CHAPTER 3

NEW 3D NORMATIVE REFERENCES FOR CRANIOFACIAL MORPHOLOGY IN MALAYSIAN MALAYS

3.1 Introduction

The need for normative craniofacial data as reference standards for sound diagnosis, disease evaluation and treatment of craniofacial abnormalities is widely recognised. Prior to the development of cephalometric radiography, normative data derived from direct measurements on hard and soft tissues of the skull, face and dentition were used extensively. Direct measurements are relatively easy to make, without the need for complicated equipment, and are still being used nowadays. The advent of cephalometric radiography (Broadbent, 1931; Hofrath, 1931) has provided a more sophisticated analytical tool for patient management, particularly in orthodontics and surgery, but also for research purposes. Radiographic records can be kept and used repeatedly for research projects years after their initial collection, such as the Aboriginal records from the Yuendumu Growth Study that are stored in the Murray Barrett Laboratory, School of Dentistry, University of Adelaide (Campbell, 1925; Brown, 1965).

Cephalometric normative data from different parts of the world have been published and used as reference material, especially in orthodontics (Riolo *et al.*, 1974; Broadbent *et al.*, 1975; Bhatia and Leighton, 1993; el-Batouti *et al.*, 1994; Axelsson *et al.*, 2003). These data usually consist of a selection of linear and angular measurements presented in tabular and graphical forms. They have also been collected longitudinally, often at yearly intervals, allowing the study of craniofacial morphology of individual subjects during their growth period. Thus, cephalometric radiography has the ability to offer very useful information about growth processes that is needed when treating growing patients.

Craniofacial norms are known to vary widely between different ethnic groups. Previous investigations have shown that there are differences in craniofacial form between ethnic groups (Altemus, 1960; Drummond, 1968; Nanda and Nanda, 1969; Kowalski *et al.*, 1975; Harris *et al.*, 1977). Researchers have indicated that findings from one ethnic group cannot be applied to other ethnic groups. Moreover, differences between sexes (Riolo *et al.*, 1974; Bhatia and Leighton., 1993) and across different ages (Riolo *et al.*, 1974; Broadbent, *et al.*, 1975; Bishara, 1981) have also been documented. It is now recognised that use of a single standard of normative craniofacial data is not appropriate when making diagnostic and treatment planning decisions for patients from different ethnic backgrounds.

Most normative craniofacial data have been generated for people of European ancestry. As far as the Malay ethnic group is concerned, no published craniofacial norms are available. The most suited data for Malays up until now were supplied by Lew (1994) and Munandar and Snow (1995). However, the study by Lew (1994) did not really provide norms because the methodology only selected ‘ideal’ faces for generation of cephalometric ideals for the three major ethnic groups in Singapore. Moreover, the study performed by Munandar and Snow (1995) for Indonesian Malays may not be applicable to Malaysian Malays because of their different geographical and cultural backgrounds. Data were collected in Jakarta, the capital of Indonesia, which is very urban and may include people from all over Indonesia which is comprised of thousands of islands that vary in environmental status and cultural practices. Additionally, some limited information on normal values of upper eyelid and eyebrow dimensions in Malays, mainly for the purpose of cosmetic eyelid surgery, was provided by Dharap and Reddy (1995).

More recently, computed tomography (CT) which was pioneered by Cormack and Hounsfield (Cormack, 1979; Hounsfield, 1980) has allowed comprehensive imaging of the whole craniofacial complex. CT enables visualisation of the tissue of interest in sequential layers without the problem of superimposition. This technology is further enhanced by computer software that allows three-dimensional reconstructions of the CT slices, allowing life-like visualisation of the skull and face for measuring purposes. CT has provided new tools for medical investigation and has been widely used for pre- and post-operative imaging when evaluating patients with craniofacial abnormalities. Because of this, there is a need to develop CT craniofacial reference data so that abnormalities can be compared to base-line data to facilitate more accurate diagnosis and treatment planning for affected patients. When this study was commenced in 2001, normative craniofacial data in 3-dimensions derived from CT technique were not available. There was a report concerning normal values derived from CT but measurements were made on CT slices that only covered the upper aspect of the face and no 3D reconstructions of the slices were generated (Waitzman *et al.*, 1992).

3.2 References or Standards

When reference data are obtained from healthy subjects for growth assessment, excluding subjects with growth disorders or disturbances, then the data can be referred to as standards (Cameron, 2002). While it may be advantageous to restrict a reference population to healthy individuals, it can be contentious because it is difficult to then assess the growth of those subjects who have been excluded. Standards will be biased to some extent because they have been generated according to the arbitrary definition of “health”. For example, should subjects with asthma or renal disease be included as these conditions affect growth in some subjects but not others.

Data based on an unselected population can be called references. For growth assessment in the developed world it is simpler to use references rather than standards, so that all children are eligible for inclusion in the reference data set, irrespective of health status. In practice, the proportion of children excluded on health grounds is generally small. The subjects in the reference sample should be selected from the target population in a way that ensures generalisation, ideally by random sampling. A random sample can be collected either by simple random sampling or by a complex multistage design involving clusters or strata (Cameron, 2002).

For this study, it is appropriate to refer to the data collected as references. The potential source of data were subjects presenting with a broad range of medical conditions that necessitated CT investigations, but these conditions were not associated with obvious abnormalities in craniofacial growth and morphology (Section 2.5.1).

3.3 Types of Growth Studies

Growth studies may be cross-sectional, longitudinal or mixed longitudinal.

3.3.1 Cross-sectional Studies

This is the most common growth study design. It involves collecting data on subjects over a range of ages, each subject contributing to a measurement only once. It is conventionally called a growth survey but contains no information about growth as each subject is seen only once. An attempt is made to include as many subjects as possible at each age level while growth is progressing. Each child in the study provides only one datum but statistics for the selected measurement at each age can be calculated from the sample.

Statistical comparisons of human craniofacial growth patterns derived from cross-sectional and longitudinal data sets, using materials collected from Bolton-Brush study (Broadbent *et al.*, 1975; Richtsmeier *et al.*, 2000), have shown that significant differences in facial growth patterns were only evident in the earliest age intervals spanning the period between 6 months and 3 years. Growth patterns occurring from 3 to 18 years were similar among all age-matched longitudinal and cross-sectional samples. Moreover, the cross-sectional average measures stayed within the limits of the longitudinal data even though cross-sectional data could not characterise the various patterns of growth seen in the longitudinal data sets. The researchers concluded that cross-sectional studies can assess trends and provide valid representations of growth patterns, defined as geometric changes in structure occurring over time (Richtsmeier, *et al.*, 2000). However, cross-sectional study designs are unable to provide knowledge of growth rates and information about growth in an individual subject. An advantage of the cross-sectional design is that these studies are relatively easy to conduct and can be completed more quickly and with less expense than longitudinal studies.

3.3.2 Longitudinal Studies

To assess growth, a study needs to measure subjects more than once and this can be achieved by a longitudinal study design. Subjects are measured at regular intervals, usually annually, throughout the growth period. More frequent observations should be made at times of rapid growth such as at puberty. When a full set of growth data are available they can be analysed with specialised statistical techniques to obtain detailed information on the timing and magnitude of growth velocities, as well as the distance achieved at each age level. The technique of curve fitting is often employed to estimate the growth parameters for each child.

These studies provide information on individual growth patterns and variation in growth patterns. Growth information offered by this design, even when only a small number of subjects can be recruited, is far more valuable than the cross-sectional design. However, longitudinal studies are usually extremely expensive and cover longer periods of time. An ideal longitudinal study would extend from birth to young adulthood and would require a reasonable number of males and females to remain in the study until completion. Problems faced by this type of study include loss of participants and loss of key members in the research team.

3.3.3 Mixed Longitudinal Studies

When only some of the subjects in a longitudinal study are measured again the study becomes mixed longitudinal. This study design may also involve performing measurements on subjects in selected different age groups at the same time. Each age cohort will be studied for successive years overlapping observations in another age group. One of the reasons these studies are performed is to shorten the span of the study so that it will not take as long as pure longitudinal studies. Population standards can be developed at each age level and growth velocities and patterns can be estimated from the longitudinal records. Many originally planned longitudinal growth studies become mixed longitudinal because of subject fall-out or enrolment of new subjects at later stages of the study.

In the present study, records could only be obtained once because CT investigation involves high radiation exposure to patients. Therefore, a cross-sectional study design was more suitable. Patterns of changes between measurements obtained at different age intervals will be described.

3.4 Standardisation of Methods

During the nineteenth century, before x-rays were available, the need for standardisation of the methods used in craniometry was realised and became an important issue. Broca and Topinard constructed early forms of craniostats to achieve reproducible results when comparing head forms (Finlay, 1980). Due to the need for standardisation, many bodies and organisations have met to better define points and planes to be used and also to try to agree on common methods of measurement. The most important meeting concerning this matter was the 13th General Congress of the German Anthropological Society held in Frankfurt-am-Maine in 1882 where the Frankfurt agreement was achieved to define craniofacial landmarks and planes. Following this meeting, Rudolf Martin published a reference book with very detailed craniometric instructions including alternative methods of measurements (Martin, 1914).

In 1895, x-rays were discovered by Professor Wilhelm Conrad Roentgen and they began to be used widely in the field of medicine. The use of x-rays provided the means of obtaining a different perspective on the arrangement and relations of bones, thus expanding the horizons of craniometry and cephalometry. Attempts at using x-rays initially led to the same problems of reproduction of results as occurred with direct measurements.

In 1931, Hofrath and Broadbent separately invented equipment, referred to as the cephalostat, for positioning the head in relation to the x-ray source and the film prior to exposing the film. Therefore, images could be captured in a standardised fashion so that they could be compared over time for an individual or comparisons could be made of measurement values from different subjects. Cephalometric radiography has been widely used ever since as a descriptive, analytical and diagnostic tool in the field of orthodontics and in research.

As with earlier radiographic methods, obtaining CT scan images also requires a standardisation process. This is explained in Section 2.6.3.

3.5 Concepts of Human Growth

Different tissues and systems of the body display differential growth. This differential growth is well-demonstrated by Scammon’s growth curves (Tanner, 1962) which display four major types of growth in the human body.

These are:

- General or somatic growth as displayed by skeletal tissues, muscles and the body, involving measurements such as body height, weight and some facial dimensions.
- Lymphoid growth pattern displayed by the thymus gland, lymph nodes and various lymphoid tissues of the body.

- Neural growth pattern of the brain, spinal cord, peripheral sense organ and cranial vault that holds the brain and which show rapid growth in childhood that is almost complete by the age of eight years.
- Reproductive growth pattern of the reproductive system that is very slow in childhood and very rapid from adolescence until adulthood.

Differential growth patterns can also be observed in the head which account for the changing proportions between the cranial vault (neurocranium) and the facial skeleton (visceral organs) from birth to adulthood. At birth, the skull is large relative to the face and represents more than half of the total head. In contrast, the face is still rudimentary at this stage (Proffit and Fields, 1993). The orbit appears large, the maxilla small and the mandible is retruded. The skull grows rapidly during early childhood and almost reaches adult size by age 8 years. The face grows and develops markedly from childhood to adulthood not only in size but also accompanied by shape changes (Enlow, 1990).

Additional patterns can be observed in general growth of the body, namely a juvenile or mid-growth spurt, identified as a slight increase in velocity at about 7 to 8 years, and an adolescent growth spurt which is recognised as a marked increase in growth velocity at about 13 to 15 years. The adolescent growth spurt is observed in all children but a great deal of individual variations in timing, intensity and duration occurs. It occurs in most skeletal tissues including the face and jaws. On average this event takes place nearly two years earlier in girls than in boys (Profitt and Fields, 1993).

Growth of the body, craniofacial structures included, is influenced by genetic factors as well as environmental influences. Variation within and between populations results from complex interactions between genetic and environmental factors operating during the formation and growth of these structures.

This research project was initiated to provide a three-dimensional description of craniofacial morphology and growth changes in normal Malaysian Malays. These 3D data will serve as comprehensive normative references for Malaysian Malays and this is the first time that such references have been constructed.

The specific objectives of this section of the thesis are:

- To construct 3D normative references for selected linear and angular craniofacial variables in Malaysian Malays at different age groups from birth to adulthood.
- To quantify patterns of growth changes for selected linear and angular craniofacial variables from birth to adulthood.

3.6 Materials and Methods

The methods of data collection have already been outlined in Chapter 2.

3.6.1 Data Collection

The sources of patients selected for this study, the breakdown by age categories and sex, and the problems encountered in collecting this information are detailed in Section 2.5.

3.6.2 CT Protocol

Axial scans were obtained with a GE Lightspeed Plus CT Scanner System at the Department of Radiology, Hospital Universiti Sains Malaysia. The protocol used is detailed in Section 2.6.3.

3.6.3 Craniofacial Variables

Craniofacial variables were categorised into various regions of the face, cranial base and cranial vault. The face was further categorised into separate major structures, i.e. the orbit, maxilla, zygoma and mandible. Width or distance, height and length measurements were recorded for all major structures. A few variables that represented inter-regional dimensions were also defined, as well as a few angular variables and indices.

The linear variables, angles and indices are represented diagrammatically in Figures 2.7 to 2.21 and defined in the legends of the figures in Section 2.6.9.

3.6.4 Statistical Analysis

The results of this section are descriptive in nature and are summarized in graphical and tabular formats. Descriptive statistics such as mean values and standard deviations were calculated for each age category, and standard errors of the mean were also calculated.

3.6.5 Curve Fitting

Graphs are presented separately for males and females for the linear variables. A second graph showing a magnification of the first graph for the age interval from 0-5 years is also presented. Values for every subject corresponding to their age were plotted in the form of scatter plots. Males and females were differentiated by using different symbols in the plots.

Individual points in the scatter plots have been preserved for presentations and no line smoothing was performed. A line that best fit the data and lines at ± 2 standard deviations were constructed and fitted to the plots. These lines were calculated following Abbott *et al.* (1998) with a three parameter monomolecular non-linear curve fitting model being utilised to create a parametric representation of the data according to the following formula:

$$y=a(1-e^{-k(x-b)})$$

These three parameter curves pass through y=0 at x=c and increase asymptotically to y=a controlled by the rate constant k. A reparameterisation of this equation in terms of expected values is given by:

$$y=y_1+(y_2-y_1)\{1-[(y_2-y_3)/(y_3-y_1)]^q\}/(1-[(y_2-y_3)/(y_3-y_1)]^2)$$

where $q=2(x-x_1)/(x_2-x_1)$ and the parameters to be estimated y_1, y_2, y_3 are the values of y at $x=x_1$, $x=x_2$, and $x=(x_1+x_2)/2$

These lines were constructed for graphical purposes and they are best considered to represent the trends in mean values and standard deviations rather than as growth curves.

Trends in angular variables and indices were represented by simple straight lines as the data showed linear changes with age.

3.6.6 Errors of the Method

The methods for quantifying errors in landmark localisation and measurement of anthropometric variables derived from these landmarks are outlined in Section 2.8.4. Systematic errors in landmark location were assessed using Hotelling's T^2 statistic. For anthropometric variables, Student's paired t-tests were used to detect systematic errors (i.e. to ascertain whether the mean difference between repeated measures deviated significantly from zero) and Dahlberg's (1940) method of double determination was used to quantify the magnitude of random errors.

3.6.7 Data Cleaning Process

Once data have been collected, they cannot be immediately analysed. An important preliminary stage includes looking at the data to search for errors of measurements or coding and then to correct them. These errors can seriously affect the validity of any analyses. In this study, the data cleaning process took place in several stages.

Initial data cleaning occurred directly after landmark determination for each bone in every patient. This was achieved by viewing and superimposing a wire-frame model over the 3D-CT reconstructions for validation of the landmark position. Separate bones could be selected from a *Wire Selection* menu to view their outlines (Figure 2.6 in Section 2.6.7). This wire-frame facility incorporated into the PERSONA software provided a method of checking for major errors in identification of landmarks. Obvious errors occasionally occurred that were detectable by wire-frame superimposition, e.g., errors in saving landmarks into landmark files and sometimes mistaking left and right landmarks.

The author also calculated z-scores for each measurement from each person to compare with the mean from their respective age categories. This was done following the formula:

$$z = \frac{|x_i - \bar{x}|}{sd}$$

Z-scores with values of 3 or larger were considered as possible outliers and were rechecked.

Finally, data cleaning was performed by viewing the scatter plots for each variable against age, fitted with best fit lines and standard deviation lines below and above the average. Occasionally, points were noted that lay outside the 2 standard deviation lines. These measurements were re-examined and adjusted if necessary.

3.7 Results

For each linear variable, results are presented in tabular and graphical forms separately for males and females. For angular variables and indices, the graphs are combined for both sexes with males and females represented by different symbols. The graphs are in scatter plot format with measurement values plotted against age. Each point on the plots represents a subject. For linear variables, magnified graphs representing measurements up to age five years are also presented.

Mean values, standard deviations, and minimum and maximum values are presented in the tables. The subjects are categorised into age intervals as follows; 0-1 years, 1-3 years, 3-5 years, 5-10 years, 10-12 years, 12-14 years, 14-16 years, 16-18 years, 18-25 years for the linear variables. The reason for presenting the tables in this manner was because the most active growth occurred in the first 5 years. Between 10 and 18 years, small age intervals were again selected to capture any evidence of acceleration of growth that corresponded to the adolescent growth spurt. For angular variables and indices, the subjects were categorised into 5-year age intervals, i.e. 0-5 years, 5-10 years, 10-15 years, 15-20 years and 20-25 years. These results are presented in Figures 3.1 to 3.114 and Tables 3.1 to 3.114.

Another set of tables is also presented for linear variables to demonstrate the percentage of adult size achieved by the age of one and five years for each craniofacial region. The age interval of 0 to 1 year is referred as one year, the age interval of 3 to 5 years is referred as 5 years, and the age interval of 18 to 25 years is referred as adult. Percentage of adult size obtained was calculated by dividing the mean value for the measurement variable in question by the mean value at the age interval of 18 to 25 years. These results are presented in Tables 3.115 to 3.122.

Cranial vault

Cranial vault measurements showed that 70 to 80% of adult size was achieved by one year of age and this increased to between 90 and 97% by the age of 5 years. An exception to this was interporion width (*po.l-po.r*) which only achieved 58.8% of adult size by the age of one year and 84.3% by the age of 5 years. Measurements of posterior cranial vault height (*l-br*) reached the highest percentage of adult size at one year and five years of age. The graphs followed neural growth patterns where the fitted lines levelled off beyond the age of 5 years for most measurements.

For all cranial vault measurements, the greatest size increments were between 0 and 3 years of age. For males, subtle increments in size can be observed between some of the measurements obtained between 5 to 10 years and 10 to 12 years; and between 14 to 16 years and 16 to 18 years. These include measurements of maximum cranial width (*cindx.l-cindx.r*), cranial height (*ba-br*), left and right lateral cranial vault height (*br-po.l*, *br-po.r*), anterior cranial vault height (*n-br*) and posterior cranial vault height (*l-br*). Size increments occurred earlier for lambdoid height (*l*-*o*), between the ages of 3 to 5 years and 5 to 10 years, but no obvious increments of size differences were noted between other age intervals. In contrast, left and right lateral cranial vault length measurements (*spc.l*-*as.l, spc.r*-*as.r*) did not exhibit increments in size at earlier ages but only between age intervals of 14 to 16 years and 16 to 18 years. Additionally, no obvious increments of size between the age intervals were observed for maximum cranial length (*cindxa*-*cindxp*).

For females, some variables showed increments of size that could be observed between 3 to 5 years and 5 to 10 years; and between 14 to 16 years and 16 to 18 years. These were measurements for maximum cranial width (*cindx.l*-*cindx.r*), interasterion width (*as.l*-*as.r*), interporion width (*po.l*-*po.r*) and left and right lateral cranial vault length (*spc.l*-*as.l, spc.r*-*as.r*). Posterior cranial vault height (*l*-*br*) and lambdoid height (*l*-*o*) measurements showed increment in size between the ages of 3 to 5 years and 5 to 10 years only. Cranial height (*ba*-*br*) and anterior cranial vault height (*n*-*br*) measurements displayed increments in size between age intervals 10 to 12 years and 12 to 14 years. No obvious increments of size between age intervals were observed for maximum cranial length (*cindxa*-*cindxp*) and left and right lateral cranial vault height (*br*-*po.l, br*-*po.r*).

Cranial base

For cranial base measurements, 53 to 78% of adult sizes were obtained by one year of age and this increased to between 70 and 93% by the age of 5 years. An exception to this was foramen magnum length (*ba*-*o*) which had already achieved 87.7% of adult size by the age of one year and had completely attained adult size by the age of 5 years. The smallest percentages of adult size attained at one and five years were for measurements of left and right spheno-occipital synchondrosis (*pts.l*-*petsa.l, pts.r*-*petsa.r*).

Generally all graphs for cranial base variables followed a neural growth pattern but two obvious variations were noted. Some measurements showed that certain cranial base structures were growing rapidly during the first 3 years but, instead of levelling off, they kept on growing until adulthood. Cranial base measurements that showed this pattern included anterior cranial base width (*spa.l-spa.r*), anterior clinoid width (*ac.l-ac.r*), superior spheno-occipital synchondrosis width (*petsa.l-petsa.r*), inferior spheno-occipital synchondrosis width (*pts.l-pts.r*), external cranial base width (*ss.l-ss.r*), left and right anterior cranial fossa length (*sor.l-spa.l, sor.r-spa.r*), left and right spheno-occipital synchondrosis length (*pts.l-petsa.l, pts.r-petsa.r*), inferior posterior cranial base length (*ba-h*), cranial base length (*ba-n*), posterior cranial base length (*ba-s*) and anterior cranial base length (*s-n*).

Another pattern involved measurements that showed rapid growth for the first 3 years and then a levelling off beyond five years of age. Cranial base measurements that showed this pattern were posterior cranial fossa width (*pept.l-pept.r*), foramen magnum width (*fmlhg.l-fmlhg.r*), left and right lateral middle cranial fossa length (*spa.l-pept.l, spa.r-pept.r*), left and right petrous ridge length (*petsa.l-pept.l, petsa.r-pept.r*) and foramen magnum length (*ba-o*). All cranial base variables that displayed this pattern had reached between 91 to 94% of adult size by age five years, with foramen magnum length already achieving adult size at this stage, as noted earlier.

Most cranial base measurements displayed the greatest size increments between the 0 and 3 years age intervals. For males, some variables showed greater size differences between 3 to 5 years and 5 to 10 years. Variables that exhibited this pattern included anterior cranial base width (*spa.l-spa.r*), anterior clinoid width (*ac.l-ac.r*), inferior spheno-occipital synchondrosis width (*pts.l-pts.r*) and posterior cranial fossa width (*pept.l-pept.r*). Measurements of cranial base length (*ba-n*) and posterior cranial base length (*ba-s*) showed increased size changes between the ages of 5 to 10 years and 10 to 12 years. Increased size differences also occurred between the ages of 10 to 12 years and 12 to 14 years. This was found for measurements of posterior cranial fossa width (*pept.l-pept.r*), external cranial base width (*ss.l-ss.r*), foramen magnum width (*fmlhg.l-fmlhg.r*), left and right lateral middle cranial fossa length (*spa.l-pept.l*, *spa.r-pept.r*), left and right petrous ridge length (*petsa.l-pept.l*, *petsa.r-pept.r*) and anterior cranial base length (*s-n*). Other measurements were associated with size changes between the ages of 12 to 14 years and 14 to 16 years, including measurements for left and right anterior cranial fossa length (*sor.l-spa.l*, *sor.r-spa.r*). Moreover, no obvious increments of size between the age intervals were observed for superior spheno-occipital synchondrosis width (*petsa.l-petsa.r*), left and right spheno-occipital synchondrosis length (*pts.l-petsa.l, pts.r-petsa.r*) and foramen magnum length (*ba-o*).

For females, variables showed size differences at various age intervals. For example, between 3 to 5 years and 5 to 10 years for measurements of superior spheno-occipital synchondrosis width (*petsa.l-petsa.r*), inferior spheno-occipital synchondrosis width (*pts.l-pts.r*) and posterior cranial fossa width (*pept.l-pept.r*), external cranial base width (*ss.l-ss.r*), left and right lateral middle cranial fossa length (*spa.l-pept.l, spa.r-pept.r*), left and right petrous ridge length (*petsa.l-pept.l*, *petsa.r-pept.r*), left and right spheno-occipital synchondrosis length (*pts.l-petsa.l, pts.r-petsa.r*) and posterior cranial base length (*ba-s*). Measurements of anterior cranial base width (*spa.l-spa.r*) showed increased size changes between the age intervals of 5 to 10 years and 10 to 12 years and, again, between the ages of 14 to 16 years and 16 to 18 years. Cranial base length (*ba-n*) and anterior cranial base length (*s-n*) displayed increased size differences between the ages of 10 to 12 years and 12 to 14 years. Increased size differences were also noted between the ages of 14 to 16 years and 16 to 18 years for external cranial base width (*ss.l-ss.r*) and foramen magnum width (*fmlhg.l-fmlhg.r*). No obvious increments of size between the age intervals were noted for foramen magnum length (*ba-o*).

Orbital region

Orbital measurements revealed that 60 to 77% of adult size was achieved by the age of one year and this increased to between 76 and 93% at the age of 5 years. Interorbital width (*morfl.l-morfl.r*) and left and right orbital heights (*sor.l-or.l, sor.r-or.r*) attained about 77% of adult size at the age of one year. Orbital length and other orbital width measurements showed similar size attainment at this age. At five years of age, orbital height measurements (*sor.l-or.l, sor.r-or.r*) had reached 93% of adult size. Orbital length measurements had obtained between 87 to 93% of adult size at this age and orbital width measurements had reached 76 to 89% of adult size. The smallest percentage of adult size achieved at one to five years was for posterior orbital width (*ofa.l-ofa.r*).

With the exception of interorbital width (*morfl.l-morfl.r*), the plots for orbital width showed rapid growth of structures during the first 3 years but, instead of levelling off, the structures kept on growing until adulthood. These measurements included anterior superior orbital width (*sor.l-sor.r*), maximum orbital width (*lor.l-lor.r*), anterior inferior orbital width (*or.l-or.r*), posterior orbital width (*ofa.l-ofa.r*) and left and right orbital distances (*lor.l-morfl.l, lor.r-morfl.r*).

Interorbital width (*morfl.l-morfl.r*) followed another pattern noted whereby structures showed rapid growth for the first 3 years and then a levelling off beyond five years of age. This can be seen in the graphs for orbital height and orbital length measurements.

Orbital variables showed increased size differences at various age intervals. For males, increased size differences between 3 to 5 years and 5 to 10 years were observed for left and right orbital distances (*lor.l-morfl.l, lor.r-morfl.r*). There were also variables that displayed increased size changes between the ages of 5 to 10 years and 10 to 12 years. Variables that exhibited this pattern included left inferior orbital length (*ofa.l-or.l*), left and right medial orbital lengths (*ofa.l-morfl.l, ofa.r-morfl.r*) and left lateral orbital length (*ofa.l-slor.l*). Measurements of anterior superior orbital width (*sor.l-sor.r*) and left orbital height (*sor.l-or.l*) showed increased size changes between the ages of 10 to 12 years and 12 to 14 years. No obvious size differences between age intervals were noted for interorbital width (*morfl.l-morfl.r*), maximum orbital width (*lor.l-lor.r*), anterior inferior orbital width (*or.l-or.r*), posterior orbital width (*ofa.l-ofa.r*), right orbital height (*so.r-or.r*), left and right superior orbital lengths (*ofa.l-sor.l, ofa.r-sor.r*), right inferior orbital length (*ofa.r-or.r*) and right lateral orbital length (*ofa.r-slor.r*).

Most size differences in females were observed between the ages of 5 to 10 years and 10 to 12 years. Variables that displayed this pattern included maximum orbital width (*lor.l-lor.r*), posterior orbital width (*ofa.l-ofa.r*) and left and right orbital heights (*sor.l-or.l*, *so.r-or.r*). There were some variables that displayed increased size changes between the ages of 3 to 5 years and 5 to 10 years, namely anterior inferior orbital width (*or.l-or.r*) and right inferior orbital length (*ofa.r-or.r*). Measurements of left inferior orbital length (*ofa.l-or.l*) and left and right medial orbital lengths (*ofa.l-morfl.l, ofa.r-morfl.r*) showed increased size changes between the ages of 10 to 12 years and 12 to 14 years. No obvious increments of size differences between the age intervals were noted for anterior superior orbital width (*sor.l-sor.r*), interorbital width (*morfl.l-morfl.r*), left and right orbital distances (*lor.l-morfl.l, lor.r-morfl.r*), left and right superior orbital lengths (*ofa.l-sor.l*, *ofa.r-sor.r*), and right lateral orbital length (*ofa.r-slor.r*).

Nasal region

Nasal width measurements achieved 70 to 97% of final adult size at the age of one year and between 90 and 97% at the age of 5 years. Nasal length and height measurements showed similar size attainment at both ages relative to adult size. At age one year, the percentages of adult size obtained for nasal height and length measurements were between 47 and 51% respectively, and at five years these attainment were between 67 and 77%.

The graphs for nasal width measurements revealed rapid growth for the first 3 years and then a levelling off beyond five years of age. Moreover, the graph for superior nasal width (*snm.l-snm.r*) measurement was flat without showing visible size increments from birth to adulthood.

Graphs for nasal height and length variables showed rapid growth during the first 3 years but the structures seemed to keep on growing until adulthood with the slopes for these graphs being quite steep.

Nasal length and height variables showed increased size differences at various age intervals. No evidence of increased size differences between the age intervals was noted for nasal width variables. For males, most of the greater size differences were observed to occur between 5 to 10 years and 10 to 12 years. Variables that displayed this pattern included left and right naso-maxillary suture lengths (*inm.l-snm.l, inm.r-snm.r*), left and right nasal heights (*n-al.l, n-al.r*), posterior nasal height (*pns-h*) and nasal bone length (*na-n*).

For females, increased size differences were observed to occur mainly between the 3 to 5 years and 5 to 10 years age intervals. These variables included left and right naso-maxillary suture lengths (*inm.l-snm.l, inm.r-snm.r*), left and right nasal heights (*n-al.l, n-al.r*), nasal aperture height (*na-ans*) and nasal bone length (*na-n*). No evidence of increased size differences between the age intervals was noted for posterior nasal height (*pns-h*).

Maxilla

Percentages of adult size gained at one year of age for maxillary variables ranged from 57 to 63% for width, 35 to 53% for height, and 49 to 53% for maxillary length. At age five years, these percentages of adult size attainment were in the range of 70 to 80% for width, 70 to 83% for height, and 69 to 81% for length.

Graphs for maxillary variables showed rapid growth of structures during the first 3 to 5 years without levelling off, so that the structures appeared to grow constantly until adulthood.

As with variables in other regions of the skull and face, maxillary variables exhibited increased size differences at various age intervals. For males, most of the increased size differences were observed to occur between 5 to 10 years and 10 to 12 years. Variables that displayed this pattern included maximum maxillary width (*zmi.l-zmi.r*), anterior upper face height (*n-ans*), left and right posterior maxillary heights (*mxt.l-ms.l, mxt.r-ms.r*), left and right anterior zygo-maxillary suture lengths (*or.l-zmi.l, or.r-zmi.r*), left and right naso-maxillary suture lengths (*inm.l-snm.l, inm.r-snm.r*) and left and right inferior maxillary lengths (*mxt.l-pr, mxt.r-pr*). Increased size differences were noted to occur between the age of 3 to 5 years and 5 to 10 years for posterior superior maxillary width (*ms.l-ms.r*) and posterior inferior maxillary width (*mxt.l-mxt.r*). A few variables showed increased size differences on two occasions. This included maximum maxillary width (*zmi.l-zmi.r*), right posterior maxillary heights (*mxt.r-ms.r*), right anterior zygo-maxillary suture lengths (*or.r-zmi.r*) and left and right inferior maxillary lengths (*mxt.l-pr, mxt.r-pr*), where a second increase in size differences was observed to occur between the ages of 14 to 16 years and 16 to 18 years.

For females, these events were detected to occur between the ages of 3 to 5 years and 5 to 10 years for the majority of maxillary measurements. Additionally, subtle increased size differences were detected between the ages of 10 to 12 years and 12 to 14 years for maxillary alveolar height (*ans-pr*) for both sexes.

Zygoma

Zygomatic variables reached between 47 to 57% of adult size at the age of one year and between 71 to 79% of adult size by the age of five years. The graphs for zygomatic variables showed rapid growth of the structures during the first 3 to 5 years and then they demonstrated continous growth until adulthood.

The majority of zygomatic variables in males showed increased size changes at between two different age intervals, i.e. between the ages of 5 to 10 years and 10 to 12 years and also between 12 to 14 years and 14 to 16 years. Left and right zygomatic length (*zti.l-or.l, zti.r- or.r*) showed increased size differences on both occasions. For females increased size differences were identified to occur between the ages of 3 to 5 years and 5 to 10 years.

Variables that were in this category were right zygomatic height (*slor.r-zmi.r*) and left and right zygomatic arch length (*zt.l-au.l, zt.r-au.r*).

Mandible

Percentages of adult size gained at age one year for mandibular variables ranged from 48 to 59% for width, 38 to 45% for height, and 44 to 50% for length. At age five years, these percentages of adult size ranged from 73 to 80% for mandibular width, 70 to 76% for height, and 73 to 75% for length.

The graphs for mandibular variables showed rapid growth of the structures during the first 3 to 5 years and then they demonstrated continuous growth until adulthood.

The majority mandibular variables showed increased size differences between the ages of 5 to 10 years and 10 to 12 years in males. Intercondylar width (*cd.l-cd.r*) showed increased size differences on two occasions, i.e. between 3 to 5 years and 5 to 10 years and, again, between 14 to 16 years and 16 to 18 years.

In females, more variations in the patterns were observed. The majority of mandibular variables displayed increased size differences between the ages of 3 to 5 years and 5 to 10 years. There were some variables that showed increased size differences on two occasions but at different times. These included intergonion width (*go.l-go.r*) and left and right total mandibular lengths (*gn-cd.l, gn-cd.r*) which experienced increased size differences initially between the ages of 3 to 5 years and 5 to 10 years and then again between 10 to 12 years and 12 to 14 years. Another pattern observed was for variables that revealed increased size differences between the ages of 3 to 5 years and 5 to 10 years and again between 12 to 14 years and 14 to 16 years. Mandibular variables that followed this pattern were intercondylar width (*cd.l-cd.r*) and left body length (*go.l-gn*).

Inter-regional variables

Inter-regional variables had reached between 48 to 67% of adult size by the age of one year and between 77 to 87% of adult size by the age of five years. Total facial length measurements gained about 56% of adult size by the age of one year and then around 78% by the age of five years. Measurements of maxilla related to the cranial base were found to achieve 48 to 67% of adult size at one year of age and between 77 to 87% by the age of five years.

The graphs for inter-regional variables also showed a pattern of rapid growth of the structures during the first 3 to 5 years and then there appeared to be continuous growth until adulthood.

For males, left and right total face lengths (*au.l-ans*, *au.r-ans*) showed increased size differences between the ages of 12 to 14 years and 14 to 16 years. All other inter-regional measurements demonstrated this increase in size between the ages of 5 to 10 years and 10 to 12 years.

Increased size differences were observed to occur for the majority of inter-regional variables between the ages of 3 to 5 years and 5 to 10 years in females. Left total face length (*au.l-ans*) measurement showed a second increase in size between the ages of 10 to 12 years and 12 to 14 years.

Angles and Indices

The graphs for angular variables showed no evidence for either a consistent increase or decrease with age. With the exceptions of nasal (*s-n-na*) and cranial base related to palatal plane (*s-n/ans-pns*) angles, all other angular variables in this study showed a pattern of decreasing with age and this occurred at varying magnitudes at different ages. Plots of the cranial base related to palatal plane angle appeared flat and showed little change from birth to adulthood.

The graph for the cephalic index (*cindx.l-cindx.r : cindxa-cindxp*) was almost flat with a slight tendency for values to decrease with age. Values of both left and right orbital indices (*morfl.l-lor.l : sor.l-or.l, morfl.r-lor.r : sor.r-or.r*) tended to decrease with age.

Maximum cranial width (*cindx.l-cindx.r*)

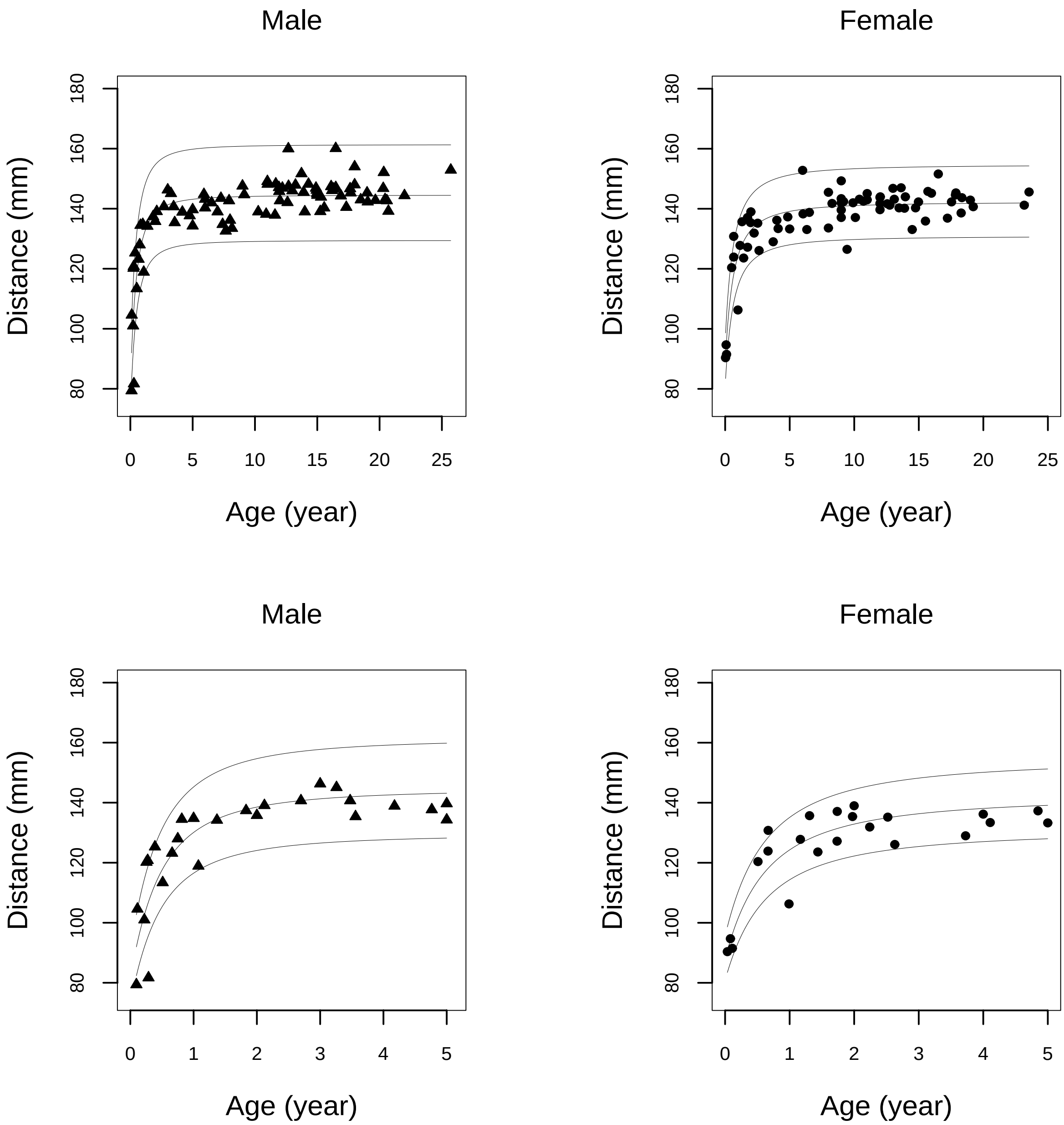

Figure 3.1 Graphs of maximum cranial width (*cindx.l-cindx.r*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.1 Means (M), standard deviations (SD), minimum and maximum values (in mm) for maximum cranial width (*cindx.l-cindx.r*) at different age intervals.

	Males					Females					Total				
	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	12	113.9	18.69	79.4	134.8	7	108.3	16.77	90.4	130.8	19	111.8	17.75	79.4	134.8
1-3	7	136.1	8.52	118.9	146.3	10	131.9	5.34	123.6	139.0	17	133.6	6.91	118.9	146.3
3-5	7	138.8	3.59	134.3	145.1	5	133.8	3.22	129.0	137.3	12	136.8	4.17	129.0	145.1
5-10	13	140.4	4.78	132.6	147.6	15	140.4	6.49	126.5	152.8	28	140.4	5.66	126.5	152.8
10-12	9	144.0	4.64	137.9	149.1	8	142.0	2.53	137.1	145.1	17	143.1	3.83	137.1	149.1
12-14	9	147.4	5.94	139.0	160.0	9	143.2	2.56	140.2	147.0	18	145.3	4.94	139.0	160.0
14-16	9	144.4	2.96	139.1	148.2	6	140.4	5.09	133.1	145.8	15	142.8	4.27	133.1	148.2
16-18	11	147.8	5.17	140.5	160.1	5	144.1	5.32	136.9	151.6	16	146.7	5.34	136.9	160.1
18-25	11	145.0	4.19	139.2	152.9	6	142.1	2.47	138.6	145.6	17	144.0	3.85	138.6	152.9

Interasterion width (*as.l-as.r*)

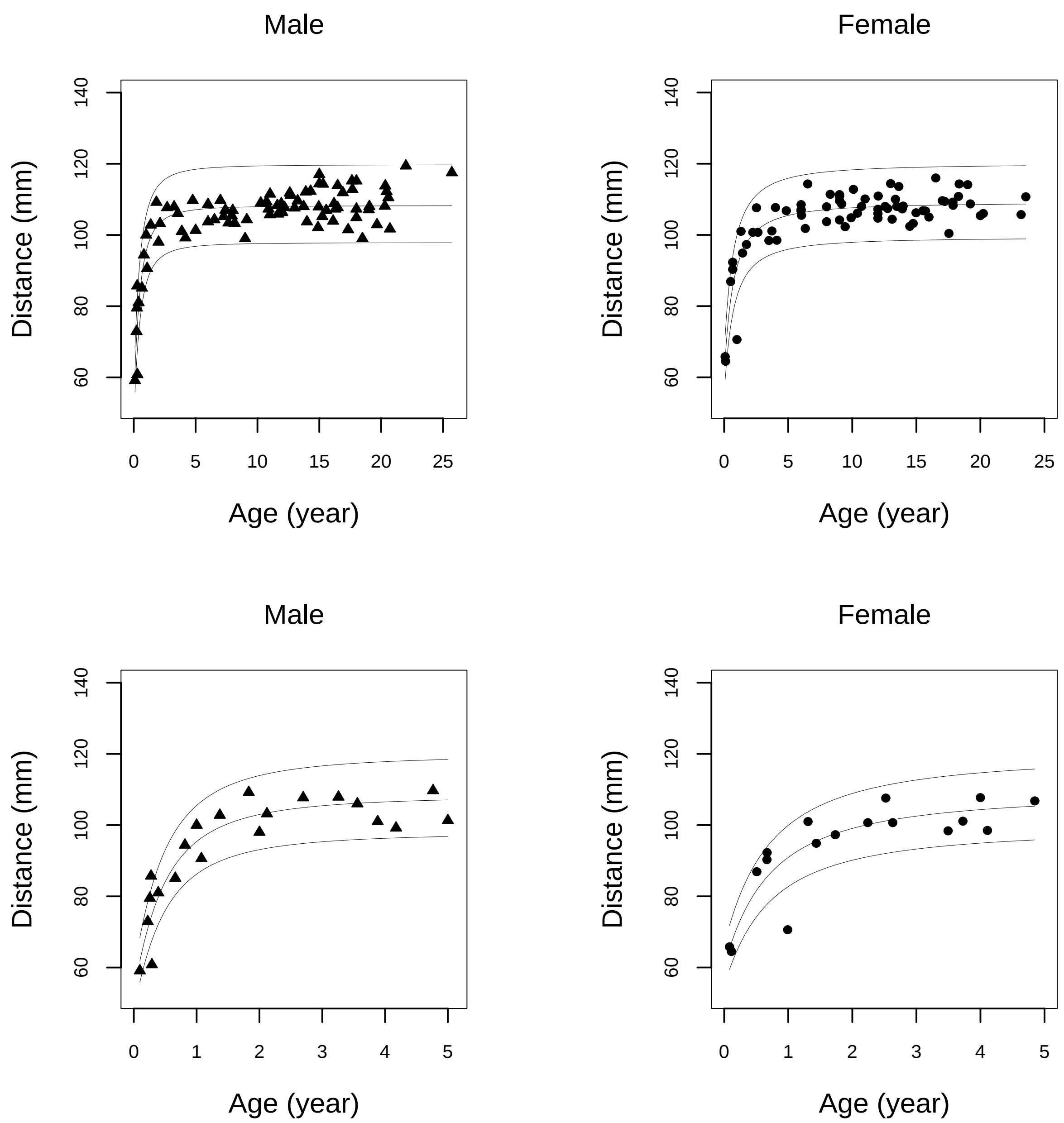

Figure 3.2 Graphs of interasterion width (*as.l-as.r*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.2 Means (M), standard deviations (SD), minimum and maximum values (in mm) for interasterion width (*as.l-as.r*) at different age intervals.

Age group	Males					Females					Total				
	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	9	79.8	13.80	59.1	100.0	6	78.4	12.81	64.5	92.3	15	79.3	12.96	59.1	100.0
1-3	6	101.9	6.82	90.6	109.2	6	100.4	4.29	94.9	107.6	12	101.1	5.49	90.6	109.2
3-5	6	104.2	4.26	99.2	109.7	5	102.5	4.48	98.4	107.7	11	103.4	4.23	98.4	109.7
5-10	12	105.1	2.81	99.0	109.7	16	107.4	3.56	101.8	114.3	28	106.4	3.42	99.0	114.3
10-12	10	107.9	1.86	105.7	111.5	7	107.8	2.78	104.7	112.8	17	107.8	2.20	104.7	112.8
12-14	8	109.0	2.81	103.7	112.1	10	109.2	3.05	104.4	114.4	18	109.1	2.87	103.7	114.4
14-16	8	110.0	5.23	102.1	117.0	6	105.1	1.87	102.4	106.8	14	107.9	4.75	102.1	117.0
16-18	12	109.2	4.57	101.5	115.2	6	108.8	4.98	100.4	116.0	18	109.1	4.56	100.4	116.0
18-25	11	109.1	6.42	99.0	119.4	8	109.5	3.61	105.4	114.3	19	109.3	5.29	99.0	119.4

Interporion width (*po.l-po.r*)

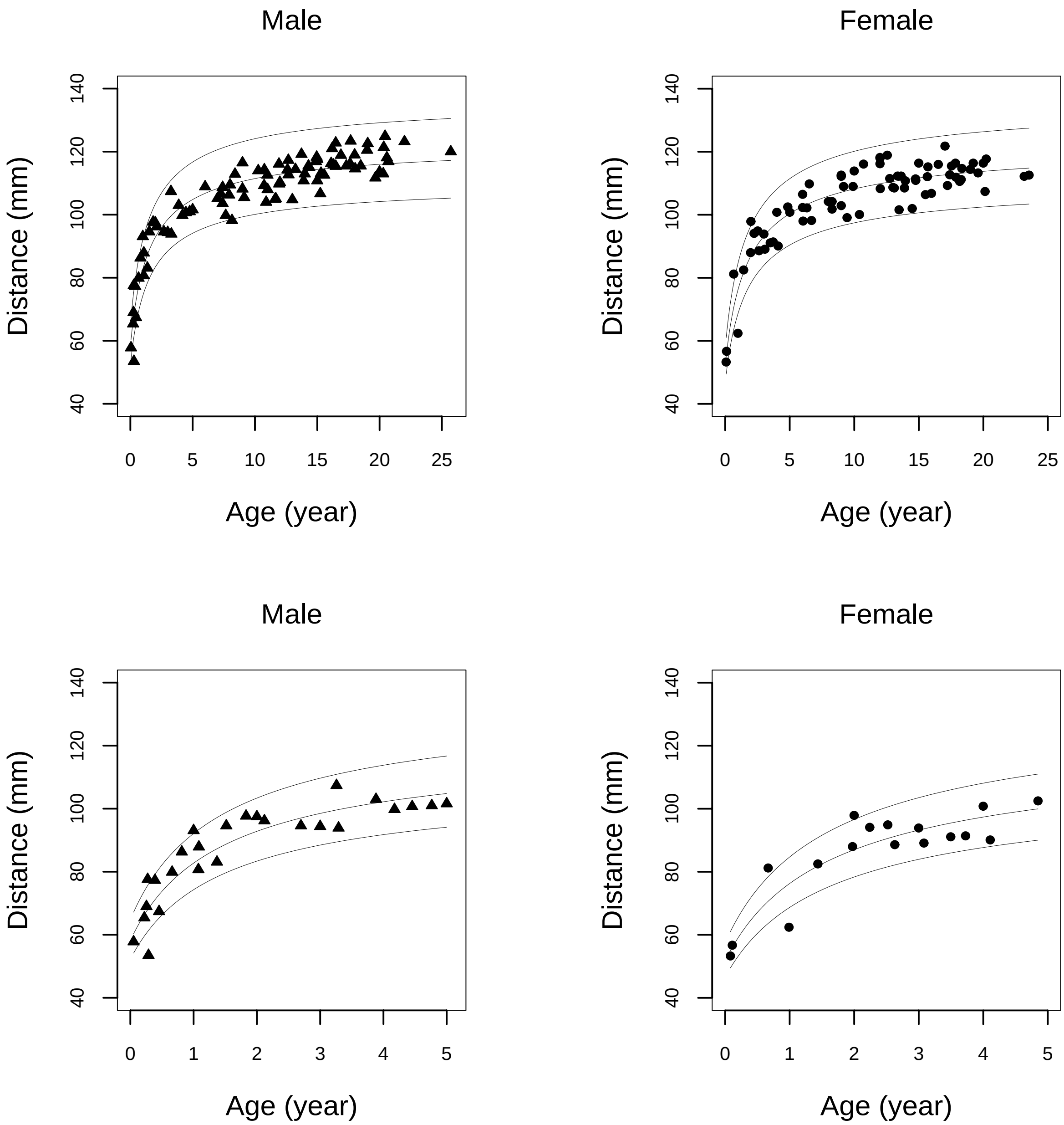

Figure 3.3 Graphs of interporion width (*po.l-po.r*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.3 Means (M), standard deviations (SD), minimum and maximum values (in mm) for interporion width (*po.l-po.r*) at different age intervals.

Age	Males					Females					Total				
group	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	10	72.7	12.40	53.5	93.1	4	63.4	12.45	53.3	81.2	14	70.1	12.70	53.3	93.1
1-3	9	91.9	6.36	80.7	97.7	7	91.4	5.27	82.5	97.9	16	91.7	5.72	80.7	97.9
3-5	7	101.1	4.03	93.9	107.4	6	94.2	5.88	89.1	102.5	13	97.9	5.94	89.1	107.4
5-10	13	106.9	4.88	98.2	116.5	17	105.1	5.15	98.0	113.9	30	105.9	5.03	98.0	116.5
10-12	11	109.9	4.11	104.0	116.1	5	113.7	7.68	100.1	118.2	16	111.1	5.51	100.1	118.2
12-14	8	113.3	4.34	104.8	119.2	10	110.1	4.37	101.6	118.9	18	111.6	4.53	101.6	119.2
14-16	9	114.1	3.69	106.7	118.3	8	110.2	4.81	102.0	116.4	17	112.2	4.59	102.0	118.3
16-18	10	118.4	3.08	115.4	123.4	7	114.8	4.01	109.3	121.8	17	116.9	3.84	109.3	123.4
18-25	13	118.2	4.29	111.7	124.9	11	113.4	3.00	107.4	117.7	24	116.0	4.41	107.4	124.9

Cranial height (*ba*-*br*)

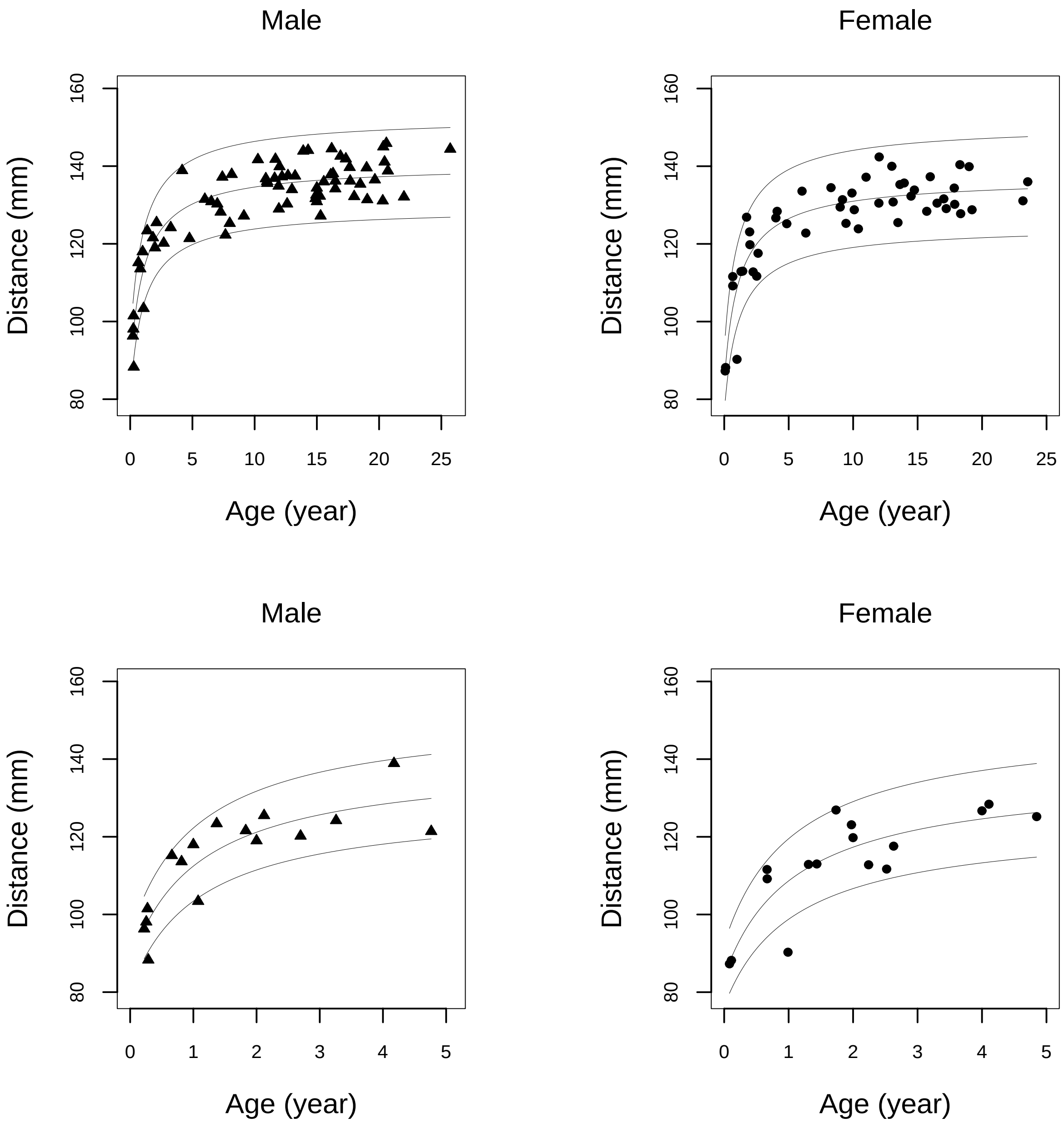

Figure 3.4 Graphs of cranial height (*ba*-*br*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.4 Means (M), standard deviations (SD), minimum and maximum values (in mm) for cranial height (*ba*-*br*) at different age intervals.

Age	Males					Females					Total				
group	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	7	104.4	11.25	88.3	118.0	5	97.3	12.02	87.3	111.6	12	101.5	11.62	87.3	118.0
1-3	6	118.9	7.91	103.4	125.5	8	117.2	5.63	111.7	126.9	14	117.9	6.47	103.4	126.9
3-5	3	128.2	9.40	121.4	138.9	3	126.8	1.60	125.2	128.4	6	127.5	6.08	121.4	138.9
5-10	9	130.1	5.12	122.3	137.9	7	130.0	4.45	122.8	134.5	16	130.1	4.68	122.3	137.9
10-12	9	137.0	3.95	129.0	141.8	4	130.1	5.50	123.9	137.2	13	134.9	5.37	123.9	141.8
12-14	6	136.8	4.51	130.3	143.9	6	135.0	6.14	125.5	142.4	12	135.9	5.22	125.5	143.9
14-16	8	133.7	4.95	127.2	144.1	4	133.0	3.69	128.4	137.3	12	133.4	4.40	127.2	144.1
16-18	10	138.3	3.87	132.2	144.5	5	131.2	2.02	129.1	134.4	15	135.9	4.80	129.1	144.5
18-25	11	138.3	5.47	131.1	145.9	6	134.0	5.54	127.8	140.4	17	136.8	5.73	127.8	145.9

Left lateral cranial vault height (*br-po.l*)

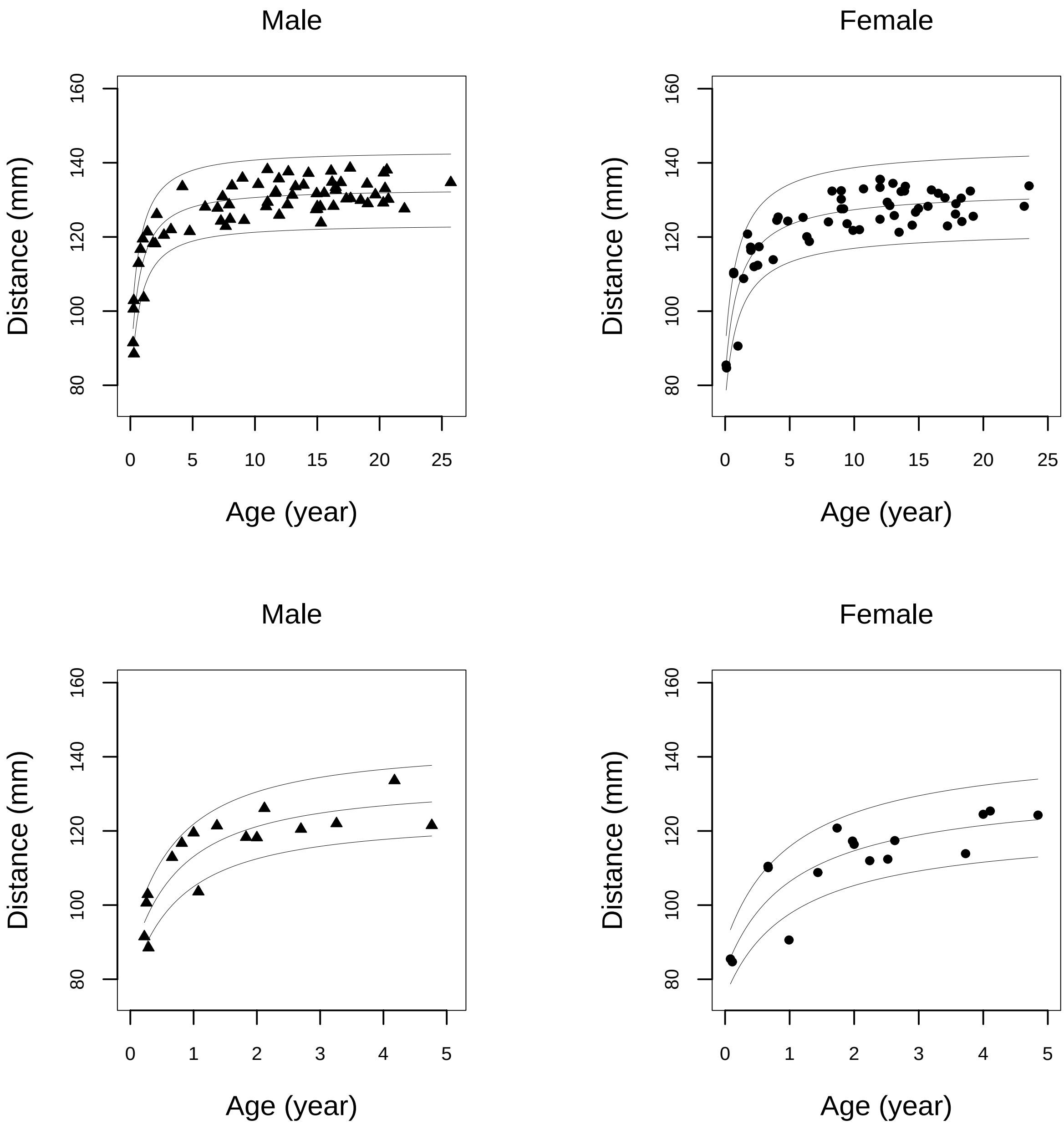

Figure 3.5 Graphs of left lateral cranial vault height (*br-po.l*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.5 Means (M), standard deviations (SD), minimum and maximum values (in mm) for left lateral cranial vault height (*br-po.l*) at different age intervals.

Age group	Males					Females					Total				
	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	7	104.7	12.16	88.5	119.5	5	96.3	13.00	84.7	110.5	12	101.2	12.68	84.7	119.5
1-3	6	118.0	7.63	103.6	126.1	7	115.0	4.10	108.8	120.8	13	116.4	5.92	103.6	126.1
3-5	3	125.7	6.85	121.5	133.6	4	122.0	5.44	113.9	125.4	7	123.6	5.85	113.9	133.6
5-10	10	128.2	4.31	122.9	135.9	11	125.8	4.69	118.8	132.5	21	126.9	4.56	118.8	135.9
10-12	8	132.0	4.06	125.9	138.2	5	129.8	5.97	122.0	135.6	13	131.1	4.77	122.0	138.2
12-14	5	133.0	3.31	128.7	137.6	9	130.4	4.61	121.3	135.5	14	131.3	4.27	121.3	137.6
14-16	8	129.5	4.03	123.8	137.2	5	127.7	3.41	123.2	132.7	13	128.8	3.76	123.2	137.2
16-18	9	133.4	3.45	128.3	138.6	5	128.1	3.55	123.0	131.8	14	131.5	4.27	123.0	138.6
18-25	11	132.3	3.50	127.6	138.1	6	129.1	3.79	124.2	133.8	17	131.2	3.81	124.2	138.1

Right lateral cranial vault height (*br-po.r*)

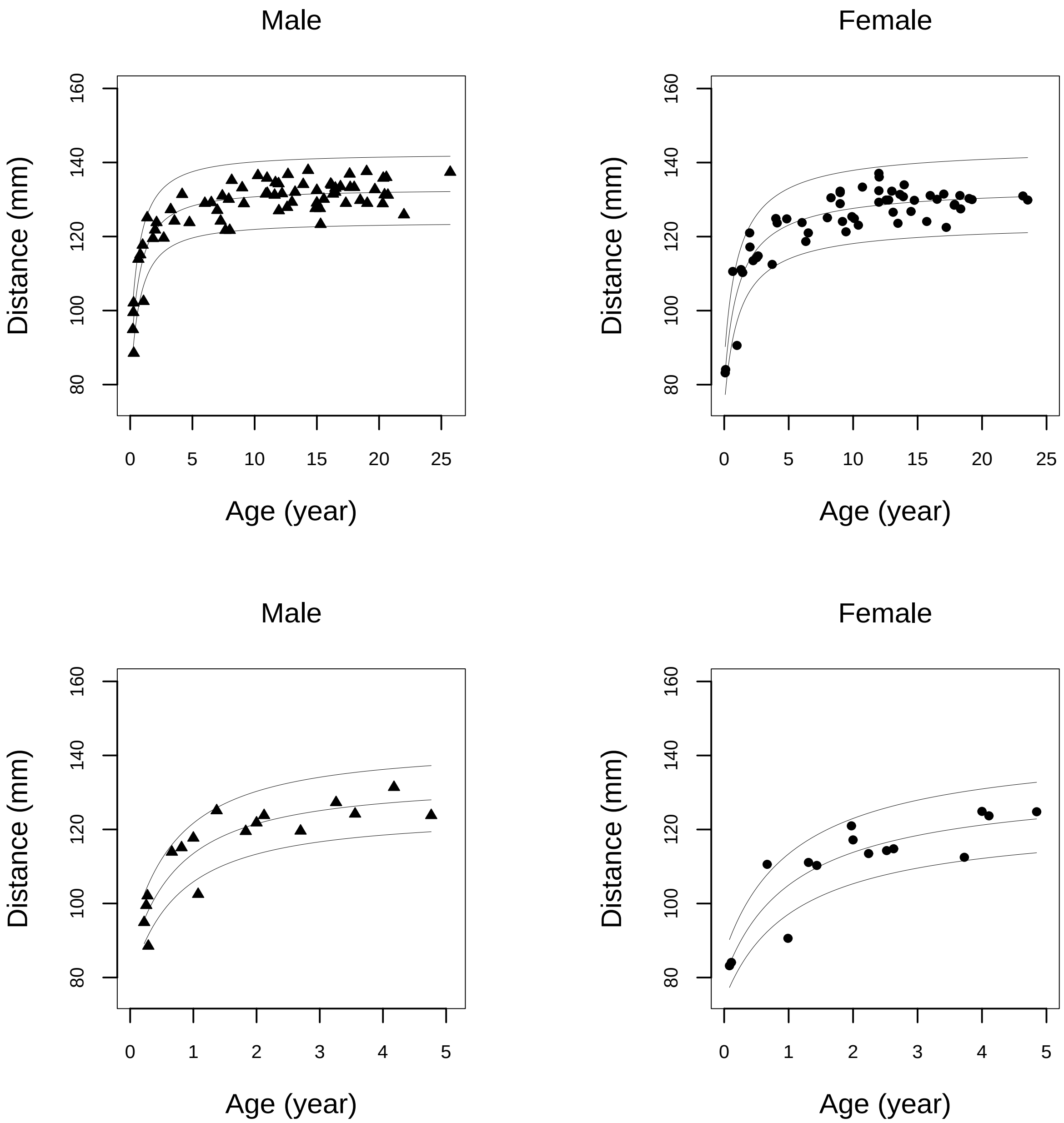

Figure 3.6 Graphs of right lateral cranial vault height (*br-po.r*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.6 Means (M), standard deviations (SD), minimum and maximum values (in mm) for right lateral cranial vault height (*br-po.r*) at different age intervals.

Age group	Males					Females					Total				
	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	7	104.5	11.21	88.5	117.7	4	92.1	12.75	83.2	110.6	11	100.0	12.78	83.2	117.7
1-3	6	118.7	8.25	102.5	125.1	7	114.6	3.65	110.3	121.0	13	116.5	6.29	102.5	125.1
3-5	4	126.7	3.52	123.8	131.4	4	121.5	6.01	112.5	124.9	8	124.1	5.34	112.5	131.4
5-10	11	128.3	4.35	121.7	135.2	11	125.7	4.61	118.7	132.3	22	127.0	4.57	118.7	135.2
10-12	8	132.8	3.10	127.0	136.5	6	130.0	5.33	123.1	137.1	14	131.6	4.26	123.1	137.1
12-14	6	132.0	3.22	127.9	136.8	9	130.5	3.73	123.6	136.1	15	131.1	3.49	123.6	136.8
14-16	8	129.5	4.28	123.3	137.9	4	128.0	3.14	124.1	131.1	12	129.0	3.86	123.3	137.9
16-18	10	133.1	2.03	129.0	136.9	5	128.3	3.44	122.5	131.5	15	131.5	3.40	122.5	136.9
18-25	11	132.3	3.90	125.9	137.6	6	130.0	1.31	127.5	131.1	17	131.5	3.37	125.9	137.6

Anterior cranial vault height (*n-br*)

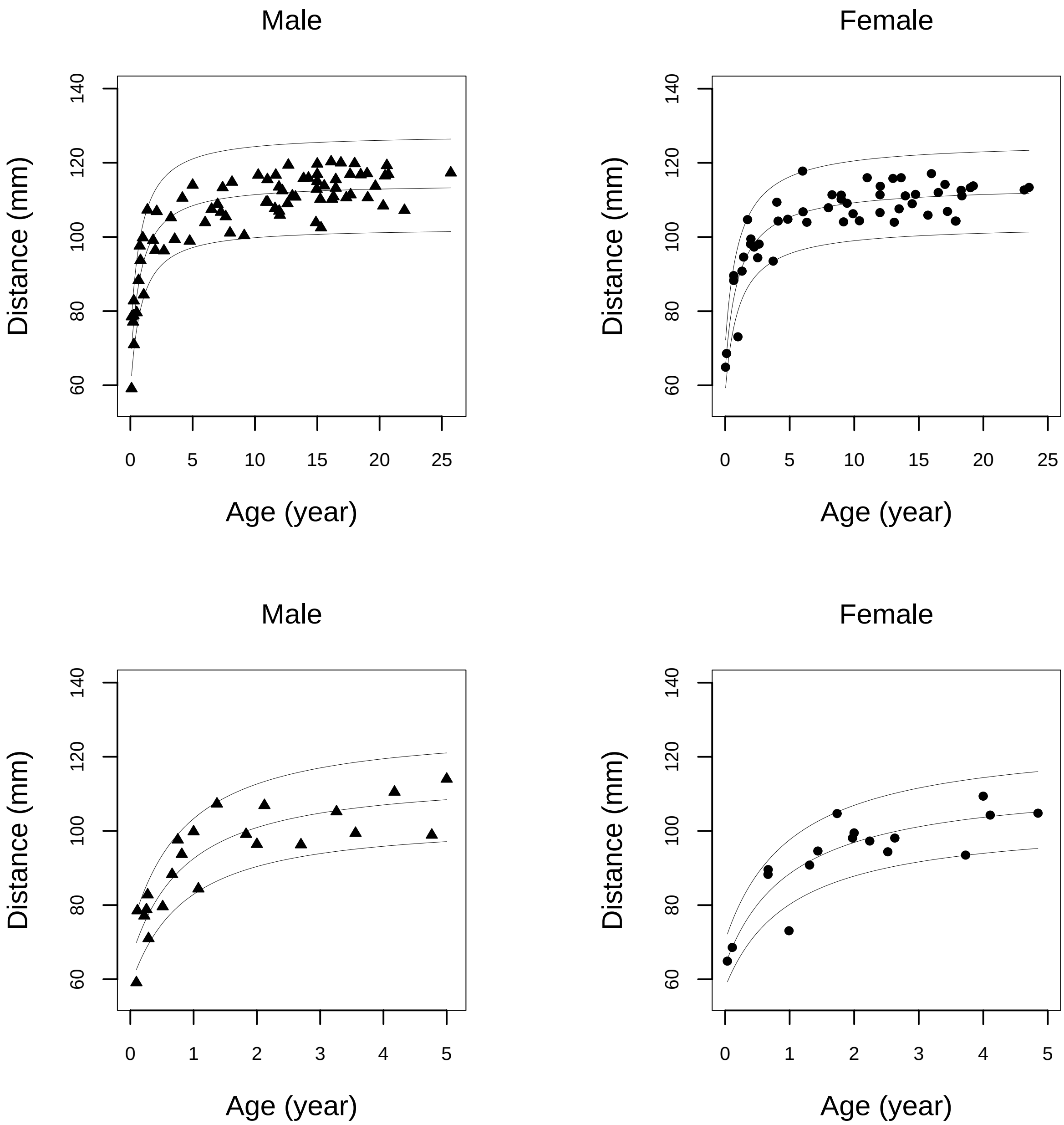

Figure 3.7 Graphs of anterior cranial vault height (*n-br*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.7 Means (M), standard deviations (SD), minimum and maximum values (in mm) for anterior cranial vault height (*n-br*) at different age intervals.

Age group	Males					Females					Total				
	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	11	82.4	11.97	59.1	99.8	5	76.9	11.39	64.9	89.6	16	80.7	11.71	59.1	99.8
1-3	6	98.4	8.44	84.4	107.3	8	97.2	4.12	90.8	104.7	14	97.7	6.08	84.4	107.3
3-5	5	105.6	6.67	98.9	114.0	4	103.0	6.74	93.5	109.4	9	104.4	6.42	93.5	114.0
5-10	9	106.9	4.93	100.4	114.8	10	108.9	4.11	104.0	117.8	19	107.9	4.51	100.4	117.8
10-12	9	111.3	4.31	105.9	116.7	4	109.6	5.17	104.4	116.0	13	110.8	4.44	104.4	116.7
12-14	6	113.1	3.83	109.0	119.4	6	111.4	4.80	104.0	116.0	12	112.2	4.24	104.0	119.4
14-16	9	112.3	5.81	102.5	119.7	4	110.9	4.74	105.9	117.1	13	111.9	5.35	102.5	119.7
16-18	10	114.9	4.15	110.2	120.3	5	108.3	4.54	104.3	114.2	15	112.7	5.21	104.3	120.3
18-25	10	114.4	4.20	107.2	119.3	6	112.8	0.95	111.1	113.8	16	113.8	3.39	107.2	119.3

Posterior cranial vault height (*l-br*)

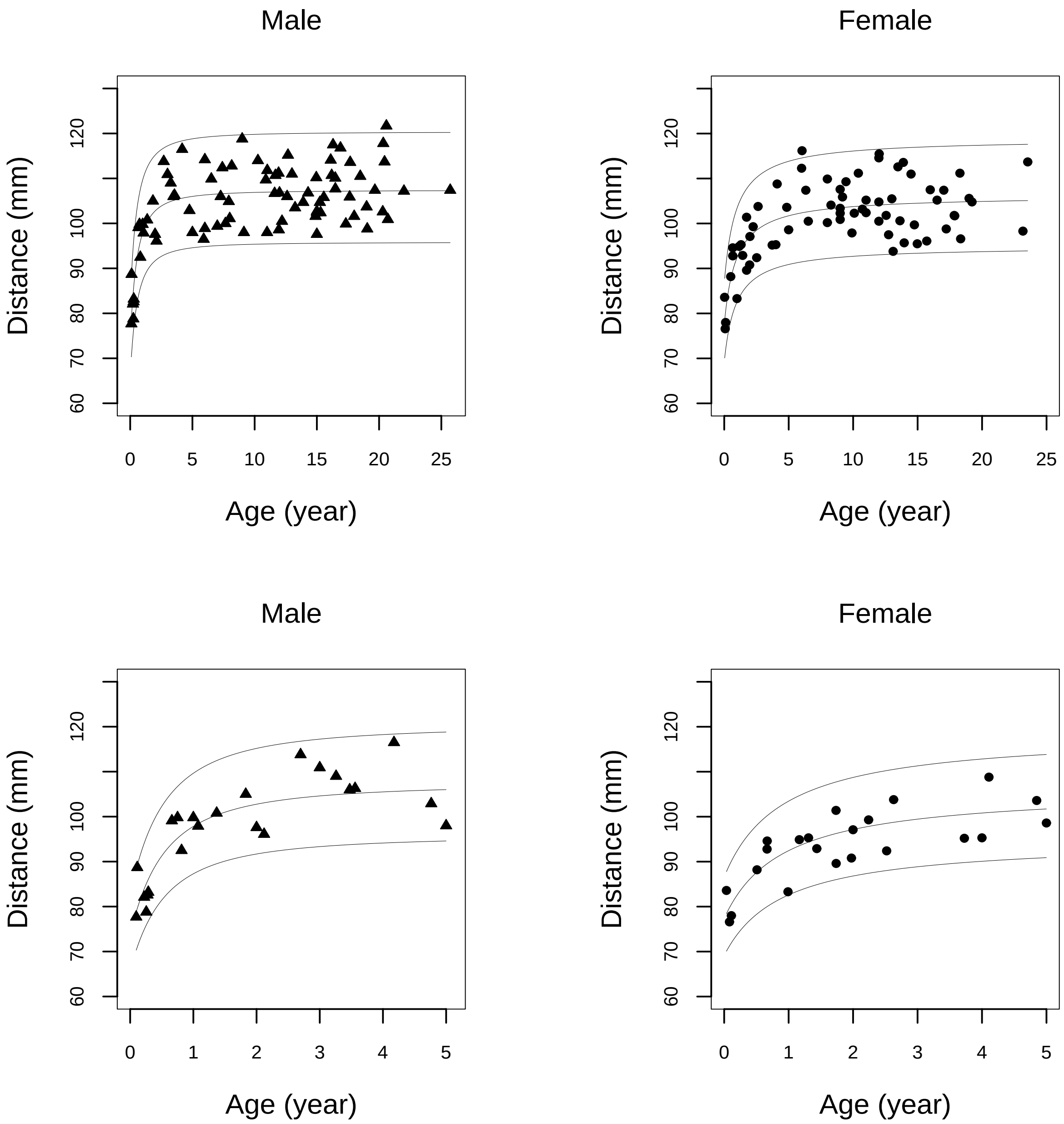

Figure 3.8 Graphs of posterior cranial vault height (*l-br*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.8 Means (M), standard deviations (SD), minimum and maximum values (in mm) for posterior cranial vault height (*l-br*) at different age intervals.

Age group	Males					Females					Total				
	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	10	88.4	8.81	77.7	99.8	7	85.3	6.92	76.6	94.6	17	87.1	8.01	76.6	99.8
1-3	7	103.2	6.96	96.1	113.8	10	95.8	4.64	89.6	103.8	17	98.8	6.66	89.6	113.8
3-5	6	106.5	6.19	98.0	116.5	5	100.3	5.85	95.2	108.8	11	103.7	6.57	95.2	116.5
5-10	13	105.6	7.31	96.5	118.8	14	105.6	5.20	97.9	116.2	27	105.6	6.18	96.5	118.8
10-12	9	107.5	5.70	98.0	114.0	8	105.5	4.87	100.5	114.6	17	106.6	5.26	98.0	114.6
12-14	6	106.8	5.36	100.5	115.2	9	104.1	8.16	93.8	115.5	15	105.2	7.09	93.8	115.5
14-16	9	103.8	3.59	97.6	110.2	5	102.0	6.96	95.5	111.0	14	103.1	4.86	95.5	111.0
16-18	10	109.8	6.03	99.9	117.5	5	103.0	3.35	98.8	107.4	15	107.5	6.13	98.8	117.5
18-25	11	108.3	7.11	98.8	121.7	6	105.0	6.78	96.6	113.7	17	107.2	6.97	96.6	121.7

Lambdoid height (*l-o*)

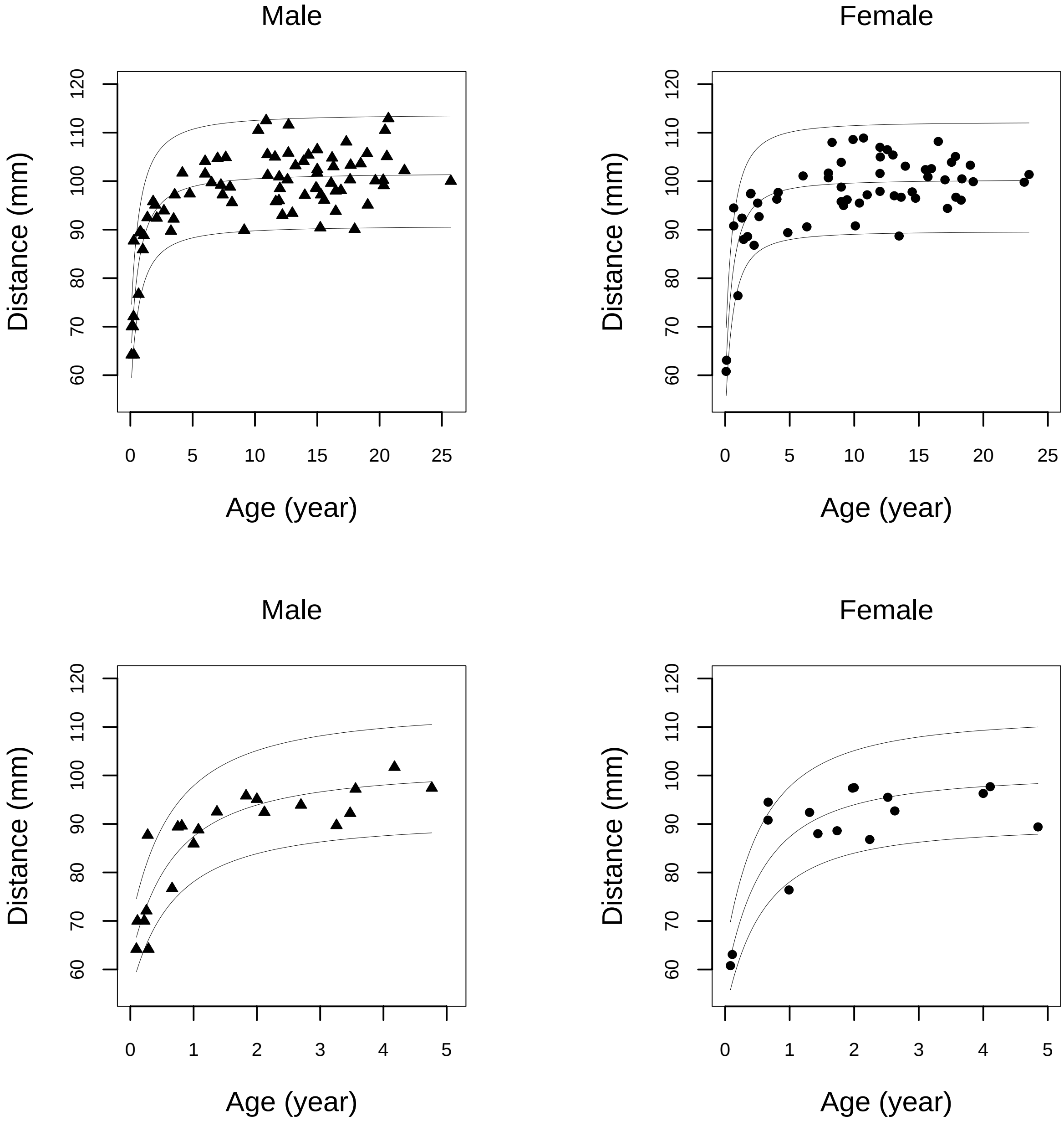

Figure 3.9 Graphs of lambdoid height (*l-o*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.9 Means (M), standard deviations (SD), minimum and maximum values (in mm) for lambdoid height (*l-o*) at different age intervals.

Age group	Males					Females					Total				
	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	10	77.0	10.31	64.2	89.6	5	77.1	15.43	60.8	94.5	15	77.0	11.68	60.8	94.5
1-3	6	93.1	2.50	88.8	95.8	8	92.4	4.24	86.8	97.5	14	92.7	3.50	86.8	97.5
3-5	5	95.6	4.73	89.7	101.7	3	94.5	4.44	89.4	97.7	8	95.2	4.33	89.4	101.7
5-10	10	99.6	4.65	89.9	104.9	11	100.0	5.52	90.6	108.6	21	99.8	5.00	89.9	108.6
10-12	9	102.9	5.97	95.8	112.5	7	99.8	6.43	90.8	108.9	16	101.6	6.16	90.8	112.5
12-14	8	101.1	6.41	93.0	111.6	7	100.3	6.49	88.7	106.5	15	100.7	6.22	88.7	111.6
14-16	9	99.6	4.98	90.4	106.5	5	100.0	2.76	96.5	102.6	14	99.8	4.20	90.4	106.5
16-18	10	99.9	5.30	90.1	108.1	6	101.4	5.26	94.4	108.2	16	100.5	5.16	90.1	108.2
18-25	11	103.1	5.19	95.1	112.9	6	100.2	2.37	96.1	103.3	17	102.1	4.56	95.1	112.9

Maximum cranial length (*cindxa-cindxp*)

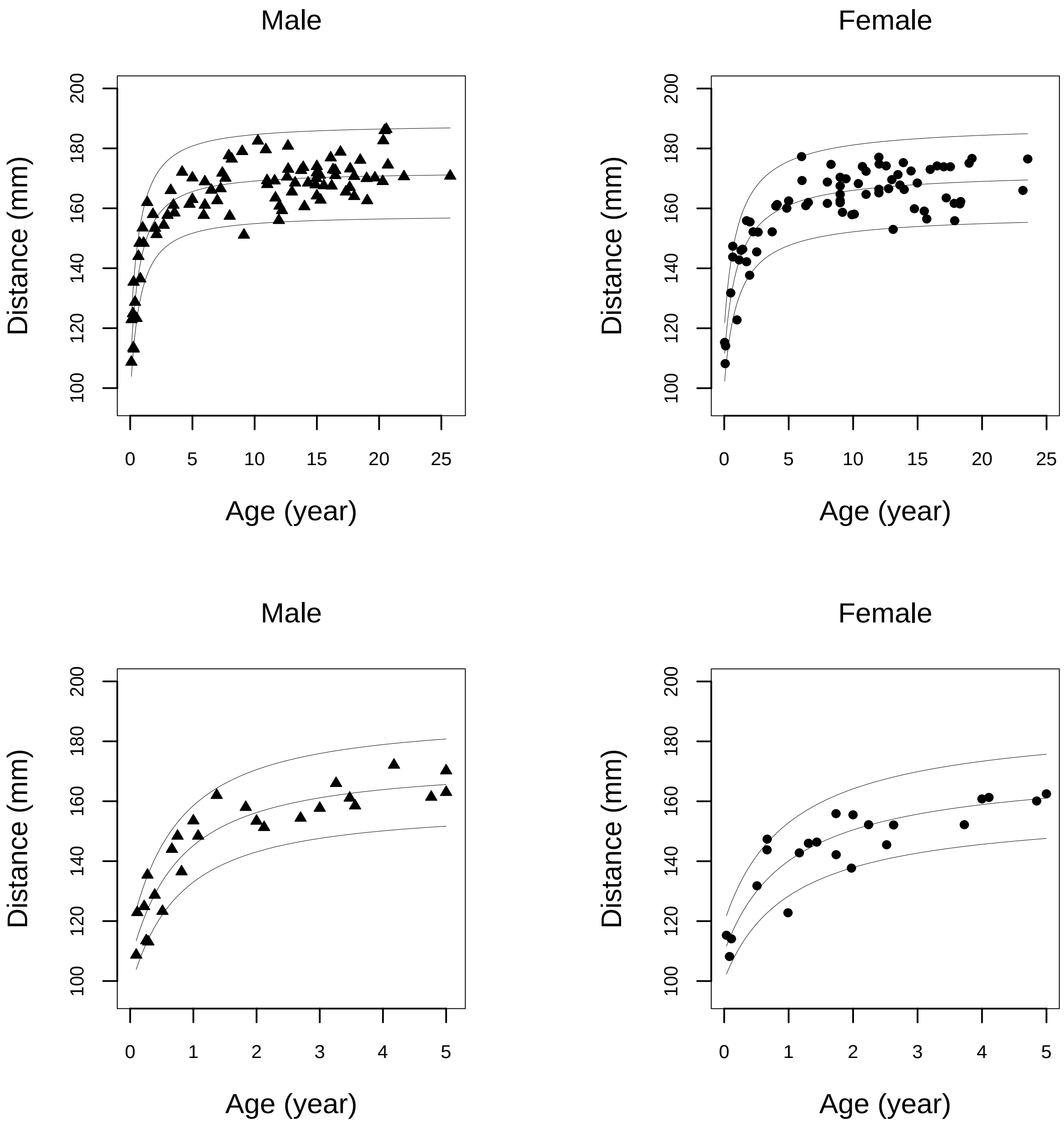

Figure 3.10 Graphs of maximum cranial length (*cindxa-cindxp*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.10 Means (M), standard deviations (SD), minimum and maximum values (in mm) for maximum cranial length (*cindxa-cindxp*) at different age intervals.

Age group	Males					Females					Total				
	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	12	129.4	14.42	108.7	153.5	7	126.2	15.23	108.2	147.4	19	128.2	14.39	108.2	153.5
1-3	7	155.0	4.57	148.4	162.0	10	147.6	6.07	137.7	155.9	17	150.7	6.53	137.7	162.0
3-5	7	164.6	5.03	158.5	172.1	5	159.4	4.11	152.2	162.5	12	162.4	5.22	152.2	172.1
5-10	13	166.7	8.50	151.1	179.0	15	165.9	5.78	157.9	177.3	28	166.2	7.05	151.1	179.0
10-12	8	168.6	8.95	156.0	182.5	8	168.3	6.06	158.1	177.1	16	168.4	7.39	156.0	182.5
12-14	9	169.4	6.80	159.3	180.8	9	168.8	6.86	153.0	175.3	18	169.1	6.63	153.0	180.8
14-16	9	168.7	3.58	162.8	174.0	6	164.9	7.29	156.5	173.0	15	167.2	5.47	156.5	174.0
16-18	11	170.9	4.63	164.0	178.8	6	167.2	7.88	155.9	174.2	17	169.6	6.02	155.9	178.8
18-25	11	174.4	7.63	162.6	186.4	6	169.7	7.21	161.5	176.7	17	172.8	7.62	161.5	186.4

Left lateral cranial vault length (*spc.l-as.l*)

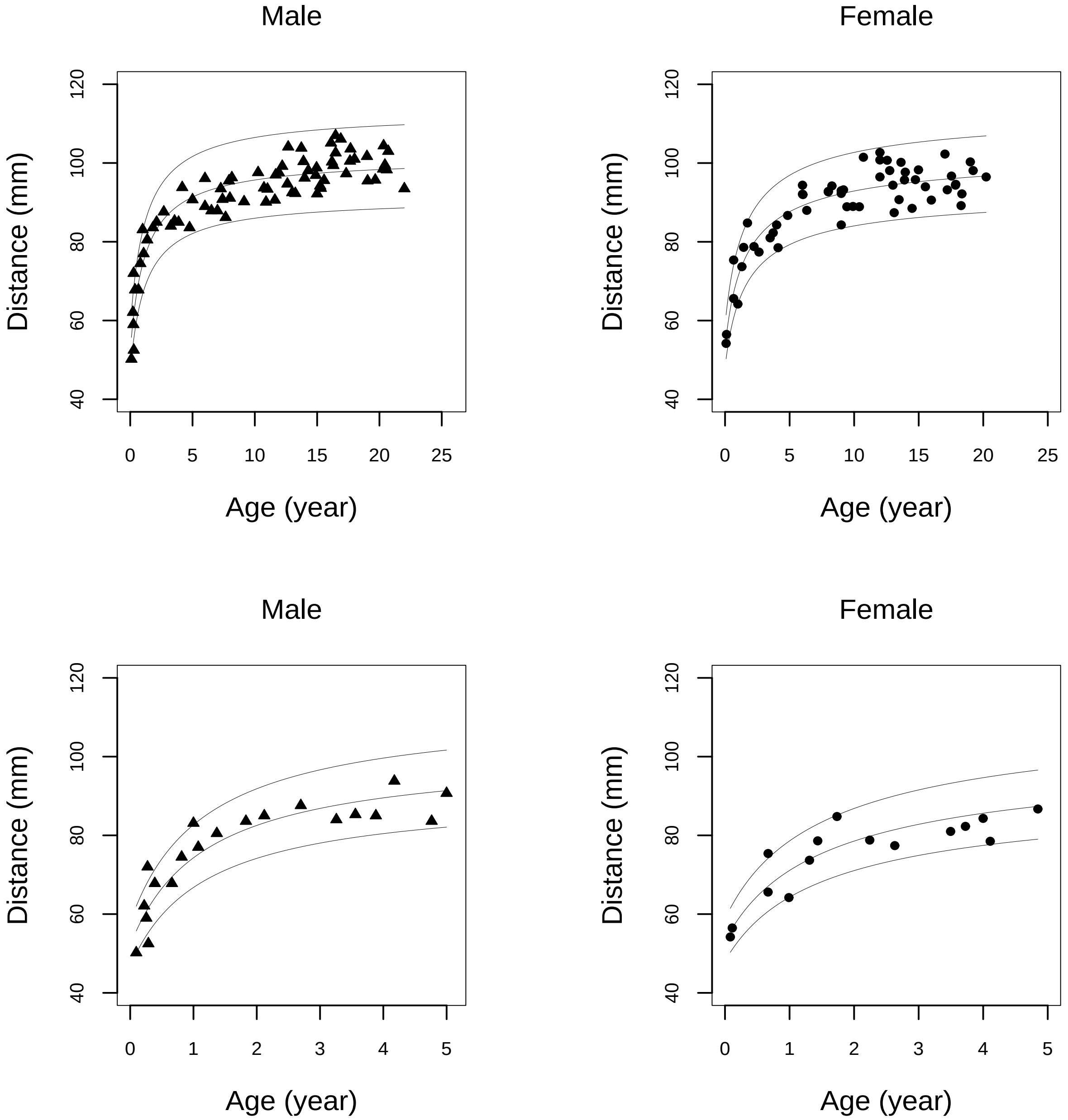

Figure 3.11 Graphs of left lateral cranial vault length (*spc.l-as.l*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.11 Means (M), standard deviations (SD), minimum and maximum values (in mm) for left lateral cranial vault length (*spc.l-as.l*) at different age intervals.

Age	Males					Females					Total				
group	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	9	65.4	10.61	50.2	83.1	5	63.2	8.39	54.2	75.4	14	64.6	9.60	50.2	83.1
1-3	5	82.7	4.11	77.0	87.6	5	78.7	4.00	73.7	84.8	10	80.7	4.38	73.7	87.6
3-5	6	87.1	4.18	83.6	93.8	5	82.6	3.13	78.5	86.7	11	85.0	4.26	78.5	93.8
5-10	11	91.3	3.56	86.2	96.3	13	91.3	2.91	84.3	94.4	24	91.3	3.15	84.3	96.3
10-12	7	94.3	3.20	90.1	97.6	5	98.1	5.64	88.9	102.7	12	95.9	4.58	88.9	102.7
12-14	8	97.9	4.70	92.3	104.1	8	95.6	4.64	87.4	100.7	16	96.8	4.66	87.4	104.1
14-16	7	95.6	2.44	92.2	98.8	5	93.4	3.94	88.5	98.3	12	94.7	3.19	88.5	98.8
16-18	10	102.3	3.14	97.3	107.0	5	96.2	3.61	93.2	102.3	15	100.3	4.33	93.2	107.0
18-25	9	98.9	3.65	93.5	104.4	5	95.3	4.50	89.2	100.3	14	97.6	4.21	89.2	104.4

Right lateral cranial vault length (*spc.r-as.r*)

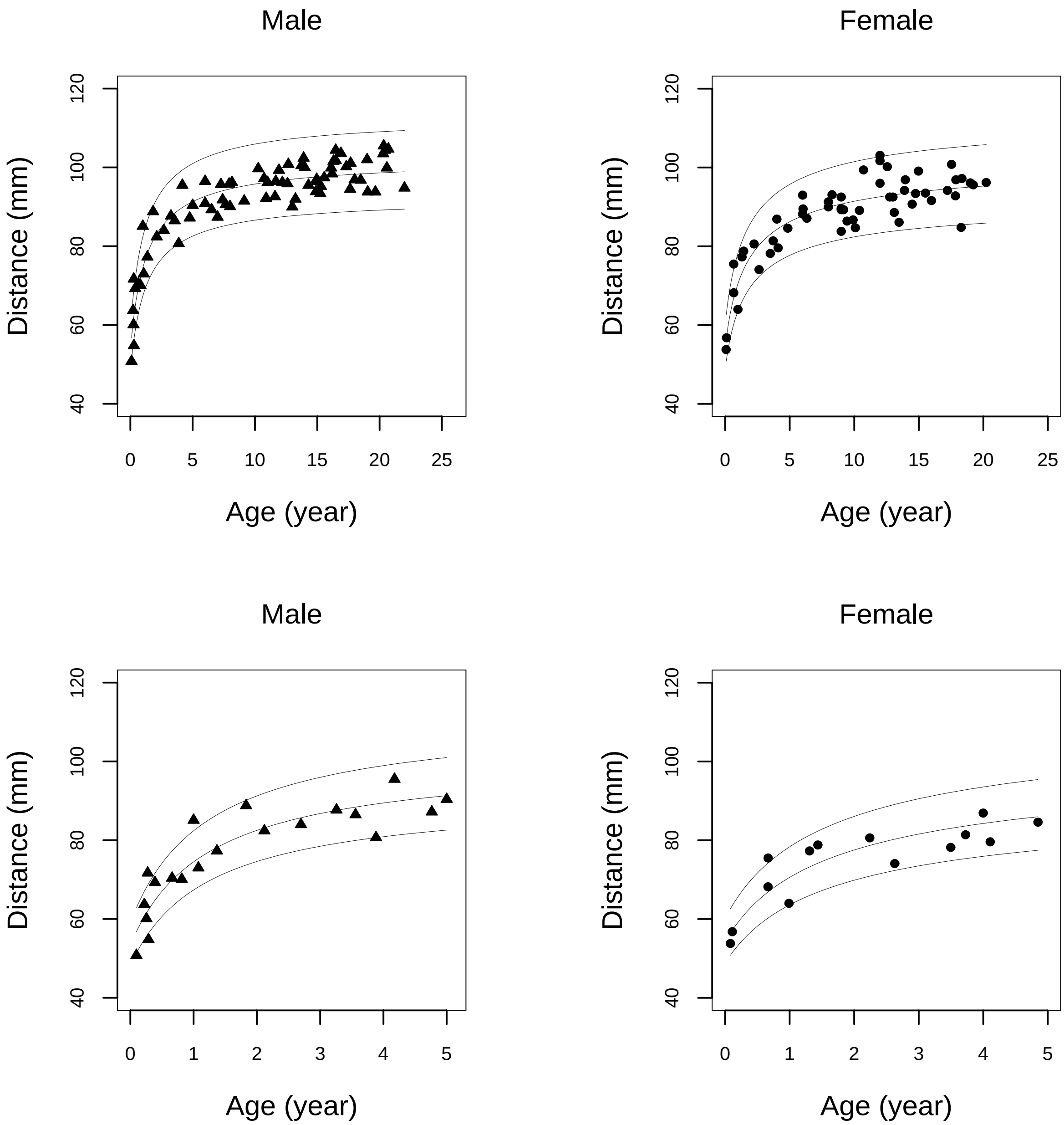

Figure 3.12 Graphs of right lateral cranial vault length (*spc.r-as.r*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.12 Means (M), standard deviations (SD), minimum and maximum values (in mm) for right lateral cranial vault length (*spc.r-as.r*) at different age intervals.

Age	Males					Females					Total				
group	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	9	66.2	10.25	50.8	85.1	5	63.7	8.73	53.8	75.5	14	65.3	9.47	50.8	85.1
1-3	5	81.1	6.11	73.0	88.8	4	77.7	2.75	74.1	80.6	9	79.6	4.97	73.0	88.8
3-5	6	88.0	4.86	80.7	95.5	5	82.1	3.58	78.2	86.9	11	85.3	5.13	78.2	95.5
5-10	11	92.3	3.17	87.4	96.5	14	89.3	2.70	83.8	93.1	25	90.6	3.25	83.8	96.5
10-12	7	96.2	2.94	92.2	99.7	6	95.7	7.34	84.7	103.1	13	96.0	5.18	84.7	103.1
12-14	8	97.2	4.48	90.0	102.4	7	93.0	4.76	86.1	100.2	15	95.3	4.95	86.1	102.4
14-16	7	95.6	1.52	93.4	97.4	5	93.7	3.27	90.7	99.1	12	94.8	2.47	90.7	99.1
16-18	10	100.2	3.00	94.5	104.4	4	96.2	3.52	92.8	100.8	14	99.1	3.57	92.8	104.4
18-25	10	99.9	4.74	93.8	105.5	5	94.0	5.16	84.8	97.2	15	97.9	5.52	84.8	105.5

Anterior cranial base width (*spa.l-spa.r*)

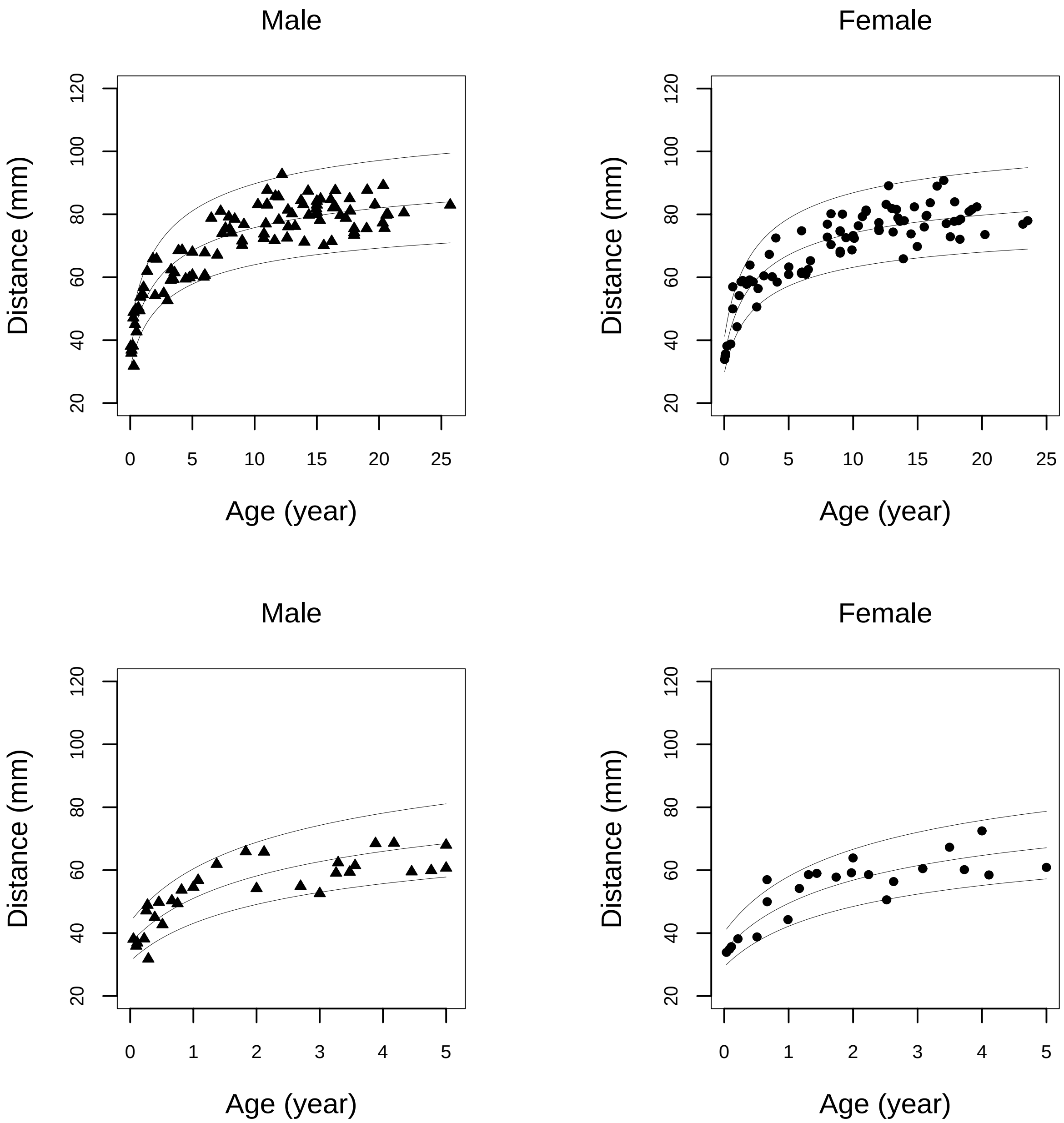

Figure 3.13 Graphs of anterior cranial base width (*spa.l-spa.r*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.13 Means (M), standard deviations (SD), minimum and maximum values (in mm) for anterior cranial base width (*spa.l-spa.r*) at different age intervals.

Age group	Males					Females					Total				
	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	14	44.5	7.21	31.8	54.6	8	41.6	8.22	33.9	57.0	22	43.4	7.53	31.8	57.0
1-3	7	58.9	5.59	52.6	65.9	9	57.6	3.68	50.6	63.9	16	58.2	4.49	50.6	65.9
3-5	10	62.8	4.00	59.1	68.6	6	63.3	5.42	58.5	72.5	16	63.0	4.41	58.5	72.5
5-10	15	72.7	6.46	60.1	81.0	20	69.6	6.38	61.0	80.2	35	70.9	6.51	60.1	81.0
10-12	11	80.1	5.75	71.7	87.7	8	77.3	3.11	72.4	81.4	19	78.9	4.92	71.7	87.7
12-14	9	79.8	6.66	71.2	92.7	10	78.6	6.19	65.9	89.1	19	79.1	6.27	65.9	92.7
14-16	10	81.0	4.72	70.1	87.4	7	77.8	4.93	69.8	83.7	17	79.7	4.92	69.8	87.4
16-18	12	79.7	5.11	71.4	87.6	6	81.9	7.14	72.9	90.8	18	80.4	5.76	71.4	90.8
18-25	10	81.2	4.67	75.5	89.2	9	78.0	3.47	72.1	82.4	19	79.7	4.35	72.1	89.2

Anterior clinoid width (*ac.l-ac.r*)

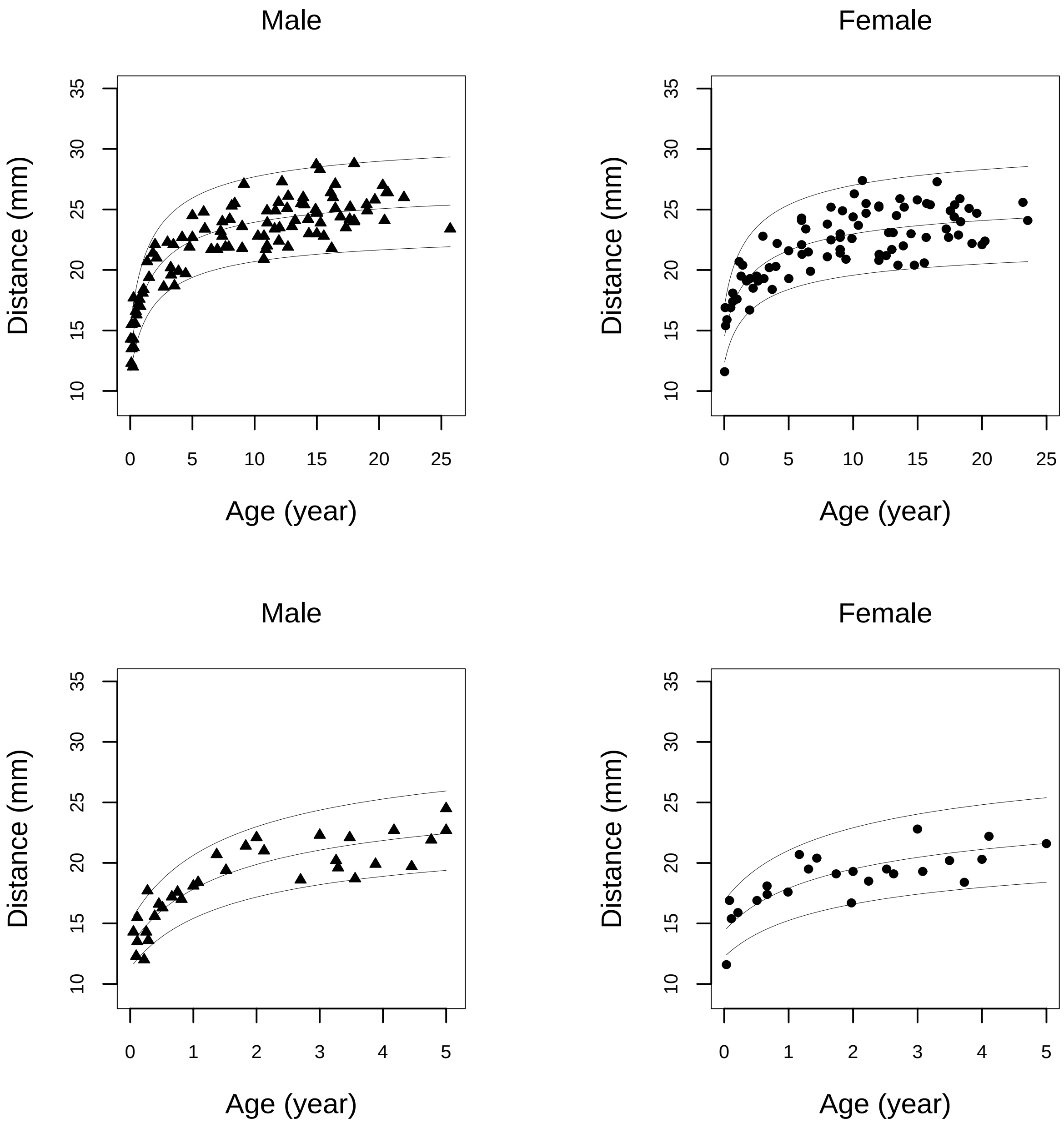

Figure 3.14 Graphs of anterior clinoid width (*ac.l-ac.r*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.14 Means (M), standard deviations (SD), minimum and maximum values (in mm) for anterior clinoid width (*ac.l-ac.r*) at different age intervals.

Age group	Males					Females					Total				
	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	15	15.4	2.00	12.0	18.1	8	16.2	2.07	11.6	18.1	23	15.7	2.01	11.6	18.1
1-3	8	20.5	1.52	18.4	22.3	10	19.6	1.57	16.7	22.8	18	20.0	1.58	16.7	22.8
3-5	10	21.2	1.84	18.7	24.5	6	20.3	1.41	18.4	22.2	16	20.9	1.70	18.4	24.5
5-10	16	23.5	1.59	21.7	27.1	21	22.5	1.61	19.3	25.2	37	22.9	1.66	19.3	27.1
10-12	12	23.2	1.42	20.9	25.6	8	24.9	1.97	20.8	27.4	20	23.9	1.81	20.8	27.4
12-14	9	25.0	1.59	21.9	27.3	10	22.8	1.85	20.4	25.9	19	23.9	2.02	20.4	27.3
14-16	10	24.8	2.09	22.8	28.7	7	23.3	2.30	20.4	25.8	17	24.2	2.24	20.4	28.7
16-18	12	25.1	1.84	21.8	28.8	6	24.7	1.62	22.7	27.3	18	24.9	1.73	21.8	28.8
18-25	9	25.5	1.17	23.4	27.0	10	23.9	1.43	22.1	25.9	19	24.7	1.51	22.1	27.0

Superior spheno-occipital synchondrosis width (*petsa.l-petsa.r*)

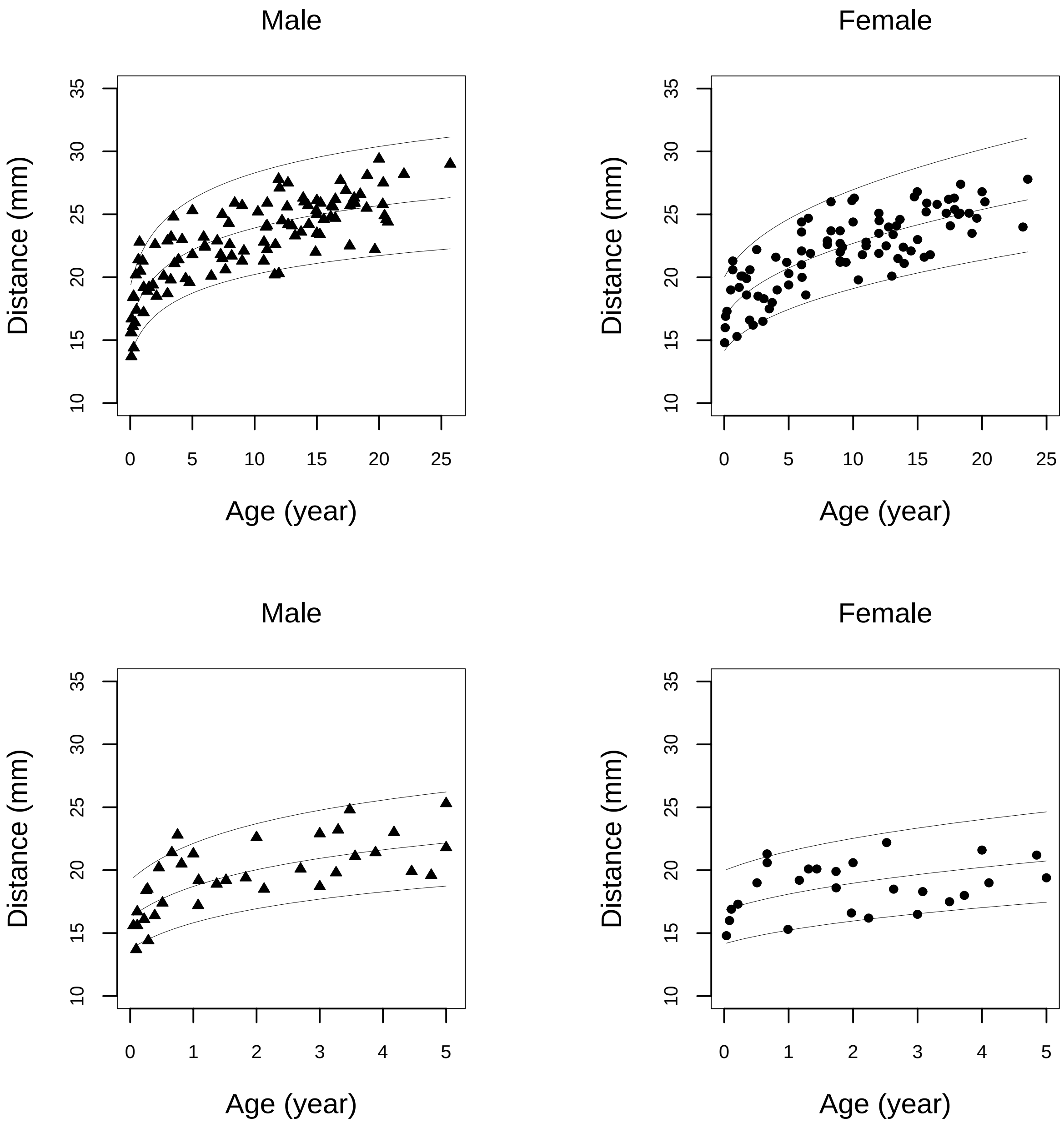

Figure 3.15 Graphs of superior spheno-occipital synchondrosis width (*petsa.l-petsa.r*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.15 Means (M), standard deviations (SD), minimum and maximum values (in mm) for superior spheno-occipital synchondrosis width (*petsa.l-petsa.r*) at different age

Age group	Males					Females					Total				
	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	15	17.9	2.78	13.7	22.8	8	17.7	2.42	14.8	21.3	23	17.8	2.61	13.7	22.8
1-3	10	19.7	1.79	17.2	22.9	11	19.0	1.91	16.2	22.2	21	19.3	1.84	16.2	22.9
3-5	10	22.0	2.04	19.6	25.3	7	19.3	1.58	17.5	21.6	17	20.9	2.27	17.5	25.3
5-10	16	22.7	1.72	20.1	25.9	22	22.6	1.90	18.6	26.1	38	22.6	1.80	18.6	26.1
10-12	12	23.6	2.51	20.2	27.8	8	23.0	2.03	19.8	26.3	20	23.4	2.30	19.8	27.8
12-14	9	25.0	1.41	23.3	27.5	10	22.8	1.55	20.1	24.6	19	23.9	1.83	20.1	27.5
14-16	11	24.7	1.32	22.0	26.1	8	24.1	2.20	21.6	26.8	19	24.5	1.72	21.6	26.8
16-18	12	25.7	1.29	22.5	27.7	6	25.5	0.82	24.1	26.3	18	25.6	1.13	22.5	27.7
18-25	13	26.3	2.07	22.2	29.4	10	25.5	1.43	23.5	27.8	23	26.0	1.83	22.2	29.4

Inferior spheno-occipital synchondrosis width (*pts.l-pts.r*)

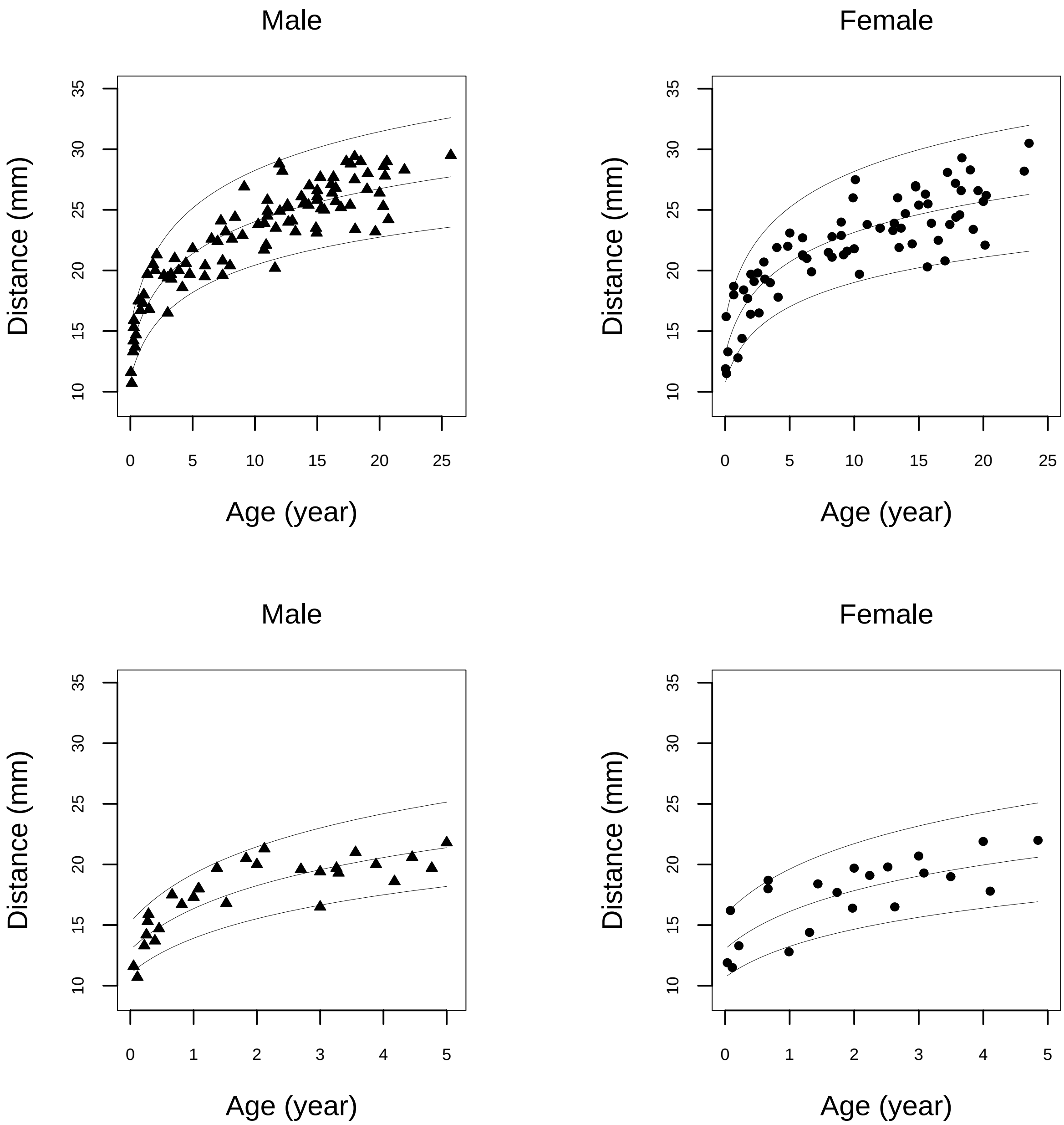

Figure 3.16 Graphs of inferior spheno-occipital synchondrosis width (*pts.l-pts.r*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.16 Means (M), standard deviations (SD), minimum and maximum values (in mm) for inferior spheno-occipital synchondrosis width (*pts.l-pts.r*) at different age intervals.

	Males					Females					Total				
Age group	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	11	14.6	2.22	10.7	17.5	7	14.6	2.97	11.5	18.7	18	14.6	2.45	10.7	18.7
1-3	10	19.0	1.59	16.5	21.3	9	18.1	2.02	14.4	20.7	19	18.6	1.81	14.4	21.3
3-5	8	20.1	1.01	18.6	21.8	5	20.0	1.87	17.8	22.0	13	20.1	1.33	17.8	22.0
5-10	13	22.3	2.14	19.5	26.9	15	22.1	1.49	19.9	26.0	28	22.2	1.79	19.5	26.9
10-12	11	24.0	2.28	20.2	28.8	4	23.6	3.19	19.7	27.5	15	23.9	2.43	19.7	28.8
12-14	9	25.3	1.45	23.2	28.2	7	23.8	1.27	21.9	26.0	16	24.6	1.52	21.9	28.2
14-16	10	25.5	1.45	23.1	27.7	8	24.7	2.39	20.3	27.0	18	25.2	1.91	20.3	27.7
16-18	11	27.2	1.46	25.2	29.4	6	24.5	2.77	20.8	28.1	17	26.2	2.35	20.8	29.4
18-25	13	26.9	2.21	23.2	29.5	11	26.5	2.52	22.1	30.5	24	26.7	2.31	22.1	30.5

Posterior cranial fossa width (*petp.l-petp.r*)

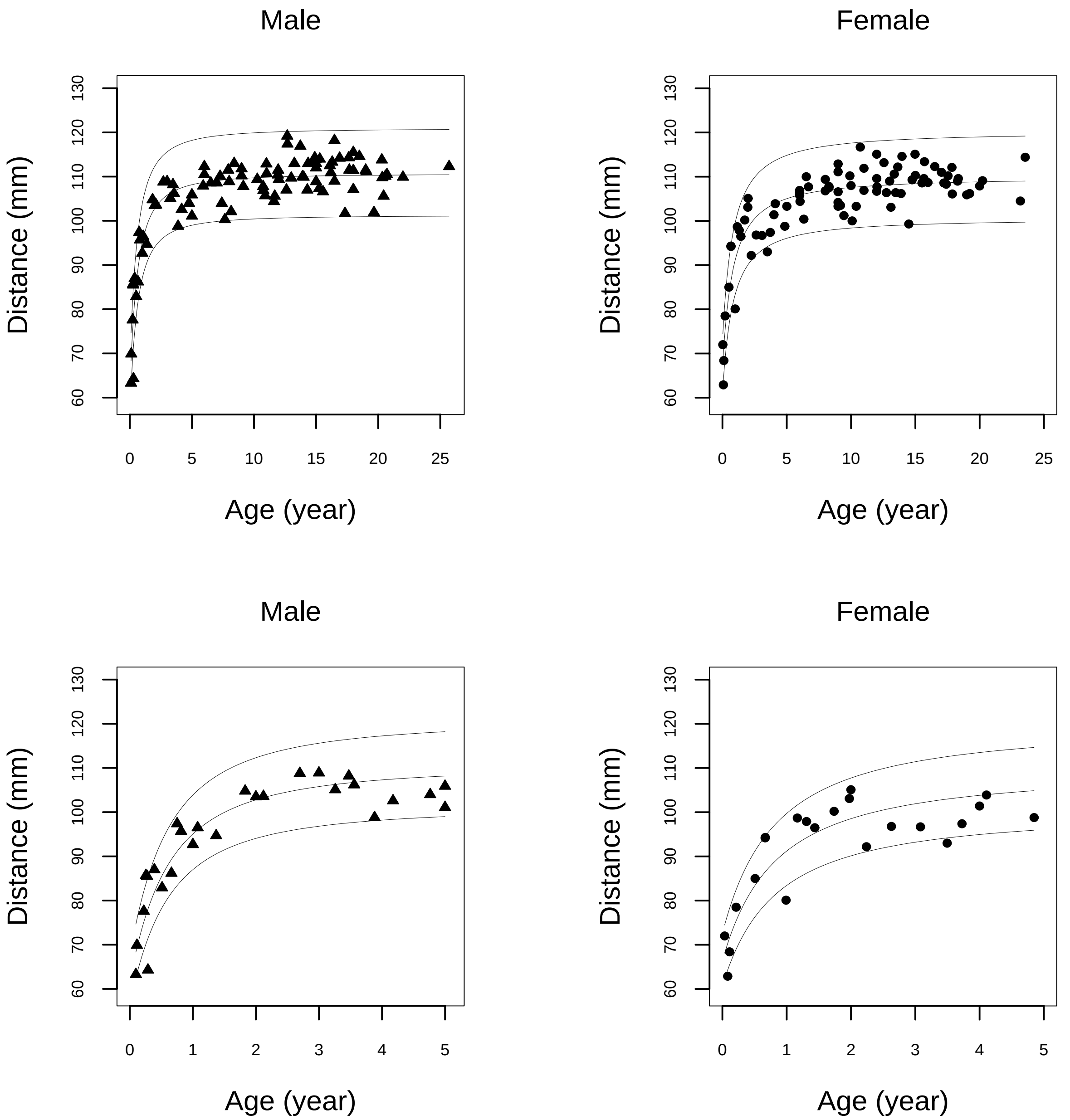

Figure 3.17 Graphs of posterior cranial fossa width (*petp.l-petp.r*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.17 Means (M), standard deviations (SD), minimum and maximum values (in mm) for posterior cranial fossa width (*petp.l-petp.r*) at different age intervals.

	Males					Females					Total				
Age group	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	12	82.4	11.43	63.3	97.4	8	79.4	11.47	62.9	94.3	20	81.2	11.24	62.9	97.4
1-3	7	103.0	5.53	94.7	108.9	8	98.8	4.03	92.2	105.1	15	100.8	5.08	92.2	108.9
3-5	8	104.0	3.04	98.8	108.2	6	98.5	3.80	93.0	103.9	14	101.7	4.29	93.0	108.2
5-10	15	108.5	3.72	100.3	113.0	21	106.5	3.23	100.4	112.9	36	107.4	3.53	100.3	113.0
10-12	11	108.6	2.73	104.4	112.9	8	108.8	5.71	100.0	116.7	19	108.7	4.10	100.0	116.7
12-14	8	112.9	4.45	107.0	119.2	10	108.9	3.65	103.1	114.6	18	110.7	4.39	103.1	119.2
14-16	10	111.0	3.18	106.6	114.3	8	109.3	4.67	99.3	115.1	18	110.2	3.88	99.3	115.1
16-18	12	111.6	4.29	101.7	118.2	7	109.8	2.26	106.1	112.3	19	111.0	3.71	101.7	118.2
18-25	11	110.1	3.60	101.9	114.6	8	108.3	3.04	104.5	114.4	19	109.4	3.41	101.9	114.6

External cranial base width (*ss.l-ss.r*)

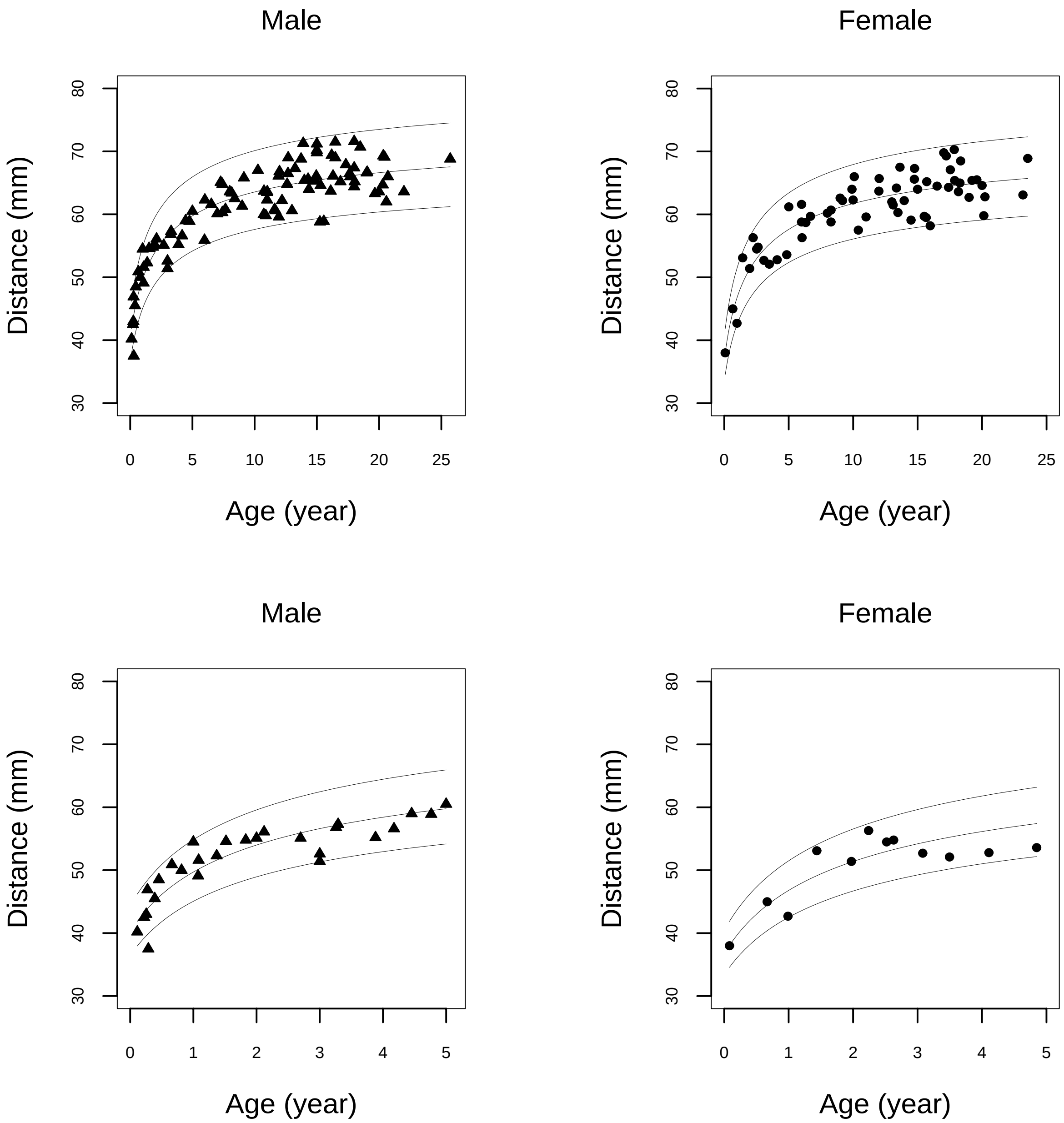

Figure 3.18 Graphs of external cranial base width (*ss.l-ss.r*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.18 Means (M), standard deviations (SD), minimum and maximum values (in mm) for external cranial base width (*ss.l-ss.r*) at different age intervals.

	Males					Females					Total				
Age group	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	10	46.0	5.24	37.5	54.5	3	41.9	3.57	38.0	45.0	13	45.0	5.08	37.5	54.5
1-3	10	53.3	2.21	49.1	56.1	5	54.0	1.85	51.4	56.3	15	53.5	2.06	49.1	56.3
3-5	7	57.8	1.80	55.2	60.5	4	52.8	0.62	52.1	53.6	11	56.0	2.88	52.1	60.5
5-10	13	62.1	2.62	55.9	65.8	13	60.5	2.08	56.3	64.0	26	61.3	2.45	55.9	65.8
10-12	12	62.8	2.74	59.6	67.0	4	61.7	3.85	57.5	66.0	16	62.5	2.95	57.5	67.0
12-14	9	66.2	3.39	60.6	71.3	7	63.3	2.56	60.3	67.5	16	65.0	3.30	60.3	71.3
14-16	10	65.5	4.28	58.8	71.2	8	62.3	3.56	58.2	67.3	18	64.1	4.18	58.2	71.2
16-18	12	67.4	2.58	63.7	71.6	7	67.2	2.57	64.3	70.3	19	67.3	2.51	63.7	71.6
18-25	13	66.1	2.71	62.0	70.7	11	64.5	2.62	59.8	68.9	24	65.4	2.73	59.8	70.7

Foramen magnum width (*fmlhg.l-fmlhg.r*)

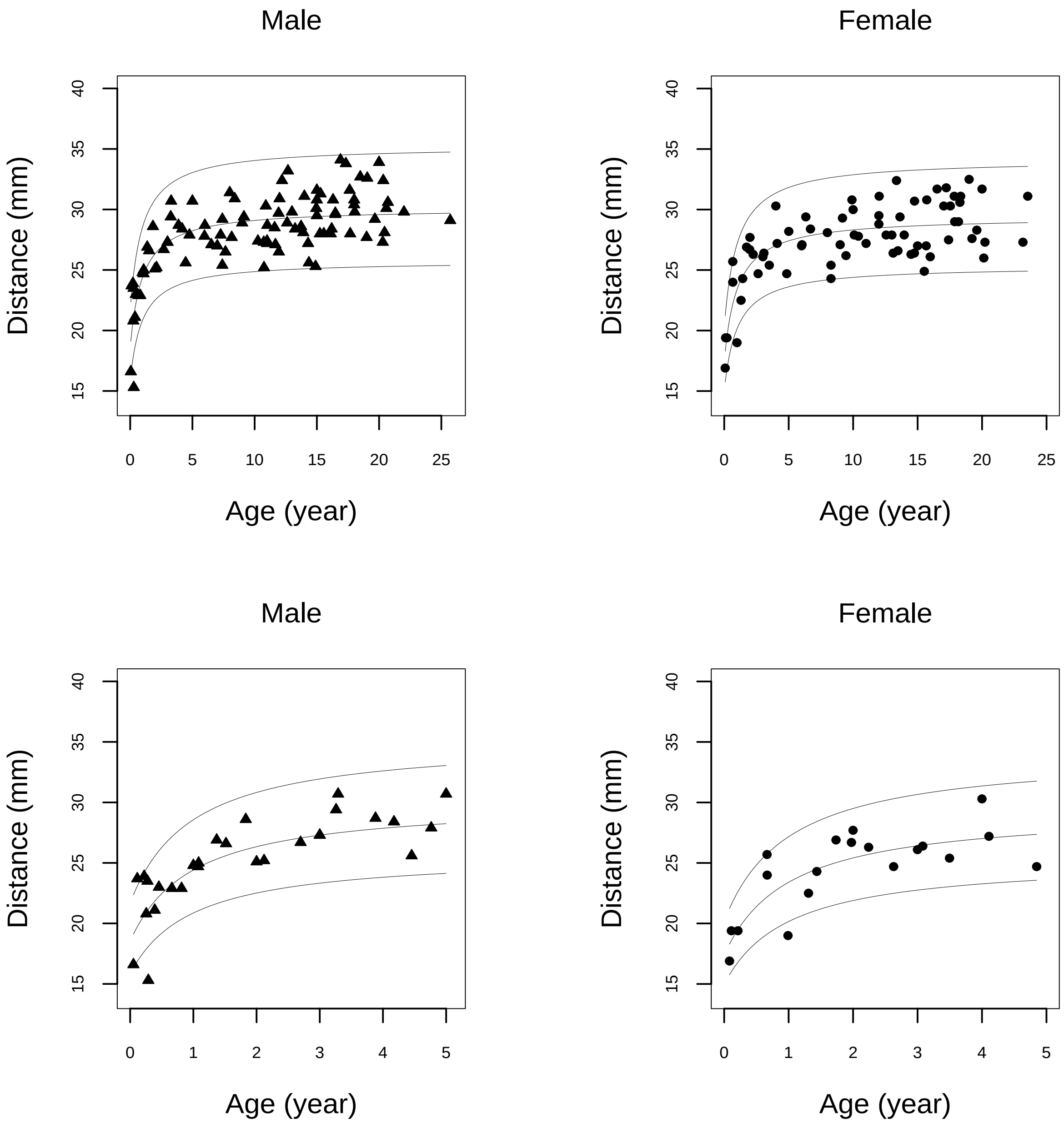

Figure 3.19 Graphs of foramen magnum width (*fmlhg.l-fmlhg.r*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.19 Means (M), standard deviations (SD), minimum and maximum values (in mm) for foramen magnum width (*fmlhg.l-fmlhg.r*) at different age intervals.

	Males					Females					Total				
Age group	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	11	21.7	3.07	15.3	24.8	6	20.7	3.36	16.9	25.7	17	21.3	3.11	15.3	25.7
1-3	10	26.3	1.28	24.7	28.6	8	25.7	1.70	22.5	27.7	18	26.0	1.48	22.5	28.6
3-5	7	28.8	1.77	25.6	30.7	5	26.8	2.18	24.7	30.3	12	28.0	2.11	24.7	30.7
5-10	13	28.3	1.69	25.4	31.4	13	27.8	1.86	24.3	30.8	26	28.0	1.76	24.3	31.4
10-12	12	28.0	1.65	25.2	30.9	5	28.2	0.91	27.2	29.5	17	28.1	1.45	25.2	30.9
12-14	8	30.1	1.95	28.1	33.2	8	28.7	2.12	26.4	32.4	16	29.4	2.09	26.4	33.2
14-16	10	28.7	2.27	25.3	31.6	8	27.4	2.17	24.9	30.8	18	28.1	2.27	24.9	31.6
16-18	11	30.5	2.09	28.0	34.1	7	30.2	1.55	27.5	31.8	18	30.4	1.85	27.5	34.1
18-25	13	30.3	2.09	27.3	33.9	11	29.3	2.17	26.0	32.5	24	29.8	2.13	26.0	33.9

Left anterior cranial fossa length (*sor.l-spa.l*)

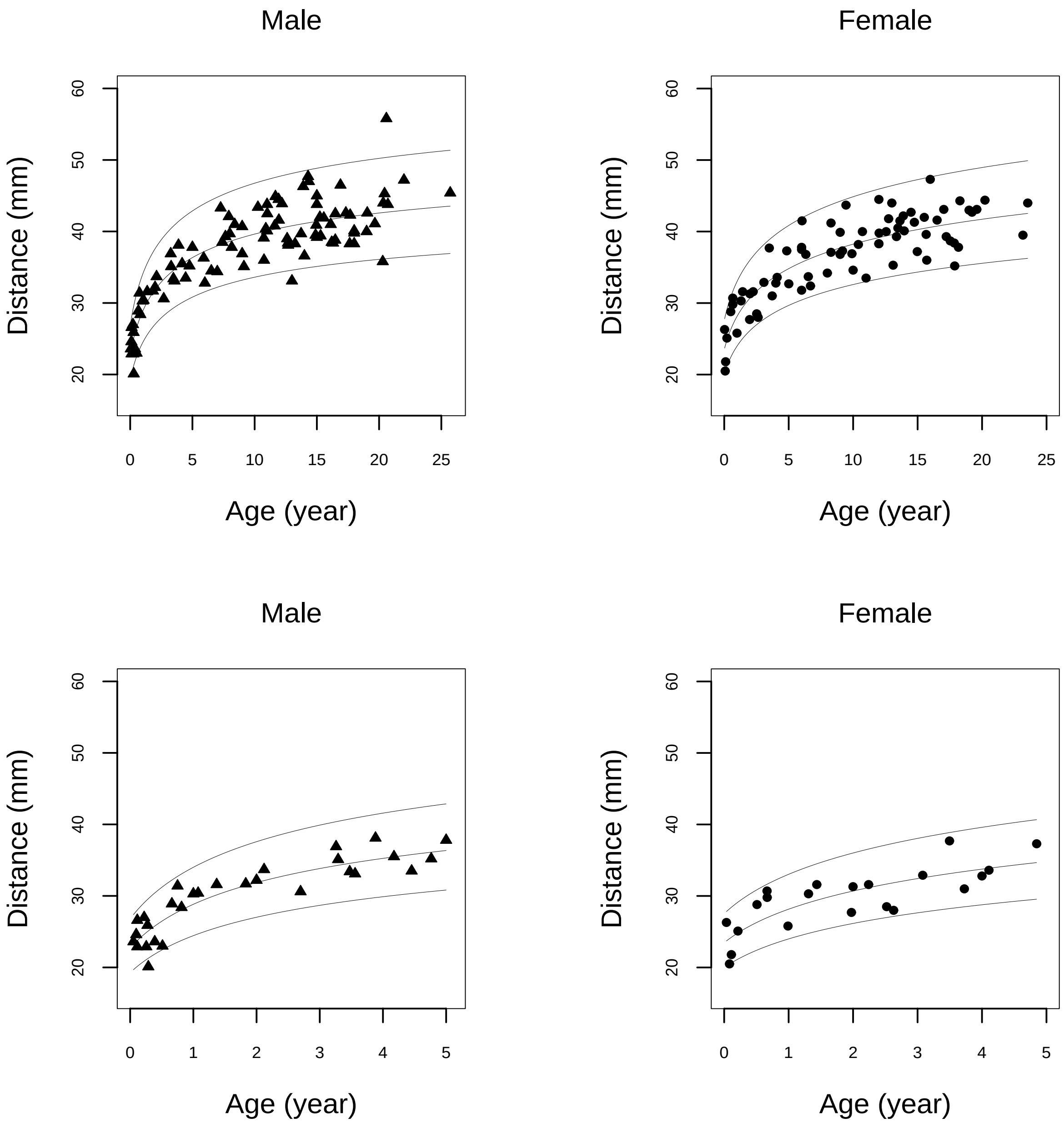

Figure 3.20 Graphs of left anterior cranial fossa length (*sor.l-spa.l*) versus age for males and females from birth to adulthood (above) and from birth to age five years (below).

Table 3.20 Means (M), standard deviations (SD), minimum and maximum values (in mm) for left anterior cranial fossa length (*sor.l-spa.l*) at different age intervals.

	Males					Females					Total				
Age group	N	M	SD	Min	Max	N	M	SD	Min	Max	N	M	SD	Min	Max
0-1	14	25.7	3.26	20.1	31.4	8	26.1	3.65	20.5	30.7	22	25.8	3.33	20.1	31.4
1-3	6	31.7	1.20	30.4	33.7	7	29.9	1.75	27.7	31.6	13	30.7	1.74	27.7	33.7
3-5	9	35.4	1.88	33.1	38.1	6	34.2	2.69	31.0	37.7	15	34.9	2.23	31.0	38.1
5-10	14	38.0	3.17	32.8	43.3	18	36.8	3.28	31.8	43.7	32	37.4	3.24	31.8	43.7
10-12	11	41.6	2.65	36.0	44.9	6	38.8	3.55	33.5	44.5	17	40.6	3.19	33.5	44.9
12-14	9	39.3	3.86	33.1	46.3	10	40.5	2.29	35.3	44.0	19	39.9	3.10	33.1	46.3
14-16	10	42.6	3.12	39.2	47.7	7	40.9	3.76	36.0	47.3	17	41.9	3.41	36.0	47.7
16-18	12	40.6	2.51	38.3	46.5	6	39.4	2.74	35.2	43.1	18	40.2	2.58	35.2	46.5
18-25	10	44.1	5.24	35.8	55.8	8	42.4	2.41	37.8	44.4	18	43.3	4.21	35.8	55.8