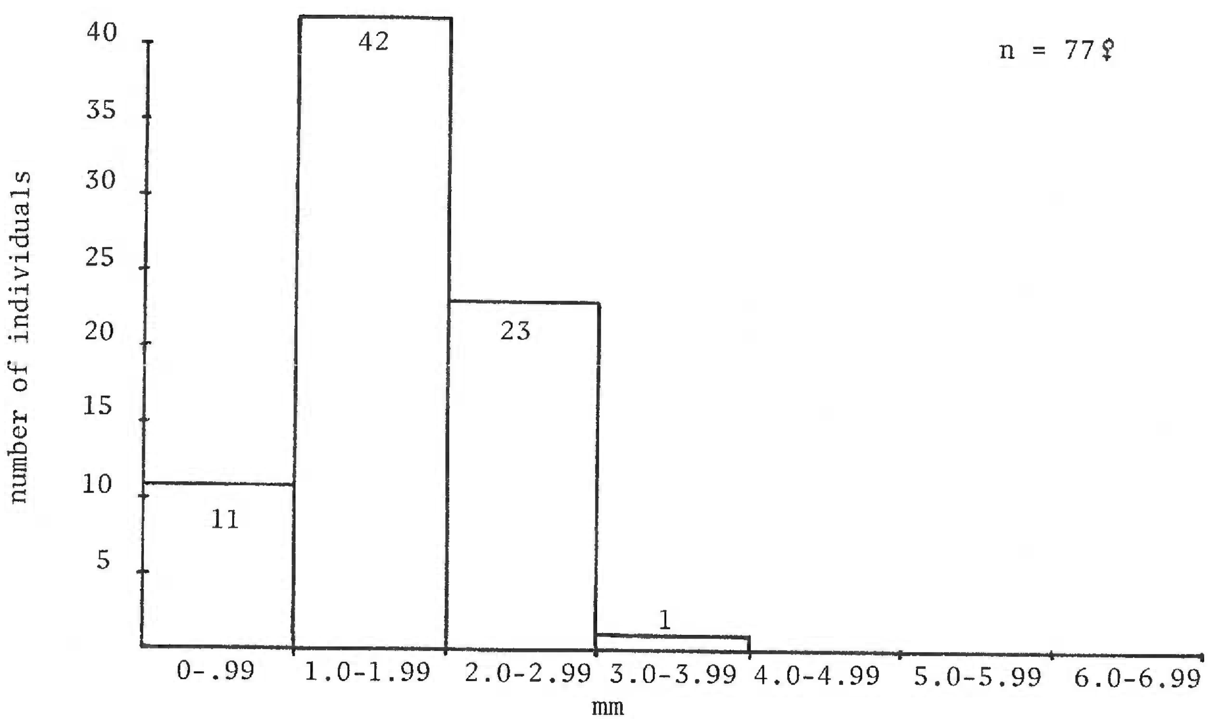


Figure 22, Distribution of growth increment (Ar-Po) during second year prior to six month period of peak growth Ar-Po

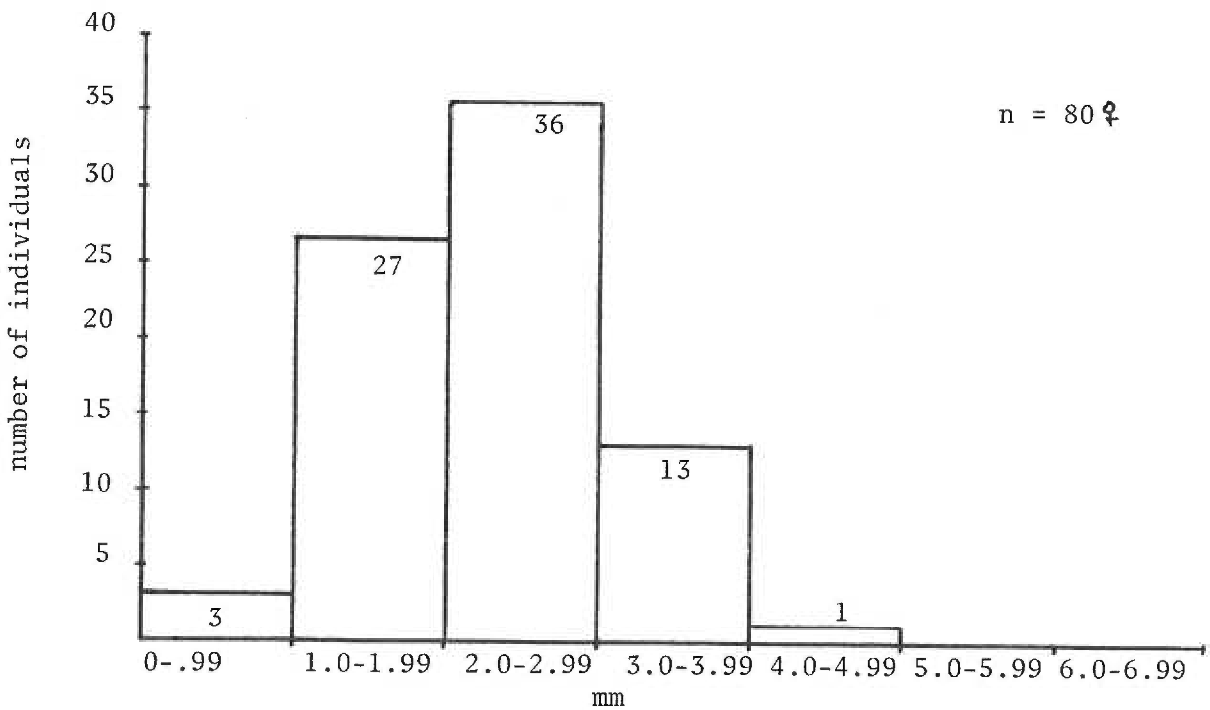


Figure 23, Distribution of growth increments (Ar-Po) during first year prior to six month period of peak growth Ar-Po

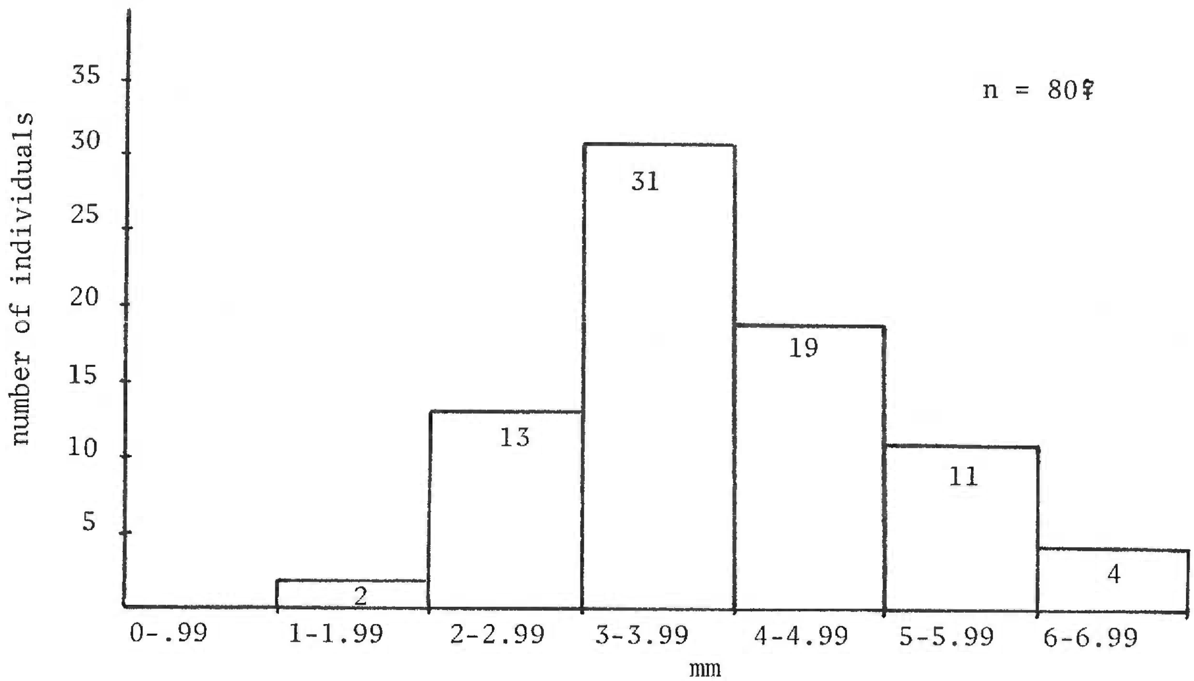


Figure 24, Distribution of annual growth rate (Ar-Po) during peak growth of Ar-Po

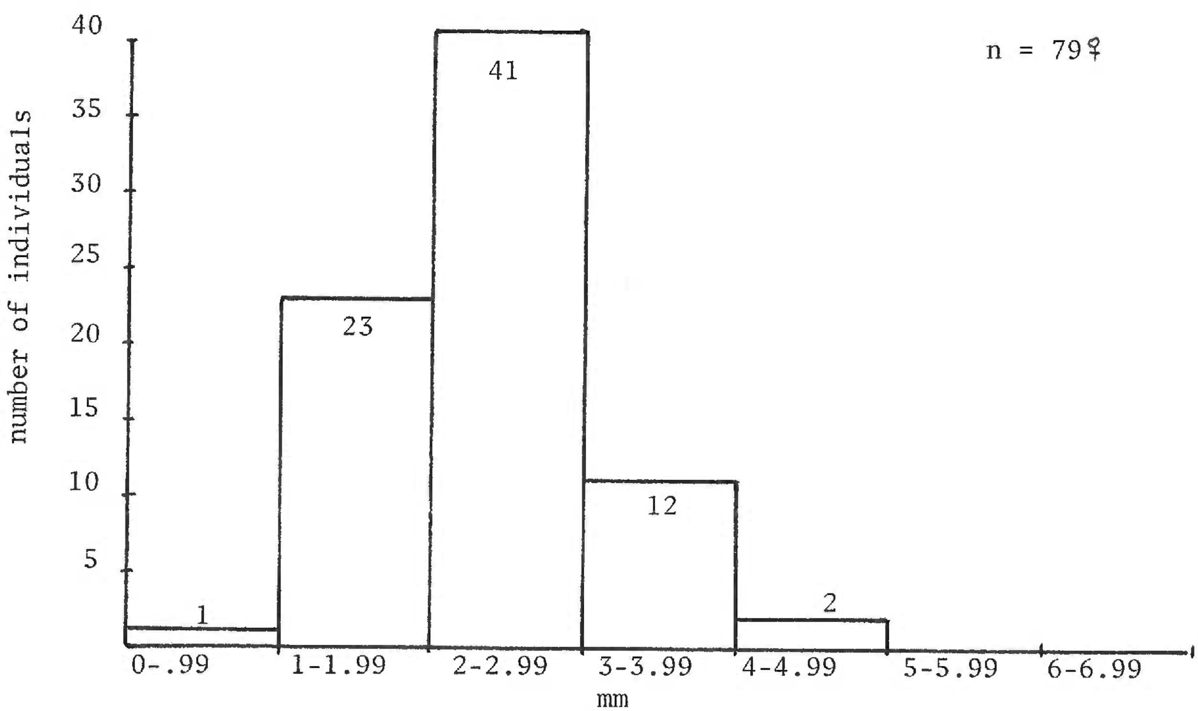


Figure 25, Distribution of growth increment (Ar-Po) during first year after six month period of peak growth, Ar-Po

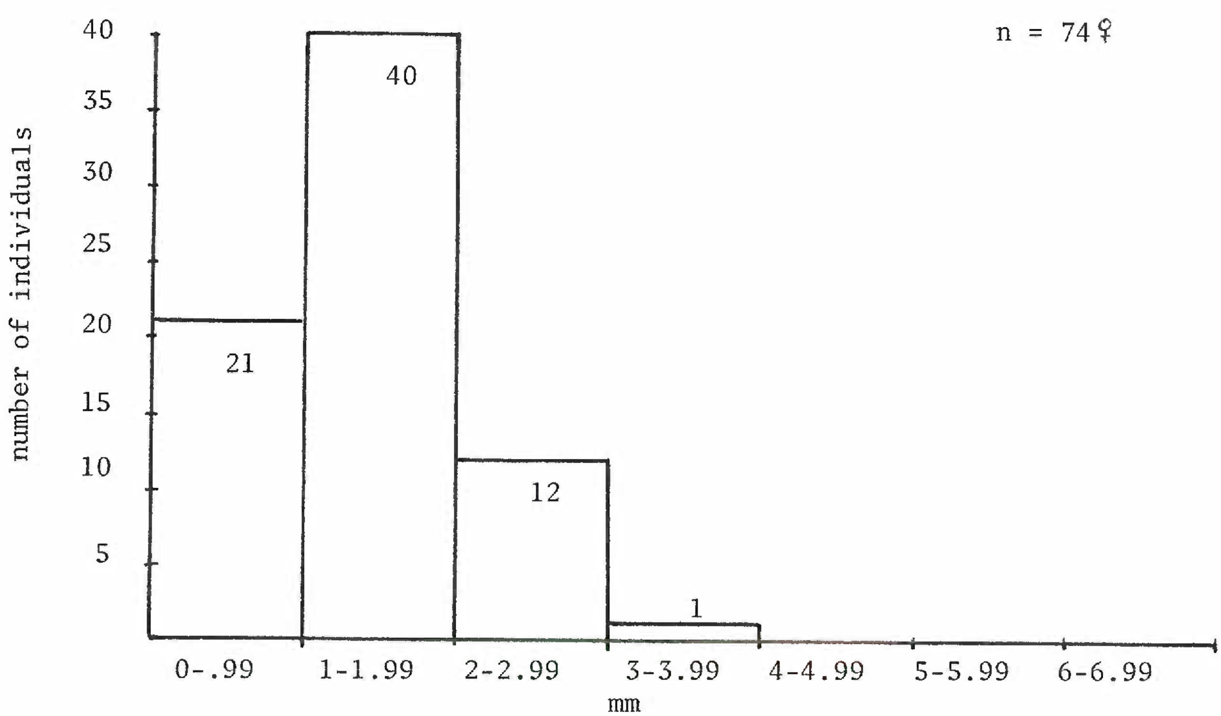
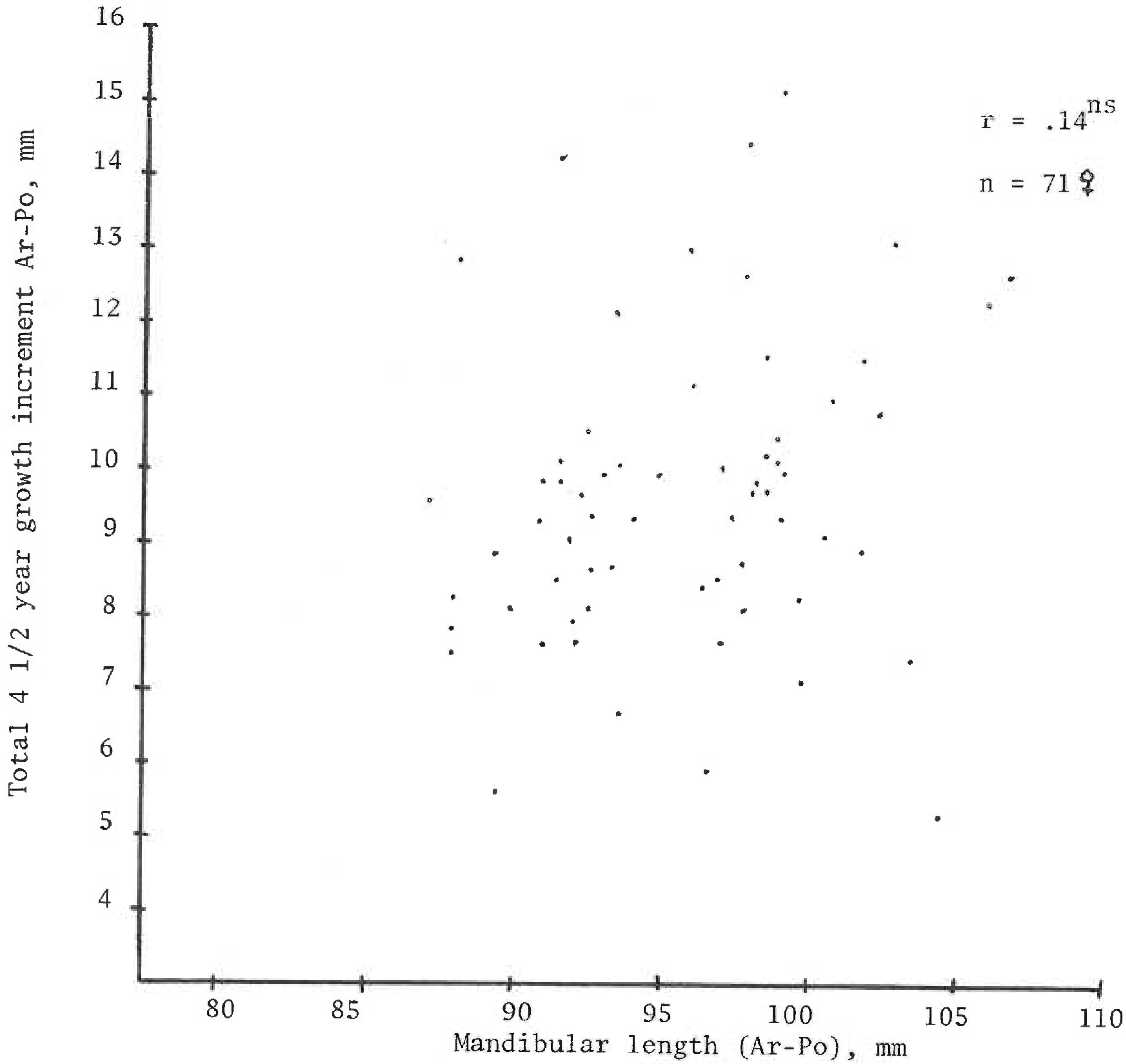


Figure 26, Distribution of growth increment (Ar-Po) during second year after six month period of peak growth, Ar-Po



ns not significant

Figure 27, Scattergram of total 4 1/2 year growth increment and absolute mandibular length at beginning of 4 1/2 year growth period.

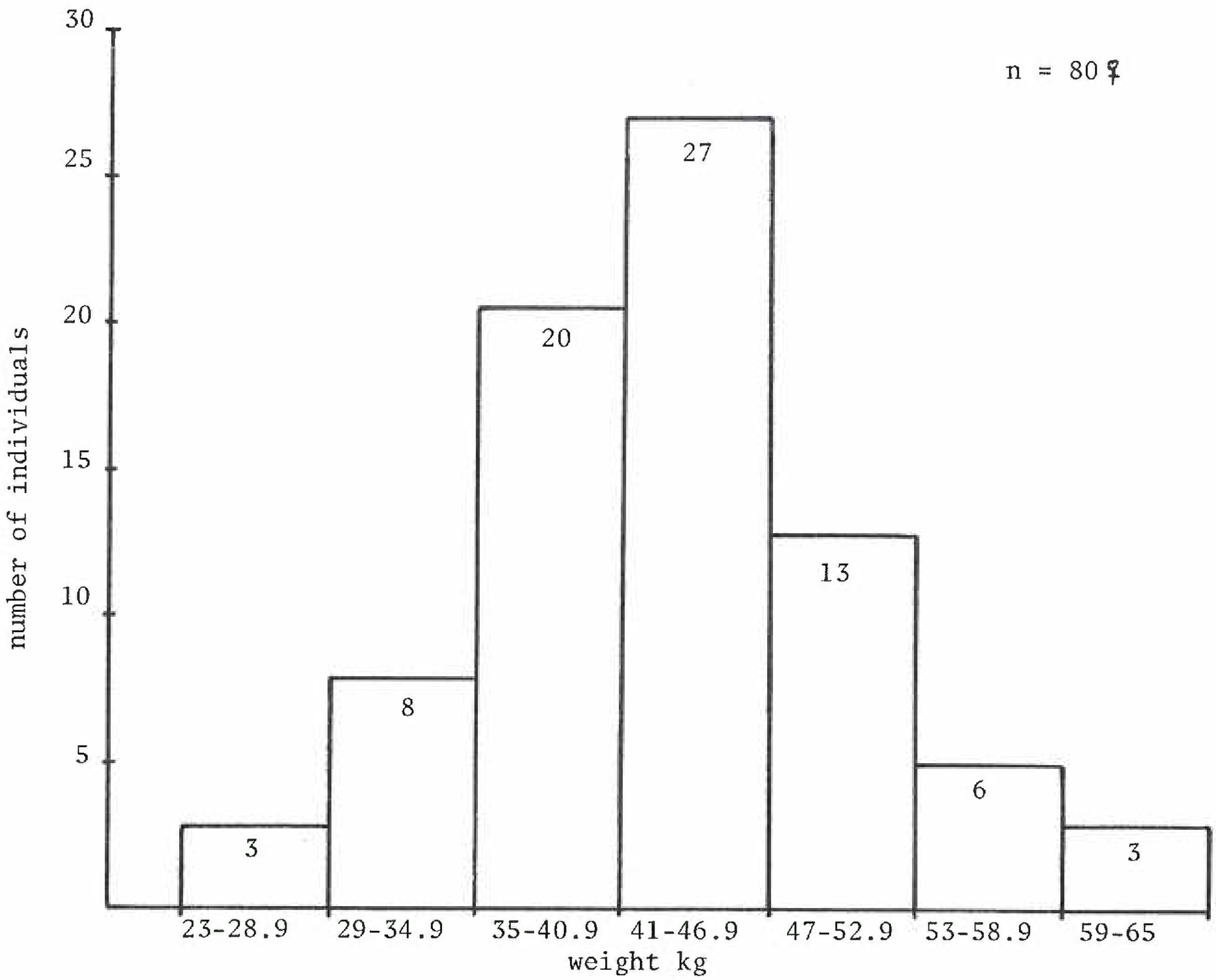


Figure 28, Distribution of total weight at the age of maximum growth of Ar-Po.

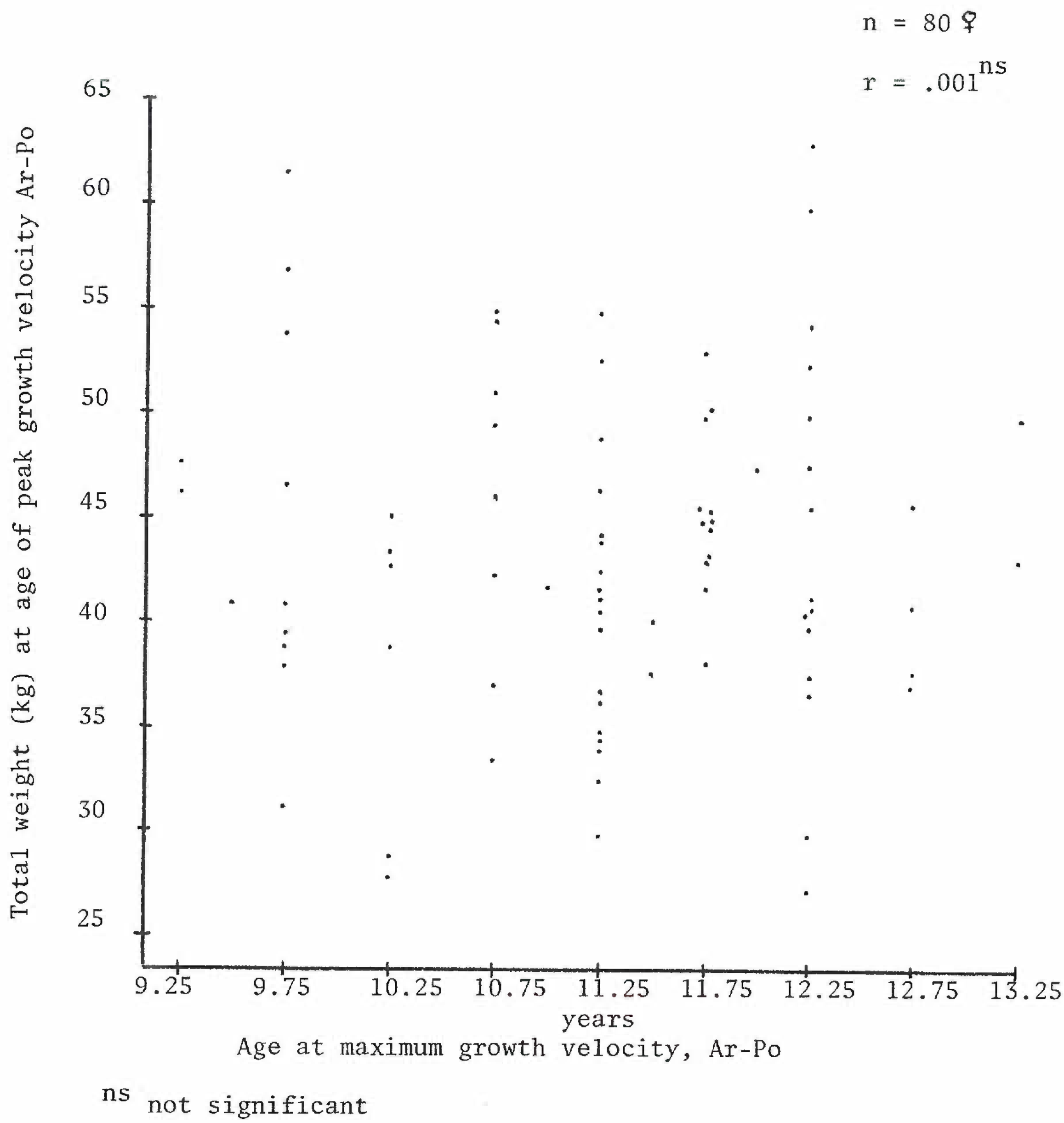
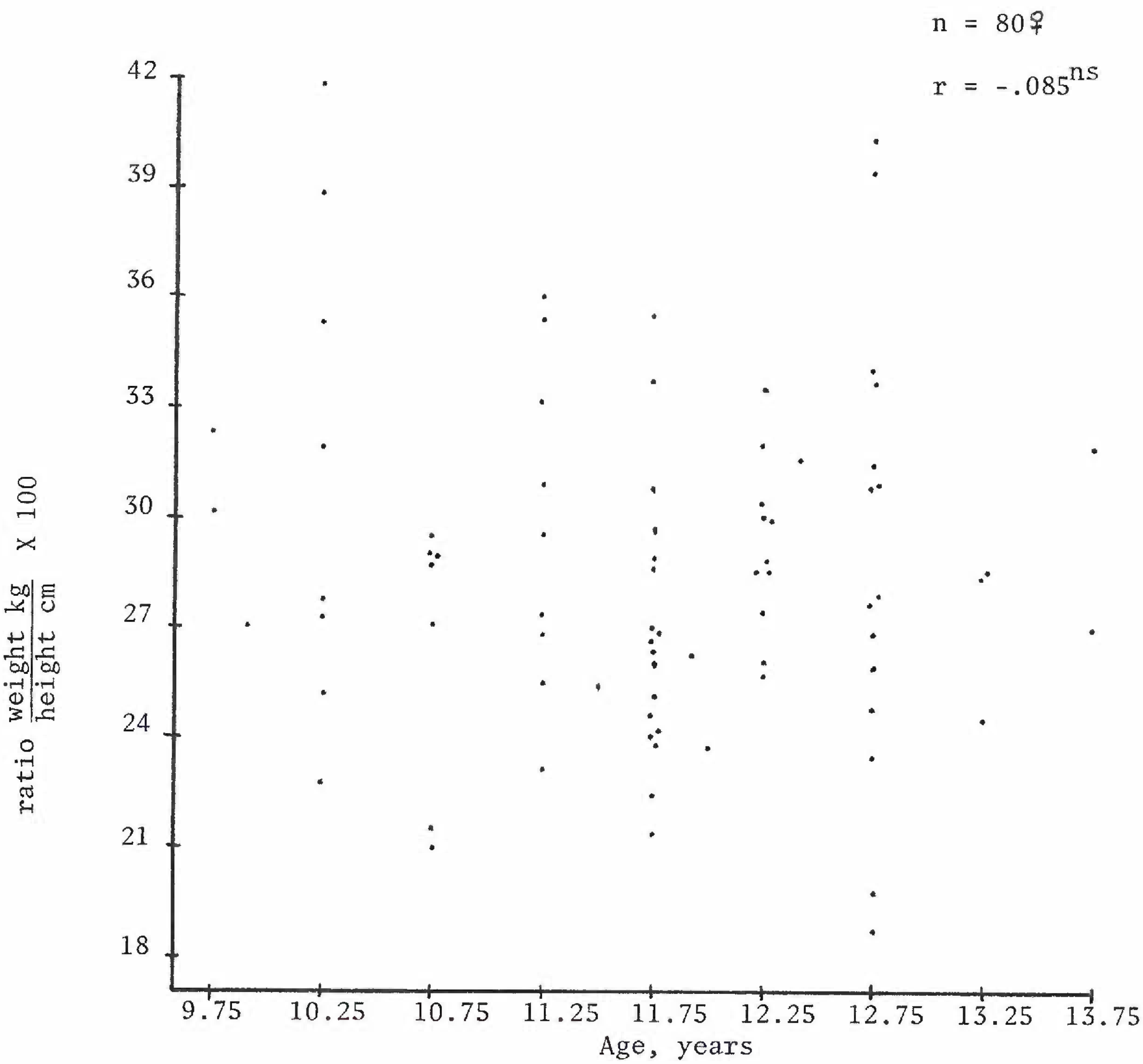
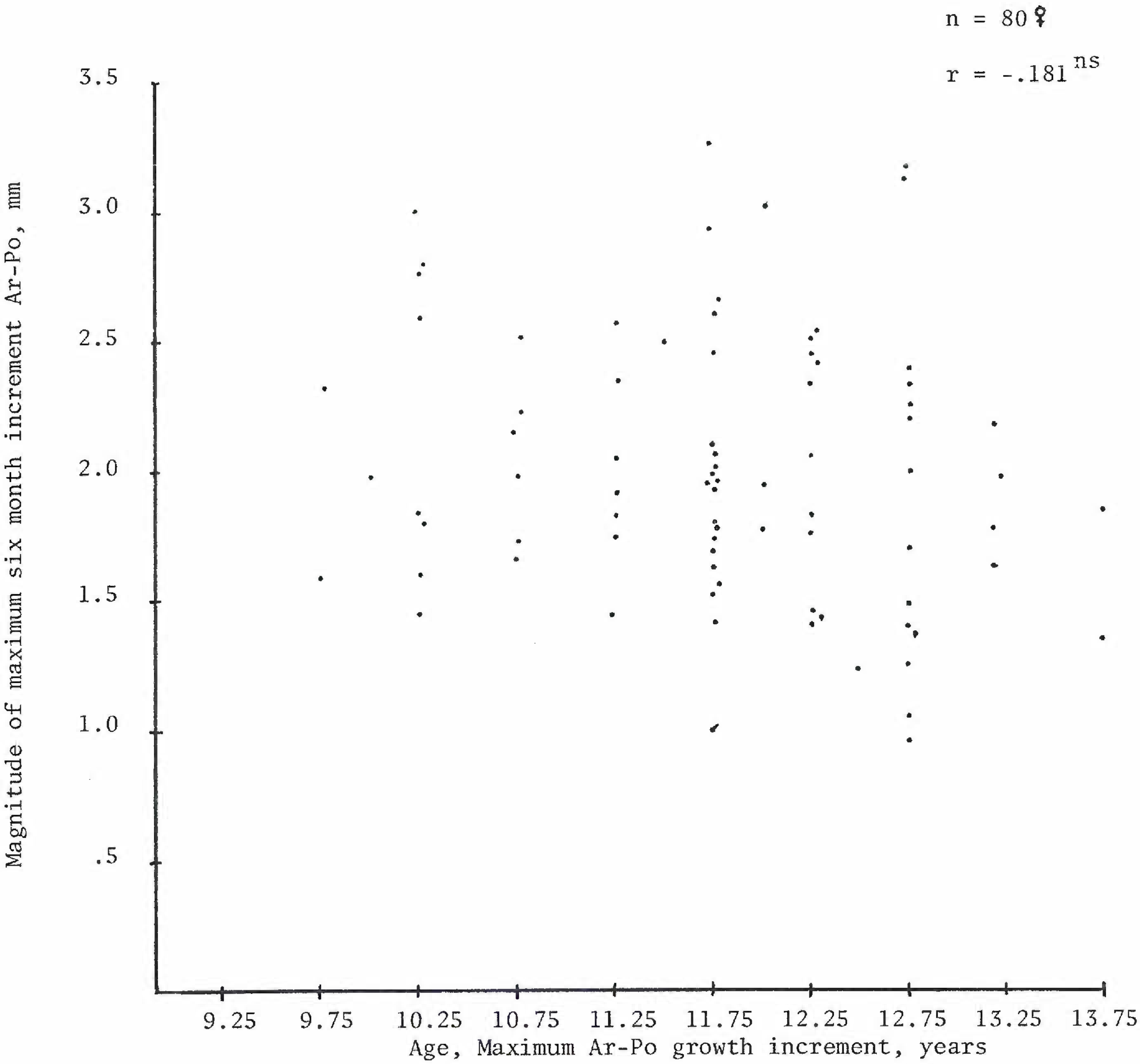


Figure 29, Scattergram, age of maximum growth velocity Ar-Po and total weight at that age.



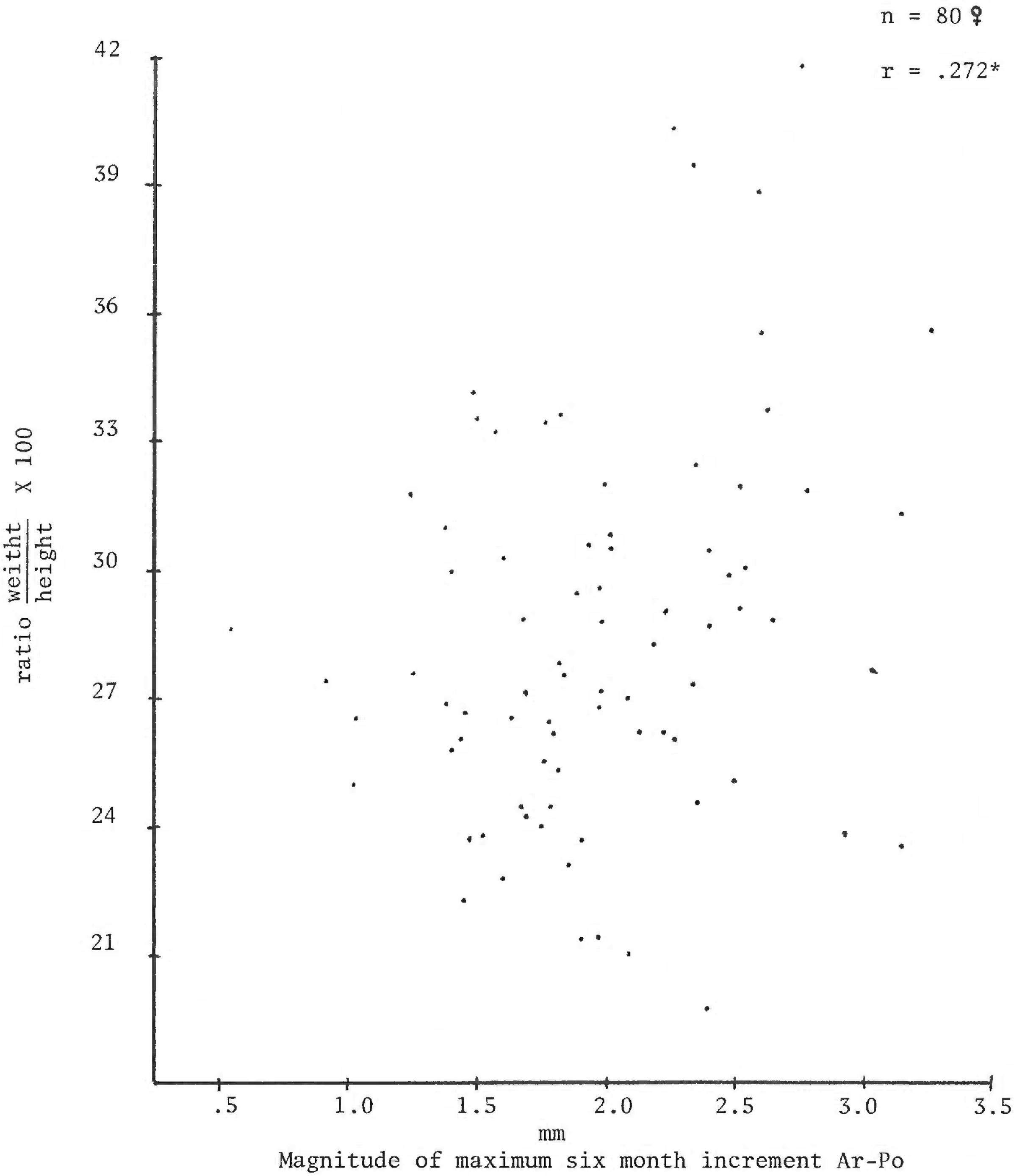
ns not significant

Figure 30, Scattergram of age of peak growth velocity Ar-Po and weight per height x 100 at that age.



ns not significant at the .05 level

Figure 31, Scattergram showing magnitude of maximum six month increment of Ar-Po and age at midpoint of that period.



*significant at the .01 level

Figure 32, Scattergram of the magnitude of the maximum six month increment of Ar-Po and the weight/height ratio at age of maximum growth increment of Ar-Po

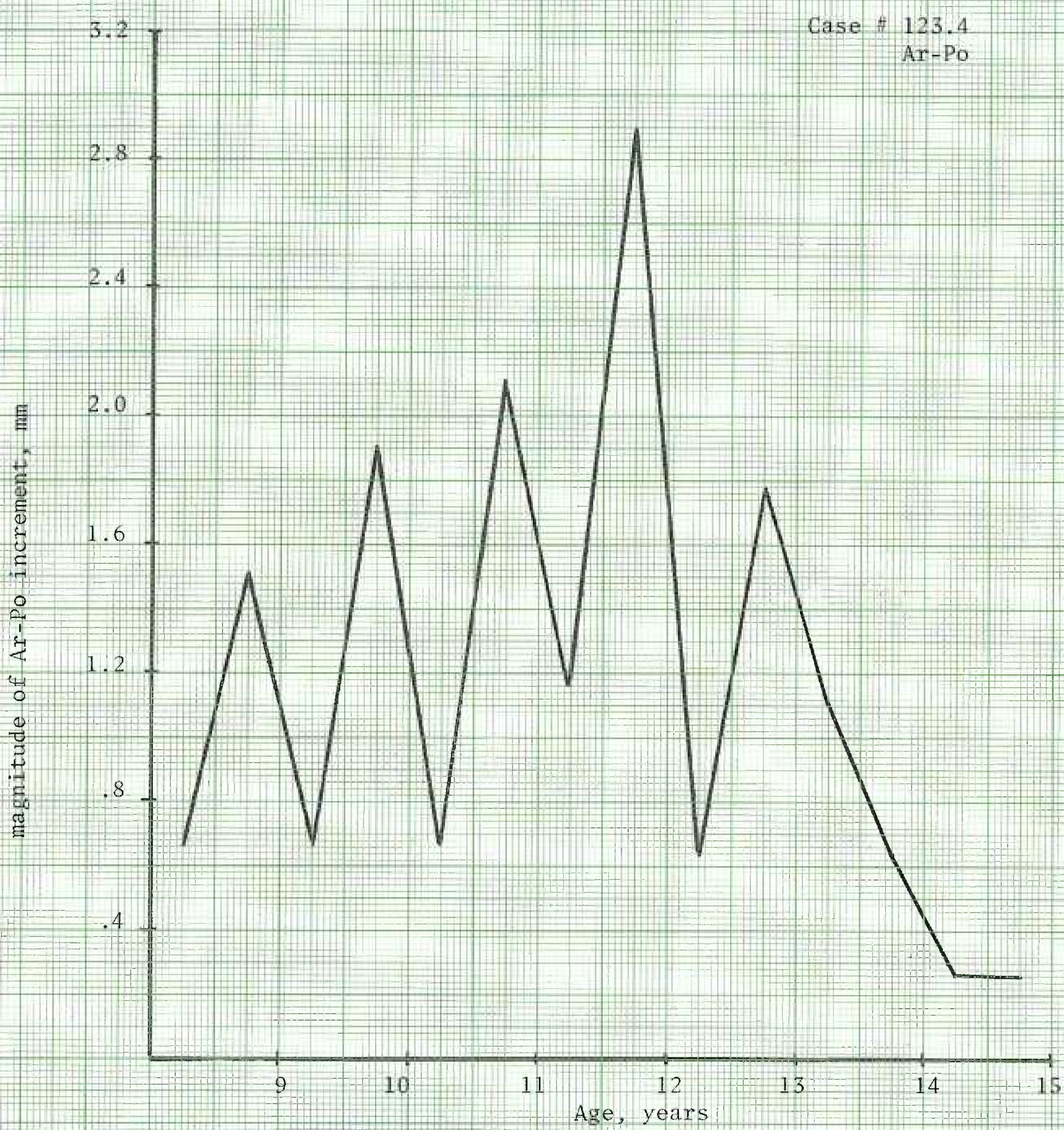


Figure 33, Bi-annual growth increments, Ar-Po.

	Ar-Po	S-Po	N-Po	Co-Po
S.E.Meas.	.26	.29	.47	.53
N	114	114	109	76
paired t	.58[ns]	.39[ns]	1.29[ns]	.47[ns]
mean of differences	.19	.15	.74	.41
S.D. of differences	3.6	4.1	6.0	7.5
degrees of freedom	113	113	108	75

[ns] not significant

Table I. Replicate measure error calculations.

Age of Maximum Growth Velocity, Years

	N	Mean	SD	Range
Height	80	11.53	1.00	9.25-13.75
Weight	80	11.91	1.41	9.50-14.25
Ar-Po	80	11.79	.96	9.75-13.75
S-Po	80	11.87	1.03	9.25-13.75
N-Po	80	11.82	1.12	9.25-13.75
C-Po	78	11.89	1.03	9.75-13.75

Table II. Mean, Standard Deviation and Range of ages of maximum growth increment of Height, Weight, Ar-Po, S-Po, N-Po, C-Po.

	Weight	Ar-Po	S-Po	N-Po	C-Po
Height	.56*	.84*	.77*	.62*	.72*
Weight	-----	.57*	.69*	.58*	.50*

*significant at the .01 level

Table III. Correlation coefficients for ages of maximum growth velocity of Height, Weight, Ar-Po, S-Po, N-Po, C-Po. n = 80

Age of maximum growth velocity of:	N	Mean, years	S.D.	t
Height	80	11.53	1.0	2.24**
Weight	80	11.91	1.14	
Height	80	11.53	1.0	1.68*
Ar-Po	80	11.79	.96	
Weight	80	11.91	1.14	.72 ns
Ar-Po	80	11.79	.96	
C-Po	80	11.89	1.03	.63 ns
Ar-Po	80	11.79	.96	
	N	Mean, years	S.D.	t

** significant at .025 level
 * significant at .05 level
ns not significant

Table IV. Tests of significance for ages of maximum growth velocity.

	N	Mean	SD	Range
Height cm	80	4.40	1.01	.79-8.84
Weight kg	80	4.48	1.62	1.82-12.13
Ar-Po mm	80	1.98	.54	.54-3.27
S-Po mm	80	2.02	.52	.45-3.43
N-Po mm	80	2.01	.64	.41-3.68
C-Po mm	80	2.08	.68	.40-4.82

Table V. Mean, Standard Deviation and Range of the magnitudes of the maximum six month growth increments for Height, Weight, Ar-Po, S-Po, N-Po, C-Po.

	Weight	Ar-Po	S-Po	N-Po	C-Po
Height	-.08	.16	.33*	.18	.38*
Weight	---	-.05	-.09	.05	-.08

*significant at the .01 level

Table VI. Correlation coefficients for magnitude of maximum growth increments of Height, Weight, Ar-Po, S-Po, N-Po, C-Po n = 80

	N	Mean, mm	S.D. mm	Range mm
ɜrowth increment Ar-Po during second year prior to peak growth period	77	1.71	.62	.37-3.21
ɜrowth increment Ar-Po during first year prior to peak growth period	80	2.29	.78	.11-4.68
ɜrowth increment Ar-Po during peak 6 month interval	80	1.98	.54	.54-3.27
ᴉnnual growth rate Ar-Po during peak 6 month interval	80	3.96	1.08	1.08-6.54
ɜrowth increment Ar-Po during first year after peak growth period	79	2.33	.74	.80-4.56
rowth increment Ar-Po during second year after peak growth period	74	1.41	.59	.28-3.21
ize of mandible (Ar-Po) at beginning of second year prior to peak growth period	77	95.4	4.19	87.2-103.3
otal 4 1/2 year growth increment Ar-Po	71	9.80	1.98	5.38-14.98

able VII. Summary of growth of Ar-Po; first and second year before and first and second year after the 6 month peak growth period.

Annual growth velocity Ar-Po	mm 0-.99	1-1.99	2-2.99	3-3.99	4-4.99	5-5.99	6-6.99
second year prior to peak	11	42	13	1			
first year prior to peak	3	27	36	13	1		
during peak*		2	13	31	19	11	4
first year after peak	1	23	41	12	2		
second year after peak	21	40	12	1			

number of individuals

* Maximum 6-month increment expressed as an annual rate.

Table VIII. Summary of distribution of annual growth increment over 4 1/2 year adolescent period

		Early Maturers	Late Maturers
Total weight, in kg, at age of maximum Ar-Po growth increment	mean	42.9	43.6
	S.D.	9.19	8.90
	range	28.5-61.3	26.3-62.3
	degree's of freedom	36	
	t	0.24^{ns}	

Ratio $\frac{\text{weight kg}}{\text{height cm}}$ x 100 calculated at age of maximum Ar-Po growth increment	mean	29.3	28.6
	S.D.	5.6	5.5
	degree's of freedom	36	
	t	0.41^{ns}	

Magnitude of maximum six month increment of Ar-Po, mm	mean	2.12	1.9
	S.D.	.48	.60
	range	1.6-3.0	.94-3.17
	degree's of freedom	36	
	t	1.1^{ns}	

ns = not significant at .05 level

Early maturers - individuals whose age of maximum Ar-Po growth increment $\leq$ 10.75 years N = 17, 21% of the total sample

Late maturers - individuals whose age of maximum Ar-Po growth increment $\geq$ 12.75 years N = 21, 26% of the total sample

Table IX. Means, S.D. and tests of significance between Early and Late maturing individuals for absolute weight, $\frac{\text{weight}}{\text{height}}$ ratio and magnitude of Ar-Po maximum increment.

Age of Maximum Increment of Height

Reported by	Sample Origin	Sex	Mean	S.D.	Range
Present Study	CSC, Portland, Oregon	F	11.53	1.0	9.25-13.75
Anderson et al	Burlington, Ontario	F	11.6		
quoted by Anderson et al	CRC Denver, Colorado	F	12.1		
	BGS Berekeley, Calif.	F	11.6		
	Harvard S.P.H. Mass.	F	11.6		
Backstrom	Finland	F	12-13		
Bayer + Bayley	U.S.	F	11.5		
Boas	New York	F	12.1	1.2	9.5-15.5
Bjork + Helm	Denmark	F	12.5	.84	11.2-14.3
Bowden	Melbourne	F	11.67	1.01	9.5-13.6
Brown et al	Australian Aborigines	F	12.0	1.2	
Grave	Australian Aborigines	F	11.8	1.2	11.4-12.5
Hunter	CRC Denver, Colorado	F	11.8	1.31	8.75-13.75
Pileski et al	Burlington, Ontario	F	11.97	1.02	8.7-14.5
Thompson et al	Burlington, Ontario	F	11.36	1.12	
Tracy + Savara	CSC Portland, Oregon	F	11.1-12.1		

Age of Maximum Increment of Weight

Reported by	Sample Origin	Sex	Mean	S.D.	Range
This Study	CSC Portland, Oregon	F	11.91	1.14	9.50-14.25
Anderson et al	Burlington, Ontario	F	12.2		
quoted by Anderson et al	CRC Denver, Colorado	F	12.3		
	Harvard S.P.H. Mass.	F	12.0		
	BGS Berekeley, Calif.	F	12.0		
Backstrom	Finland	F	13-14		
Bayer + Bayley	U.S.	F	12.5		

Table X. Review of previous investigators, ages of maximum increment of Height and Weight

Age of Maximum Growth Increment of Mandibular Length

Reported by	Sample Origin	Sex	Mean	S.D.	Range
This Study	CSC Portland, Oregon	F	11.79	.96	9.75-13.75
Brown et al	Australian Aborigines	F	12.00	1.10	
Fukuhara	"average" Japanese	F	11.50		
Pileski et al	Burlington, Ontario	F	11.97	1.02	8.70-14.50
Thompson et al	Burlington, Ontario	F	11.40	1.35	
Tracy + Savara	CSC Portland, Oregon	F	11.1-12.1	.92	
Woodside	Burlington, Ontario	F	12.00	1.60	
Bergersen	CRC Denver, Colorado	M	14.15	1.08	
Fukuhara	"average" Japanese	M	12.50		
Grave	Australian Aborigines	M	13.80	1.10	
Pileski et al	Burlington, Ontario	M	13.94	1.26	11.1-16.5
Savara + Tracy	CSC Portland, Oregon	M	13.60	1.83	

Table XI. Review of previous investigators, age of maximum increment of mandibular length (Ar-Po, C-Po, C-Sym, etc.)