A RADIOGRAPHIC AND PHOTOGRAPHIC STUDY OF THE CRANIO-FACIAL COMPLEX OF THE RABBIT

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by
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"A RADIOGRAPHIC AND PHOTOGRAPHIC STUDY OF THE CRANIO-FACIAL COMPLEX OF THE RABBIT"

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A dissertation submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

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ABSTRACT

A longitudinal three-dimensional cephalometric radiographic study was carried out on a "large" and "small" breed of rabbit. Also included in the investigation was a three-dimensional photographic study of six groups of the skulls of wild rabbits. The rabbit was chosen primarily because of its range of size variation in the different varieties. The skull is large enough to measure accurately, small enough to handle easily, and growth is completed in six months. The object of this thesis was to examine the mode of growth of the rabbit skull and relate it to the variations seen in adult animals in an attempt to predict adult form from data obtained during growth.

A method for examining the mode of growth for the rabbit skull was developed and it was concluded that:

(1) The basic nature of variation in the adult form of the different rabbit groups can be demonstrated.

(2) Growth occurring in three dimensions can be described as a precise logarithmic process involving changes in size and shape. The process is basically a *cohesive phenomenon involving the entire head.

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* --cohering, or sticking together, as in a mass. Webster's New International Dictionary, Second Edition, (unabridged).

(3) Points on the rabbit skull can be represented as closely adhering to the allometric growth equation $Y = aX^n$, thus the direction of movement for any given point throughout growth on an individual animal is constant and is represented by the two invariates "a" and "n".

(4) A precise mode of growth, if described mathematicaly, affords a method of projecting the future shape of the skull.

(5) After examining the relationship between attained adult size and the size at specific ages during growth, it was found that a strong correlation existed between the size at seven weeks and that at maturity. The method of measurement was found to be important as measurement in a traditional linear manner yielded lower correlation values than measurements made along the growth curvatures.

(6) High correlations permitted a relatively accurate prediction of "final" adult size to be made from the seven week records.

(7) The strong size correlations in combination with the dependability of the growth predictions confirm the contention that genetics and not environmental

factors are dominant in growth under controlled environmental conditions.

(8) The similar magnitude of variation in wild and domestic groups, suggest that no substantially greater environmentally induced variation occurs in adult wild animals.

(9) The application of similar techniques to man might eventually lead to a clinically valuable method of predicting the adult dimensions of the human cranium.

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INTRODUCTION

The object of this thesis is to examine the mode of growth of the rabbit skull and relate it to the variations seen in adult animals in an attempt to predict adult form from data obtained during growth.

Most studies of skull growth have examined human material in the lateral orientation. No successful method of growth prediction has emerged from these investigations. Recent investigations by McKeown (1972) has suggested that skull growth in dogs can be represented as a precise and predictable process when viewed in three dimensions.

It was decided to carry out a longitudinal three-dimensional cephalometric radiographic study using a large and small breed of rabbit. Also included in the investigation was a three-dimensional photographic study of six groups of the skulls of wild rabbits. The rabbit was chosen primarily because of the large range of size variation in the different varieties. The skull is large enough to measure accurately, small enough to handle easily, and growth is completed in six months.

REVIEW OF THE LITERATURE

Growth is a complex phenomenon and the methods used to describe it have taken many, and often divergent, pathways. There are numerous ways to represent the changes which occur in growth. Workers interested in nutrition will often describe growth as increased changes in weight and height. Physical anthropologists often use metric linear measurements on dry material to describe changes that have taken place. Many of these methods are not designed to define precisely the changes in overall form. Only in radiographic growth studies has this been attempted and it has been mainly in two dimensions.

Numerous growth studies have and are still being done in man. Broadbent (1931), in a longitudinal study of 1700 children between the ages of 9 months and 21 years, published the first work in the United States describing a standardized cephalometric technique. Keith and Campion (1922) and Krogman (1958) utilized tracings which were obtained from craniostatic drawings of skulls. Broadbent (1937) suggested that there was a pattern of facial growth which was in a downward and forward direction and showed some consistency in change. Metallic implants have been inserted into patients to study growth. Bjork (1955) placed metallic implants in the mandible and maxilla of young orthodontic patients, and a series of longitudinal records were obtained using a cephalometric radiographic technique. The changes noted were linear and no precise patterns were found to describe the mode of growth, hence, no accurate methods of prediction in the individual's growth has emerged.

Many methods have been pursued in an attempt to predict growth. These investigations have been made almost without exception using the 90 degree right lateral cephalogram, the records being superimposed often on the cranial base. Univariate, bivariate and multivariate statistical analysis have been used in attempts to identify certain trends. Most workers, however, have not been able as a result of these methods, to describe with a sufficient degree of accuracy the magnitude and direction of growth so that the ultimate shape and size of an individual can be predicted.

The development of microscopy as a method of describing growth has allowed researchers to get involved in the particular rather than the general. Another way of saying this is that they have become involved in reductionism, to the exclusion of the investigation of modes of growth of the total shape and form.

Growth is not a single, but a multiple event. It is the combined expression of the development of a number of parts of an organism. To express the sum of the parts of the growing form without looking at the whole and total morphologic shape of the growing form from inception to maturity is a form of reductionism. The fact that growth and shape could be described in measurable relationships was recognized as early as the 13th century. Most of the early mathematical descriptions of shape involved symmetry in plants and animals.(Holt, 1966) With a greater knowledge of geometry and the use of logarithms, shape and growth changes were more accurately described. Logarithmic spirals occur in the curve of elephant tusks, sheep horns, the claws of a bird and in rodent incisors. Spiraled flowers and chambered shells were found to change with a certain mathematical sequence.

Descartes, (Struik, 1948) was often skeptical of men who proudly announced that they had discovered something new. He realized that what was believed up to that point in the 17th century was brought from the past and was not exactly new, and furthermore, there was very little within the sphere of knowledge that was not still in dispute. Descartes wrote a rather philosophical book in 1637 and at the end of this book he placed a footnote which he called "The Geometry". From this footnote, which was written long before anyone had thought of such a thing as graph paper, came the basics for the techniques involved in describing growth.

In 1641, Descartes published his "Discourse on Method", (Thompson, 1971) in which the third of his four rules of logic stated that "to commence my reflections with objects which were the simplest and easiest to understand, and rise thence, little by little, knowledge of the most complex." This concept placed within his mechanistic awareness of the body the foundation for the modern "reductionist" approach (Koestler and Smythies 1968), a philosophy vigorously opposed by the concept of 'holism'. This word was used by General Smuts in 1926 to push at a very ancient doctrine that the whole is always something very different from its parts.

The work of D'Arcy Thompson, 1917, pointed out the important relationship between form and function and the biological implication of its limitations. He defined the form of objects and attempted to demonstrate the way in

Huxley (1924 and 1932) sought to clear up the diversities in terminology that were used to describe the relative growth of an organism. Many early terms were confusing. Disharmony was an early term used to denote the exaggerated proportions of some of the parts. There was a connotation associated with much of the early terms which suggested an abnormality. He suggested that the concept of allometry (Huxley, 1936) be used to describe growth of a part at a different rate than the whole. As Huxley (1932) states, "The co-ordinate method, while of ultimate importance in affording a graphic and immediate proof of the need for postulating regularities in the distribution of growth throughout the body, it is of little use for detailed analysis, because by its nature it neglects the fundamental attribute of differential growth, namely the change of relative proportions with absolute size. It is static instead of dynamic and substitutes the short-cut for a geometric solution and a more complex reality actually underlying the biological transformation."

Huxley, however, primarily concerned himself with mathematical relationships between parts. With the exception of his studies on the coiling of shells, he did not use his allometric principle to define the changes in form of a specific and relatively discreet area of the skull. McKeown, 1972, has identified the allometric nature of skull growth and its implications in the forming of the growing head.

As reviewed by Enlow (1975), the development of the x-ray enabled the researcher to see inside the body and record the relative growth of various parts. Later the researcher became involved in various microscopic investigations of tissue in the body and this led him to a description of finer and finer changes in the organism. The electron microscope is reductionism at its finest, and while it serves as a valuable tool to study the microcosm it is inadequate for studying the whole. Several concepts have forced us to begin thinking of growth changes in view of the whole.

Moss (1960) feels that growth of the skull is secondary to the growth and function of what he calls the neural mass. Moss's ideas of the functional matrix are based on the theory originated by Van der Klaaw (1948). Moss believes that the growth of the functional components, that is, all non-ossifying tissue acts as a functional matrix and the ossification mechanism is dependent upon it. He feels that the cerebral capsule passively carries the calvarial bones outward and that the suture formation is the filling-in process. His interests have created a more 'holistic' attitude to the study of skull growth.

McKeown (1972) did a study on several litters of dogs with different growth potentials. He felt that there were some unanswered questions concerning the nature of growth processes and pointed out that there was still some difficulty involving the prediction of growth. He supported earlier rejections of linearity as a meaningful biological measurement and assumed the stance that craniofacial growth must be re-examined from the viewpoint of the whole. He supported the allometric concepts of Huxley (1932) and in his three-dimensional radiographic study of the dogs' skull described logarithmically, growth patterns. Based on limited evidence he contended that the basic form of the skull is determined early in foetal life and growth thereafter is an expansive, logarithmic process.

Thus we begin to see the emergence of a description of the body form and shape of an individual at any stage of development as a function of the relative adult size of the body rather than the proportion of any of the various parts and organs to each other. The most difficult thing is to grasp the concept that there is a difference between allometry and relative growth while still using relative growth in the concept of allometry. The basic allometric relation is expressed by the equation $Y = aX^n$ with "Y" representing a part, "X" representing another part or the whole, and "a" and "n" are constants for that individual during growth. The equation can be used to describe a parabola or a hyperbola depending on whether "n" is negative or positive. In logarithmic form, the equation becomes $\log Y = n \log X + \log a$. The description of growth in terms of the allometric equation ignores time relations of growth. The allometric equation can be applied without regard to time, but in order to predict adult size you need to know the size of the curve at an early stage.

If we do show that the entire cranium adheres to the principle of allometric growth and that the basic shape of the skull is determined at early stages of foetal development we must still determine what the ultimate size and shape in the adult form will be. In other words, we should determine its final magnitude. The principles of allometric growth can tell us the future form of the skull. It cannot, by itself, indicate the magnitude of growth which has taken place at any given future point in time.

In growth prediction, what affect does the environment have on adult form and shape of the skull? Growth rate is well known to be susceptible to alteration in environmental variabilities. McCance et al. (1968), in a study of 35 pigs, demonstrated that severe undernutrition results in a retardation of skull growth. He was, however, much less certain to what extent the final adult size of the head can be so influenced. We do know that many environmental factors alter growth rate. Guerreo et al. (1973) submitted pigs to severe malnutrition for seven months and found a retardation of mandibular growth. No observations were made of any other parts of the skull. Extreme changes in environment, of course, are capable of altering the body shape and size during growth. It is not so obvious, however, that environmental factors cause noticable changes in the final, or adult, form.

McKeown (1974) in a study of wild and domestic foxes suggested that their domestication does not result in different skull form in the adult. He found that both groups had very similar skull forms, arch and tooth dimension and tooth orientation. This would support other contentions that the wild environment many animals have to endure has little effect upon their growth potential.

The variability of an animal and the ultimate size of the animal at maturity depend on many things. First of all, litter size is important. There is often a lot of competition for feeding space and a small litter will often produce a larger animal, in certain species, at least. The nutrition and general maternal environment that the animal receives in utero is important as is the food supply that it receives after it is born. McCance et al. (1962) found that there are various ways that an animal's growth can be interupted. He found that there are areas of accentuation, alteration, interference during the development of an animal. He found that there are parts of an animal with greater structural stability than others and during periods of fixed weight there will be differences in the rate of growth of certain parts of the body. During interferences of growth there is more variability in the weight of the animal with a low fat priority, whereas, the skeletal system has greater stability and is less affected by different planes of nutrition (McCance, 1962). Studies of animals on high planes of nutrition show that the velocity of the skeletal growth of animals given more nourishment than they need is related to the amount of growth that is left. The growth magnitude is a function of age only if this growth rate is uniform. It may be postulated that animals grown in a stable environment would have a more stable growth rate than animals grown in an environment where insults to the would alter the velocity or the rate at which the animal uses the growth potential that is left after the retardation.

In nutritional studies of male wistar rats, Jefferys (1969) found environment conditions affected the growth process and the catch-up phenomenon. He observed changes in the craniofacial skeleton and these changes occurred in both the size and the shape; as he defined these parameters he found that environmental influences on the general growth patterns were significant and that the influence of these environmental changes was primarily reflected on the intensity of the growth and not the ultimate size of the animal skeleton. He concluded that relatively small environmental differences can produce changes in size and in shape. Butterworth (1961) did a study on two closely related varieties of kangaroo rats. He found that there are differential rates of growth during the development of these two species and they were not always related to environment. He found that precocious growth especially during the early development brings an animal to an earlier seasonal reproductive potential and may allow for earlier dispersion. While he made no comparison between sizes of animals grown in the laboratory and those in the wild, he did conclude that the size of the litter made no appreciable difference in growth rates.

Using linear measurements, Boas (1971) found that first generation emmigrants from Europe showed certain modifications in cranial shape while Morant (1949) from a cross-sectional study, found no suggestion that the variation in living conditions in the past 10,000 years have been associated with a change in stature. Hunter (1965) did a study of inheritance of craniofacial characteristics in 72 pairs of twins, but as in many studies with twins, there is an absence of controls.

McCance, et al. (1961) in a study of 39 pigs, found that a varying plane of nutrition affect some parts of the bony framework more than others. The endocranial cavity was less affected, but was smaller to a slight degree. There was a difference between the mandible and maxilla with the mandible being affected to a lesser degree. Rehabilitation of undernourished pigs restored proportions of the skull and jaws to normal. Watt, et al. (1951) measured tooth wear and size of the mandible and maxilla of rats which were fed very hard types of food. He showed that the physical consistency of food altered the wear on the teeth. Also he postulated that this was the cause of an alteration of the weight, volume and density in the mandible.

Silberberg (1950) using varying planes of nutrition with 250 male inbred strains of mice found many microscopic changes in the skeletal system, but the results of the experiment seems to show that there is very little variability in the actual adult size of the skeleton. Later work has shown that mice fed unrestricted amounts of either high fat or high carbohydrate diets rank equally in weight-gain and mature as those fed the respective diets ad libitum. It has been also shown that animals which were fed restricted diets and then switched to a normal laboratory type of food again ad libitum, show a recovery from some of the microscopic differences in epiphyseal development. The reversability or irreversability of changes microscopically have very little effect on the total skeletal growth and are of no particular consistency and often are not related to changes in the diet.

It is of no surprise that the ad libitum fed animals in many experiments consume much larger quantities of food than in controlled diets and often show a more advanced skeletal development than those uncontrolled diets. Most workers in the field of animal research conclude that an ad libitum diet of most commercial laboratory feed, which contain proper amounts of fat and carbohydrates will give the full potential influence on skeletal growth, development and maturation.

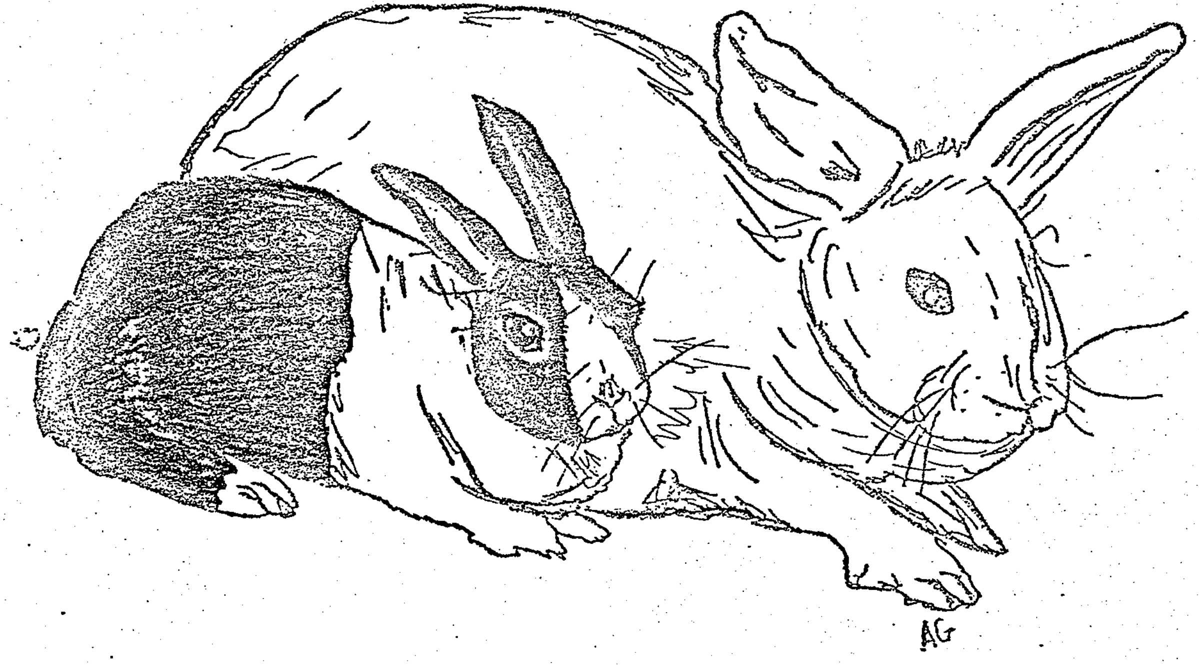
Most workers in the field of animal research conclude that an ad libitum diet of most commercial laboratory chows, which contain proper amounts of fat and carbohydrates will allow an animal to attain its whole genetic growth potential. It seems, therefore, that we must consider not only the possible effects of environmental variations, but also the probable ones.

The rabbit is a suitable model for further study in areas of growth prediction. Some general growth data is available for the longitudinal skeletal growth and maturation of rabbits with Castle (1929) and Punnet et al. (1918) indicating that the animals were generally suitable for growth studies. No long term, comprehensive studies have been made of wild animals and the insults that their skeletal systems might receive from periods of food shortage.

It seems, however, that in spite of the transient environmental insults regularly suffered by organisms during growth, there is little evidence to show that adult form is usually substantially affected by them, thus growth prediction may be possible because of the essentially genotypic nature of adult form.

By using the rabbit in a longitudinal growth study and also by studying the cross-sectional material, it is hoped that information on three dimensional growth changes can be used to obtain a cohesive and predictable picture of growth which will lead to valuable predictive methods of skull growth being observed.

MATERIAL AND METHODS



RABBITS

The animals used in this study consisted of eight groups of rabbits. The longitudinal portion of two varieties of domestic rabbit of different adult size. (Figures 1, 2 and 2). The cross-sectional sample consisted of six groups of wild lagomorphs each of which varied in adult size (Figures 5 through 12). The domestic rabbits were raised in a controlled environment which is described in the section "Care and Feeding of the Animals". The wild rabbit sample was obtained from a collection of skulls which were kept at the University of California, Museum of Natural History at Berkeley, California. All rabbits are in the order Lagomorpha family Leporidae. This includes all rabbits and hares, subfamily Leporinae. The genus, species and common name of the rabbits are listed along with Table VIII.

The two varieties of domestic rabbit were the Dutch and the New Zealand. The parents were chosen from true strains of both varieties. The 25 rabbits used in this study consisted of two litters of Dutch totalling nine rabbits and four litters of New Zealand totalling sixteen.

The Dutch is a popular and well-known domestic rabbit. This hearty little animal which weighs 4½ pounds as an adult, can be easily recogonised by its clear cut saddle,

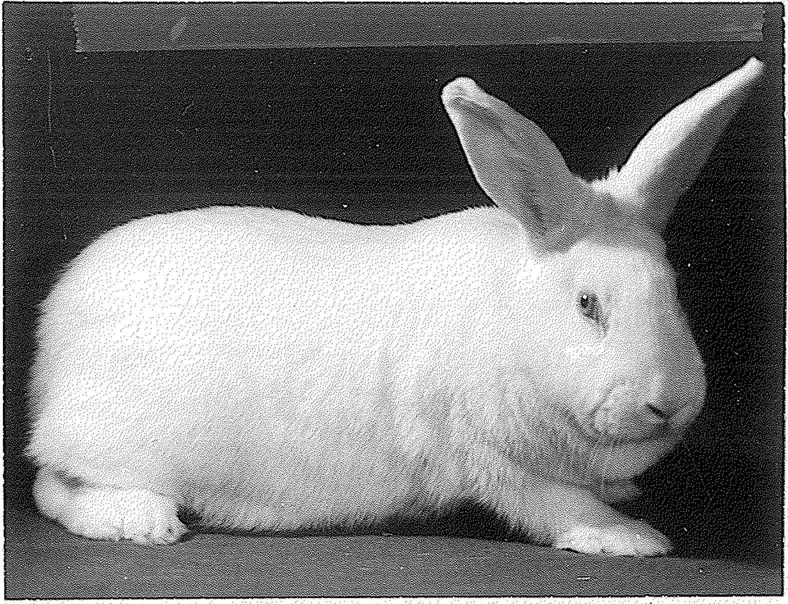


Figure 1. Oryctolagus cuniculus
(New Zealand domestic rabbit)

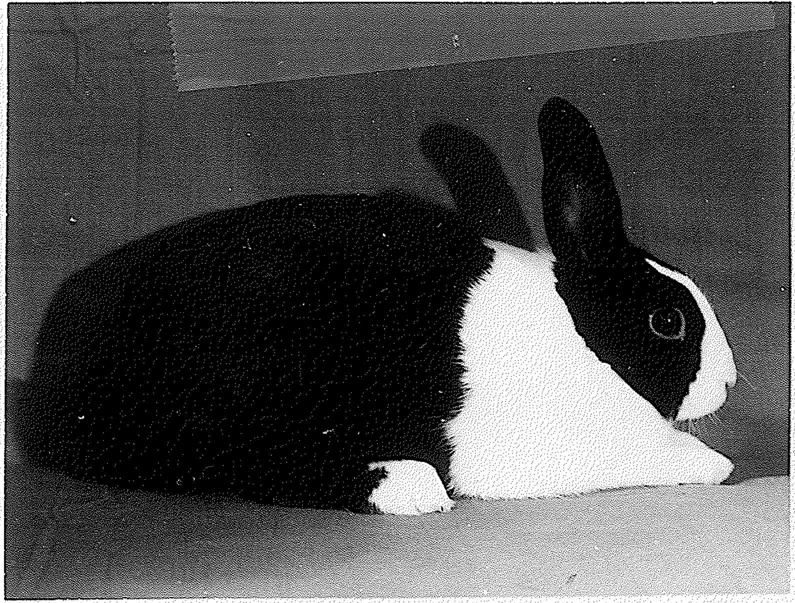


Figure 2. Oryctolagus cuniculas
(Dutch domestic rabbit)

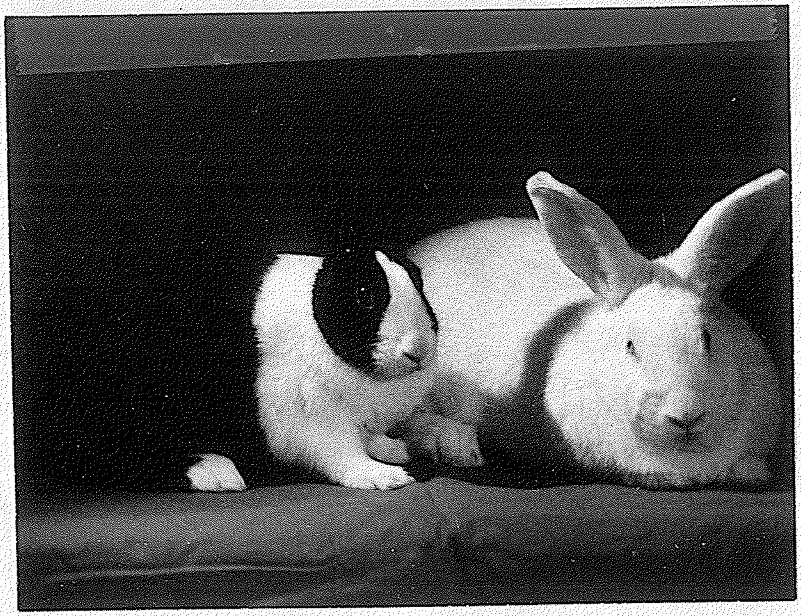


Figure 3. Dutch and New Zealand adult rabbits

Total 28

$$I.\,\frac{2}{1}\quad C.\,\frac{0}{0}\quad Pm\,\frac{3}{2}\quad M.\,\frac{3}{3}$$

Figure 4. Dental formula for the rabbit

blaze, pear-shaped cheeks and stops. The colour of this coby rabbit is found in a combination of black and white, blue and white, grey and white, steel grey and white, and tortoise shell. The larger New Zealand White originated from America with the adult weighing between nine and twelve pounds depending on its sex. It has a medium length of body, broad shoulders and haunches forming a block shape. Being an albino, it has pink eyes and a dense white coat with decidedly heavier guard hairs.

The wild sample of rabbits was collected in the Western United States. Some of the rabbits were collected as early as 1906. There was a large group in the collection that dated from the middle thirties. The largest part of the collection was obtained between 1960 and 1970. The skulls were well numbered and the skins of each rabbit had a corresponding numbered tag. They were kept in drawers which were sealed in large metal cabinets. Only adult rabbits were used in the cross-sectional study. Figures 5, 6 and 7 show the great variety in the size of the skull of the sample collected.

As can be seen in Table VII in the Results Section, the largest of the rabbits was the black-tailed jack. Measuring from the posterior occipital protuberance to the most anterior point of the premaxilla, the largest of these was 9.34 cm. The

Figure 5

Complete adult crania (lateral view) of:

- Lepus townsendi townsendi--White-tailed Jack Rabbit
- Lepus californicus deserticola--Black Jack Rabbit
- Sylvilagus bachmani tehemae--Brush Rabbit
- Sylvilagus idahoensis--Pygmy Rabbit

From top down

Figure 6

Complete adult crania (basilar view) of:

- Lepus townsendi townsendi--White-tailed Jack Rabbit
- Lepus californicus deserticola--Black Jack Rabbit
- Sylvilagus bachmani tehemae--Brush Rabbit
- Sylvilagus idahoensis--Pygmy Rabbit

Left to right

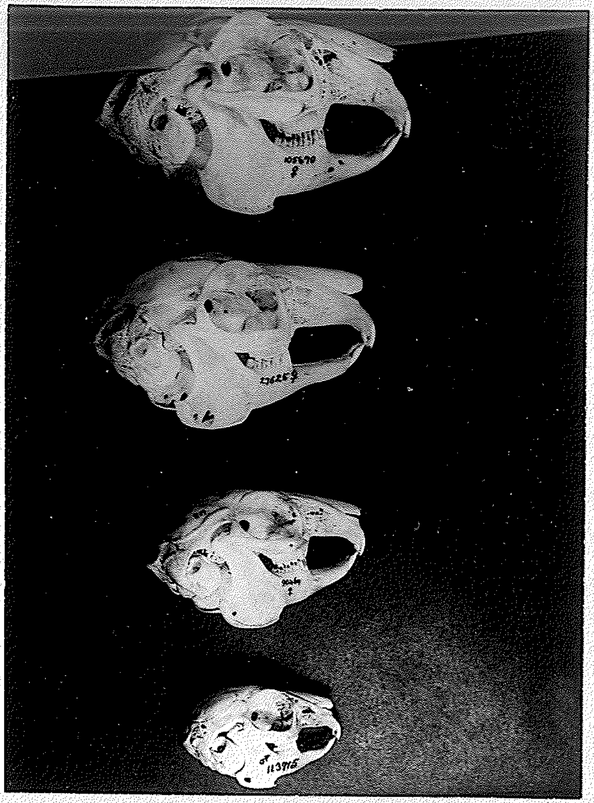


Figure 5

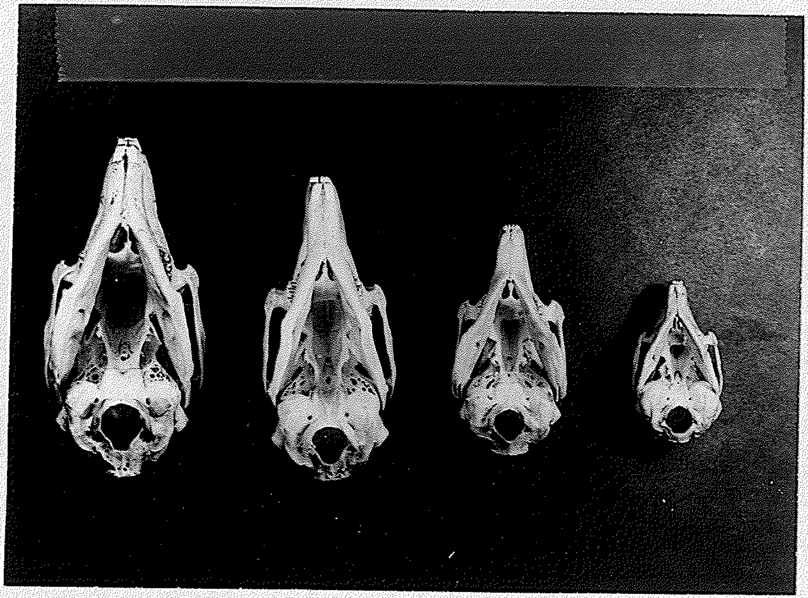


Figure 6

Figure 7

Adult mandibles of:

- Lepus townsendi townsendi--White-tailed Jack Rabbit
- Lepus californicus deserticola--Black Jack Rabbit
- Sylvilagus bachmani Tehemae--Brush Rabbit
- Sylvilagus idahoensis--Pygmy Rabbit

From top down.

Figure 8

Four stages of development of:

- Lepus californicus californicus--Black-tailed Jack Rabbit

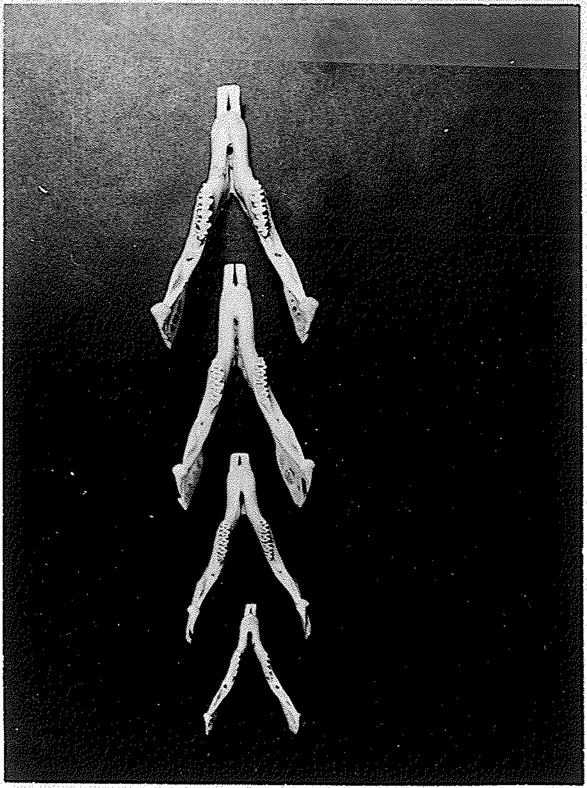


Figure 7

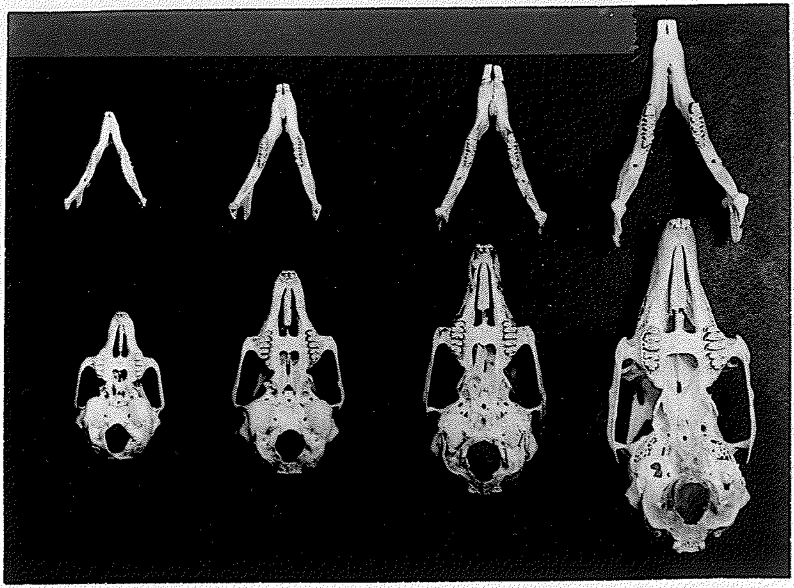


Figure 8

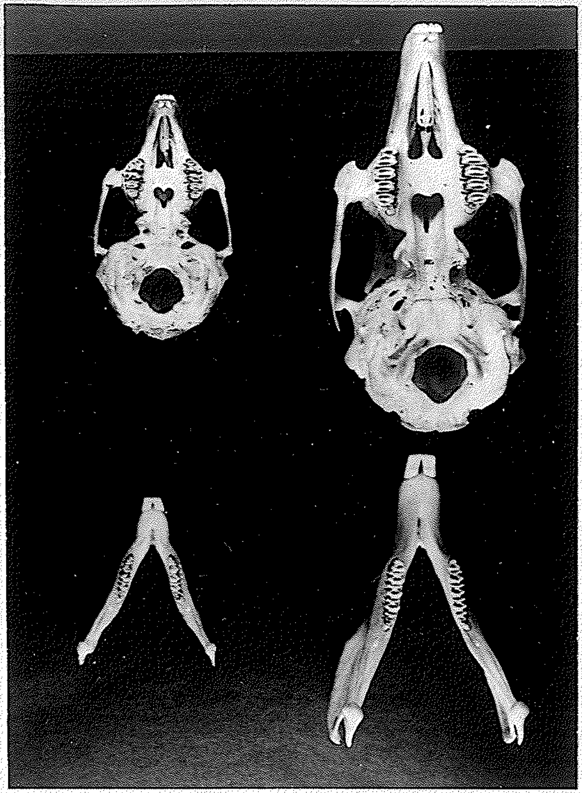
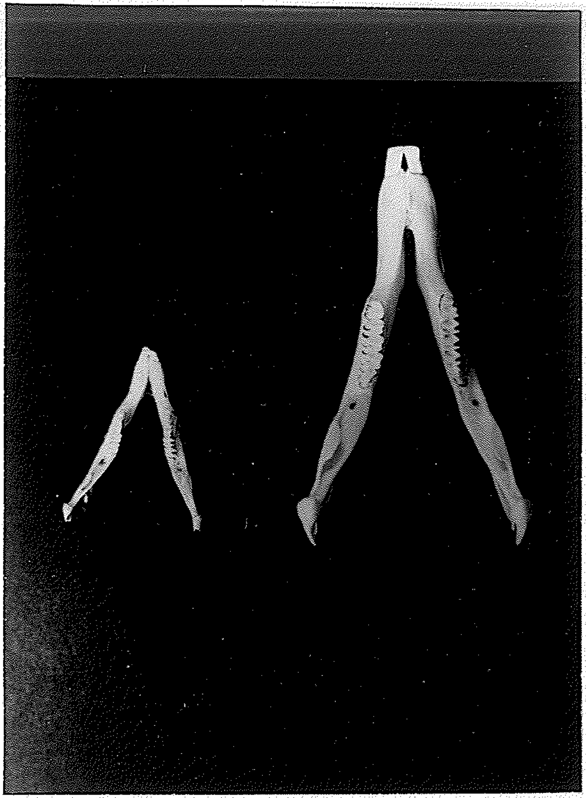


Figure 9. Sylvilagus bachmani Tehemae young and adult

Figure 10. Sylvilagus bachmani Tehemae young and adult



'Figure 11. Lepus californicus californicus young and adult

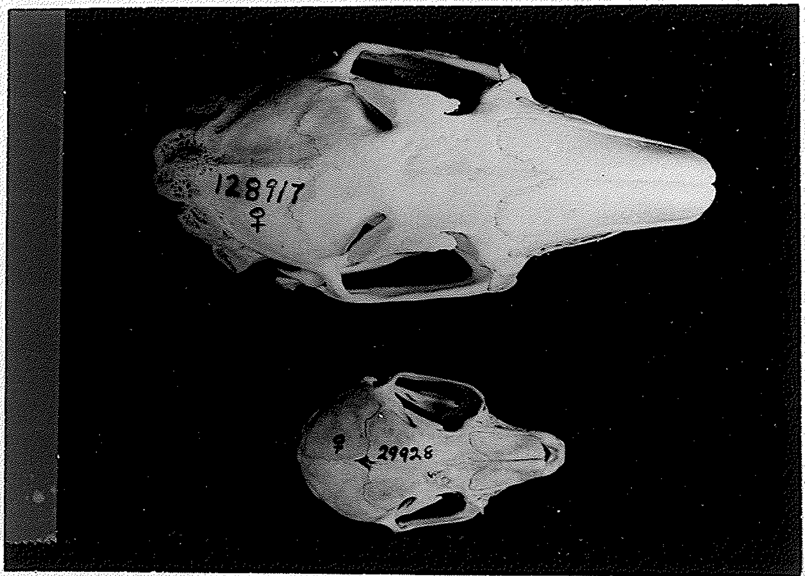


Figure 12. Lepus Californicus californicus young and adult

smallest wild rabbit was the pigmy rabbit and many of these measured less than 5 cm. in dry skull length. The order name of the rabbit, Lagomorph, literally refers to the fact that it is hare shaped and gives no clue concerning the diagnostic features of the animal. The animals used to be placed within the rodent order but it was later realized that their resemblances are largely superficial and probably reflected their similar way of life. They do share the same dental arrangements, with large chisel-like, ever-growing incisors, with no canines and a gap or diastema between the front teeth and the cheek teeth. In detail even the teeth show striking differences. All rodents, for example, have a single upper and a single lower incisor on each side of the jaw. All rabbits on the other hand, have two upper incisors on each side. The second one is small and situated behind the first. There are many additional differences in skeletal and other features that comes to light when a detailed comparison is made between the two groups. The dental formula for the rabbit can be seen in Figure 4.

Any animal in the wild collection which was suspected as not being mature was discarded from the sample. There are no dependable maturation indices for the rabbit. Crary et al. (1960) and Heikel (1966).

In many animals including man, the closure of the spheno-occipital synchondrosis is a good maturation index. The synchondrosis is the junction between the basisphenoid and basioccipital bones and extends somewhat diagonally downward and forward through the base of the cranium. Fusion occurs resulting in a transformation of this cartilage joint into a synostosis by obliterating this cartilage zone and forming a continuity of the bony trabeculae and marrow spaces of the occipital and sphenoid bones. Sawin, et al (1959) found that in most rabbits, at best, there was a partial closure and it was never any farther advanced than the presence of a very few fine osseous spicules or sutures connecting these two bones. This was considered sufficient to prohibit designation of the suture as open. The rabbit accomplishes its mature skeletal potential by the age of 20 weeks. Heikel (1966) compared the skeletal age of the rabbit and man. He made the observation that in a longitudinal studying skeletal development, the rabbit grows much older in one day than a man does in 40 days. Both man and rabbit at birth, having a nucleus which is demonstrable on the x-ray in the distal femoral epiphysis and the proximal tibal epiphysis but in no other area. It is suggested that both the rabbit and man are born at almost the same skeletal age.

Care and Feeding of the Animals

The animals were housed in a 14 by 16-foot room at the animal house in the Dental Building at the University of Manitoba. The temperature was kept at a constant 68 degrees F. and the lights were on a timer which turned them on at 7:00 a.m. and turned them off at 7:00 p.m. The animals were fed ad libitum with Lekland Rabbit food. Pregnant does were kept in 4 by 4-foot pens. The bucks were housed in another part of the animal house. The nesting boxes were completely enclosed. There was an eight-inch opening on one side and the inside dimensions of the nesting boxes were 16" by 16" by 16". The young rabbits were separated from the does at the age of three weeks, just prior to the first records. The does were removed from the pens and the small animals were allowed to live in the same pens in which they were born until they were 12 weeks old. At this time the males and females were separated but kept in the same size pens. The pens were cleaned in the morning and fresh water was given to the animals in the morning. The animals were always x-rayed in the evening and weights were always taken prior to the taking of the records. Attempts were, therefore, made to treat all the animals equally in all respects.

RADIOGRAPHIC CEPHALOMETRY

Radiographs in this study were taken using an anode film distances of exactly*3 meters, using an exposure of 3/20 second at 90 kv and 45 ma with a Universal tubehead. Rapid process film was used in an 8 x 10 cassette with intensifying screens. No part of the centre plane of the skull is more than 10 cm from the film. This produces an image with a magnification of less than 1 per cent. The orientation of the rabbit's head is determined by a plexiglass platform and a plexiglass framing device. (Figure 13) The framing device is a 4-inch cube with parallel wires both for support and for checking the accuracy of one exposure to another on the same film. The top of the framing cube is cross-haired for orientation. The "bunny box" which holds the body of the rabbit is mounted securely to the framing device and platform, but can be adjusted if necessary. The "bunny box" platform and framing device sit in a metal channel on a stand which is secured to the floor. The channeled area is exactly square and if the entire rabbit holding device is changed to a different view it can only be rotated 90 degrees. The cassette is covered with a 1/8-inch lead sheet so that only 1/4 of the film is exposed. The four records were taken on

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* Based on preliminary studies

each 8"x 10"film except for radiographs of very large skulls. A basilar view is first taken. (Figure 15) This view is with the Frankfort plane parallel to the film and the mid-sagittal plane perpendicular to the film. The animal is moved 90 degrees by lifting the frame and holder carefully so as not to move the animal within the frame. The cassette is slid into the adjustable cassette holder and the lead shield is reversed, exposing a new corner of the film. (Figure 16) This gives a basilar and a 90 degree lateral view side by side on the same film. The cassette is reversed and the same steps are repeated for the anteroposterior and a 90 degree lateral related to the A-P. (Figures 17 and 18) The film is developed immediately and if the view through the mid-sagittal plane is not easily seen on the basilar or if the basilar is tipped, the basilar and its corresponding lateral are taken over again. The same criteria is used for the A-P view, but tipping is not a major problem, since the angles of the mandible rest on the plexiglass platform as opposed to the posterior occipital protuberance used as a rest in the basilar view.

The value of this technique lies in the fact that it produces two 90 degree views of a skull which can be used to find the same anatomical points on both images. The basilar and lateral are related to each other by a base line drawn along the posterior occipital protuberance. Any point which can be seen in one view can be related to the 90 degree position by using these lines. Films do not always fit squarely in a cassette, but with this technique you do not depend on the position of the film in the film holder. If the skull is rotated 90 degrees, but is not moved vertically and the film is moved horizontally, but not vertically, a line parallel to the base line will pass through the same point on both views. Error tests consisted of taking four radiographs of the same rabbit four times, taking the rabbit out of the cephalostat and repositioning it each time. This was done with four separate animals. These were then digitized and this data was processed on the co-ordinate analysis in the same way as the rest of the data used in the study. The results of the error tests can be seen in *Tables XI, XII and XIII. With this degree of reliability it is possible to describe growth in three directions using cephalometric analyses in three dimensions, in an attempt to identify the overall morphological differences.

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* Appendix

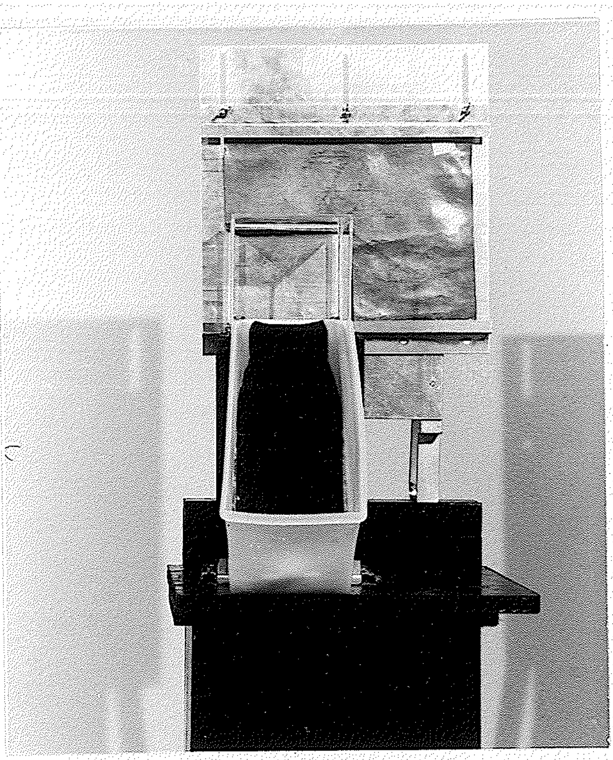

Figure 13. Position of the live animal cephalostat for a basilar or A-P record

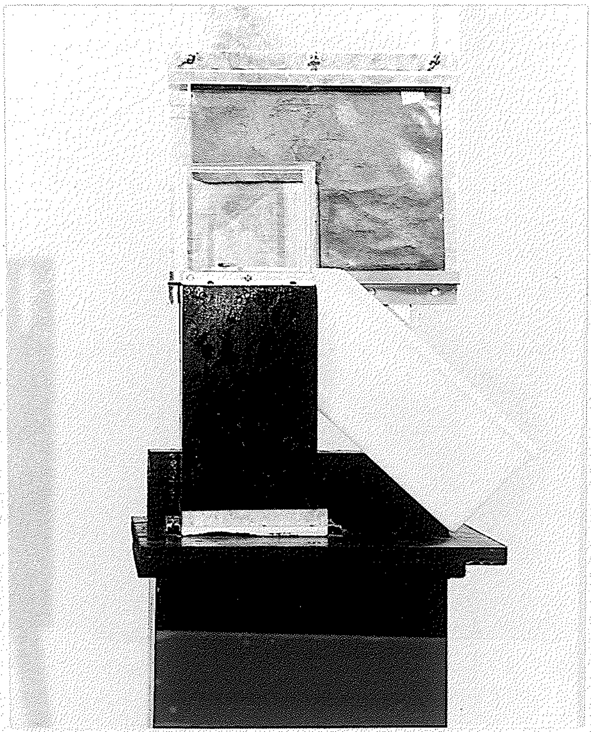

Figure 14. Position of the live animal cephalostat for the 90 degree to basilar or A-P record

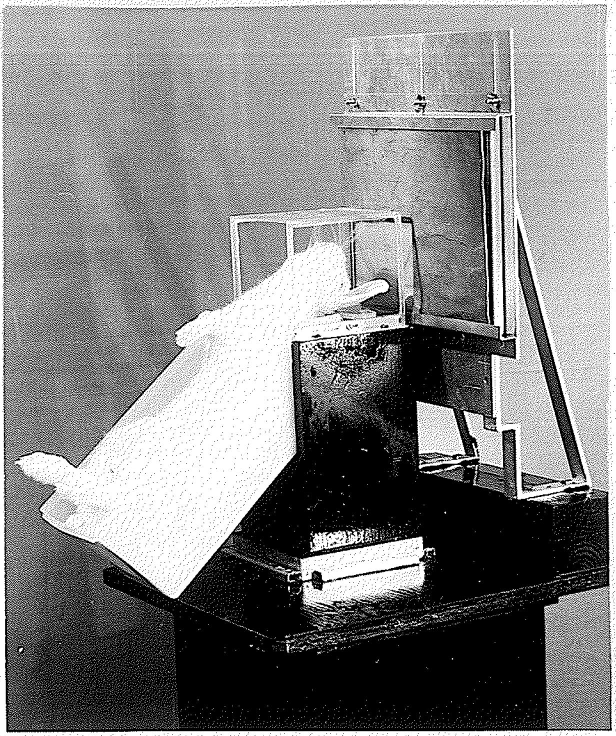

Figure 15. Animal in the basilar position

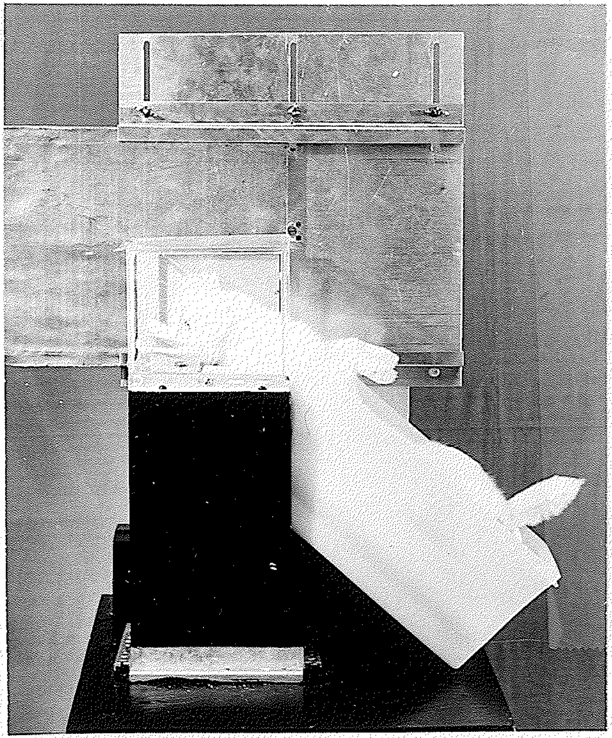

Figure 16. Animal in the 90 degree to basilar position (lateral view)

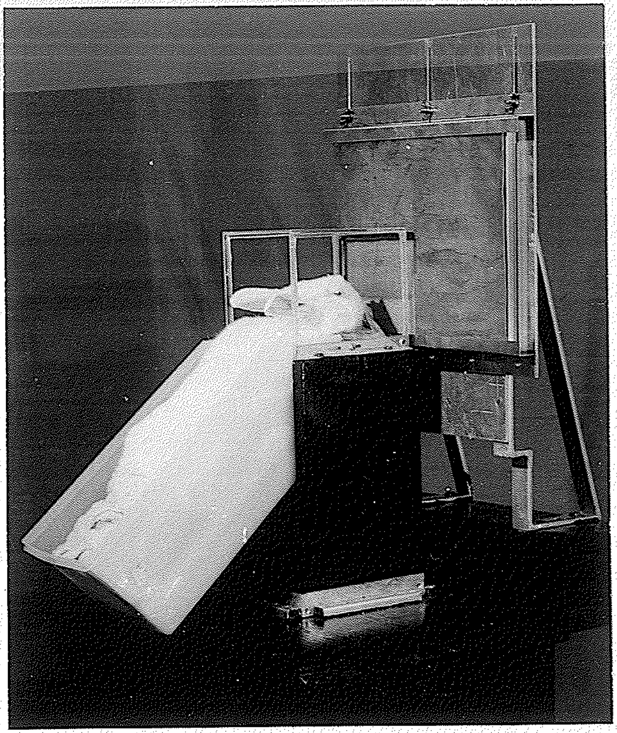

Figure 17. Animal in the A-P position

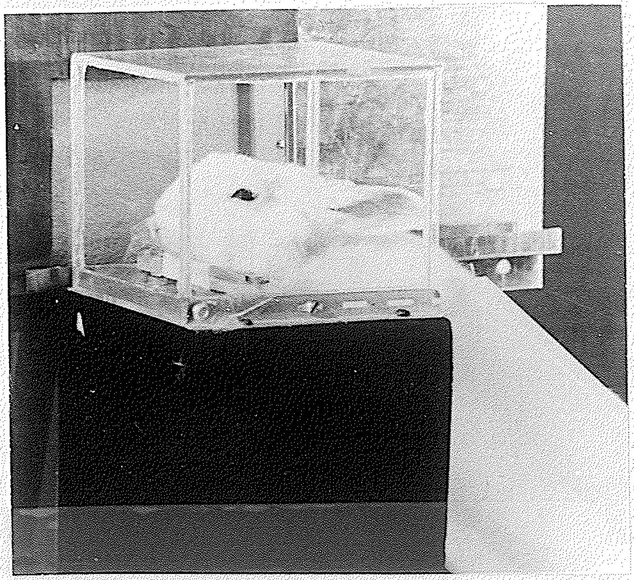

Figure 18. Animal in the 90 degree to A-P position (lateral view)

POSITIONING THE LIVE RABBIT

One of the most difficult parts of animal cephalometry is accurately positioning the head of the anesthestised rabbit and orienting the head so that you will have consistent radiographs. If the animal is well anesthestised it is best to start with an antero-posterior orientation. This is the view which does not have to be retaken as often as the basilar view. The position in the basilar view affords a clearer airway for the animal and often this view can be taken and retaken several times while the animal is recovering from the anesthetic. In the A-P and 90 degree lateral to A-P the animal's head is tilted forward and the airway is somewhat obstructed, and a lightly anesthestised animal will often begin choking and will tend to break loose from its stabilized position. The animal's head is stabilized with either commercial scotch tape or masking tape, depending on the size of the animal. Scotch tape is of sufficient strength to hold a small animal in position even if there are some minor convulsive movements. A larger animal sometimes has to have its legs wrapped with masking tape and then the legs wrapped against the body so that convulsive movements do not affect the stabilized position of the head.

A plexiglass platform is essential for stabilizing the animal's head in the A-P and 90 degree lateral positions to A-P. The posterior part of the angle of the mandible and the anterior portion give you a three-point rest on the plexiglass platform and afford a dependable orientation. In this position a horizontal line would travel from the external occipital protuberance to the inferior orbital canal and the most anterior portion of the nasal bone. The 90 degree lateral, of course, is taken without moving the skull of the animal in relation to the plexiglass platform. The basilar view is more difficult because the only resting point for the skull is the external occipital protuberance.

A well oriented film is one in which the image of the animal appears symmetrical. In the A-P position a well oriented film gives a very clear image of the mid-sagittal plane and the 90 degree position to A-P shows the tympanic bullae almost superimposed. A well positioned basilar view shows a symmetrical image with the two zygomatic arches relatively the same size and the 90 degree lateral position will again show the tympanic bullae superimposed and should have a line running from the external occipital protuberance through the most anterior point on the premaxilla vertical and perpendicular to the horizontal orientation of the cephalostat. If the animal's head is twisted in the basilar position you will not only see some asymmetry in the basilar view, you will also see a double image of the tympanic bullae. The availability of a rapid process film developing system permits the animal to be left in position while the film is being processed. If the animal is in a poor orientation it is then much easier to correct the position since the animal does not have to be completely remounted in the cephalostat.

Designation of Animals

All the live animals in the study were weighed and their ears were marked prior to their three-week records. The animals were numbered and the corresponding number was taped to each film using small lead numerals. The animal which was designated as animal number 1, had no notches placed in its ear. Animal number 2 had a single notch in the right ear, animal number 3 had a single notch in its left ear; animal number 4 had both ears notched and animal number 5 then had two notches in the right ear and the single notching sequence was then repeated if necessary.

ANESTHESIA

While Nembutal[1] produces a deep and long lasting anesthesia in rabbits, it does depress respiration and is hazardous when used on very young rabbits. Ketalar[2] seems to meet the need for a short acting anesthetic for small rabbits. It is supplied in solutions of 10 mg./ml. The usual dosage is 40 mg./kilo. It does not depress respiration and the recovery is fast. The animal is walking around after 45 minutes to an hour. It can be given by subdermal or intra-muscular injections in the thigh. When the rabbit reaches 9 weeks or 2 pounds, it takes larger doses per kilo of body weight. Cost becomes a factor when using Ketalar on a very large rabbit, but it is much safer to use than Nembutal. Field (1955) reports finding that there is a narrow margin between satisfactory anesthesia and a fatal dose of Nembutal in rabbits.

The site of injection is often more a matter of operator choice than the ultimate success of the procedure. Ketalar was developed for use in pediatrics and was intended for intra-muscular or intra-venous injection. However, intraperitoneal injections are satisfactory for both Ketalar and

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[1] Pentobarital Sodium (Abbot Laboratories)

[2] Ketamine Hydrochloride (Parke Davis & Co.)

Nembutal. Intra-venous injections in the ear give a rapid onset, but in longitudinal studies the ears of the rabbit become irritated to the point that injections become difficult. Special precautions must be taken in using additional dosages of these two drugs in that the two drugs acted differently. It was found that if the animal is not sufficiently anesthetised after the initial injection, extra Nembutal must be administered carefully and it takes very little to push the animal past the point of recovery. The Ketalar, on the other hand, is short acting and recovery is so fast that additional part dosage must be at least as great, or more, than the first. This practice has not resulted in the loss of any animals.

PHOTOGRAPHIC CEPHALOMETRY

The cross-sectional material for the study was from the collection of rabbits previously described as being obtained from the campus at Berkley, California. The photographic technique using a telephoto lens system attached to a 35 mm. single lens reflex camera was used to record the museum dry skull material. Records were taken at 6 meters with an F stop of 22 to ensure sufficient depth of field. The records, taken at 6 meters, ensured the three-dimensional object distortion was within acceptable limits (McKeown, 1972). The camera used was a Mamyia Secor 35 mm. single lens reflex with a 400 mm. telephoto lens. The 6 meter measurement was from the front of the lens to the mid plane of the craniostat. (Figure.20) The films were made with Kodak Panatomic X film with an exposure of three seconds. The light source was two, 60-watt bulbs and reflectors placed on each side of the craniostat. The films were developed in Kodak microdol developer. The films were enlarged and printed onto Ilfoprint dimensionally stable glossy single weight enlarging paper. For purposes of convenience all films were enlarged to 92.45% of actual size. The enlarger was kept in the same position throughout the processing of all of the enlargements. The accuracy of this depth was always checked by using the known dimensions of the craniostat. The difference between magnification on these enlargements and on the radiographs taken in the study were converted during the co-ordinate analysis program.

Positioning of the Dry Skull

The cross-sectional material was photographed in a craniostat.(Figure 20) It was intended that the positioning of the dry skulls be similar to the positioning of the live animal. It would have been possible to position the dry skulls with a line running from the external occipital protuberance to the anterior portion of the premaxilla on a horizontal orientation with the craniostat but there were several reasons for not doing this. Some of the mandibles of the dry material were broken at the symphis and again a three-point stabilization of the mended mandible gave the most stability. It was necessary to use some plasticine material for the basilar orientation. Plasticine material was also used behind the mandible to correctly occlude it to the main body of the skull.

The parallaxing principle which is common to both the radiographic and photographic cephalometry is shown in the next Figure(21). Notice in Figure 20 the craniostat has lines of orientation built into it. A front plate is positioned with cross hairs in relation to the plexiglass platform. These cross hairs are also present on each side and at the top of the cube. This permits a very precise orientation of each skull. The front plate is always removed after orientation so that a clear view of the skull is shown.

The animal's skull was placed on the craniostat table and a record was taken from the anterio-posterior view with the animal's head oriented in a position with a horizontal line joining the external auditory canal, the infraorbital foramen, and the anterior tip of the nasal bone. This position makes the mandibular plane approximately flat against the rotating table of the craniostat. Once the film was taken, the skull was rotated and stopped in the 90 degree position to the A-P. This second record was taken without alternating the spacial position of the skull with reference to the horizontal plane, thus simulating two records taken simultaniously at 90 degrees to one another.

The skull was then orientated to the basilar position. In the basilar position the skull was placed vertically with a vertical orientation from the most anterior point of the premaxilla through the posterior external occipital protuberance. This is the same orientation as was used in the basilar and 90 degree lateral positions on the radiographic cephalometry.

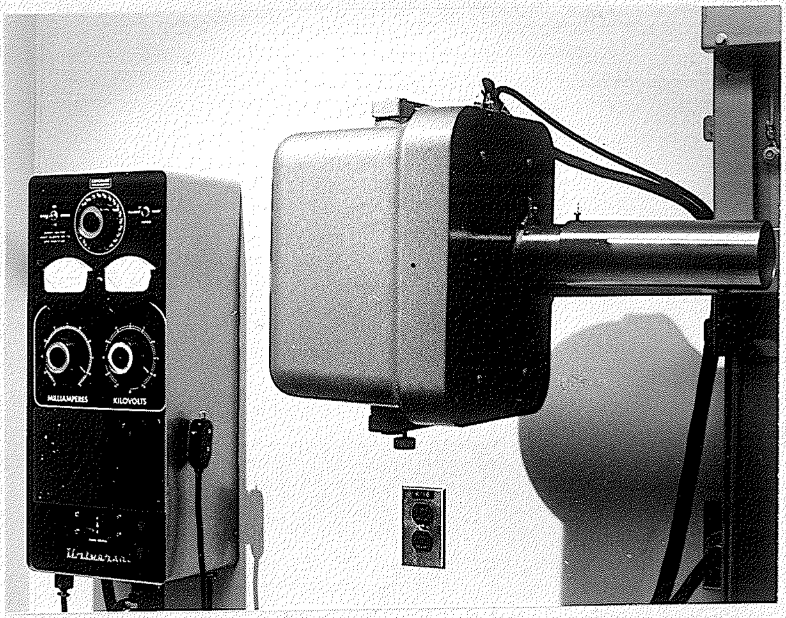


Figure 19. Universal tubehead and control panel used for radiographs

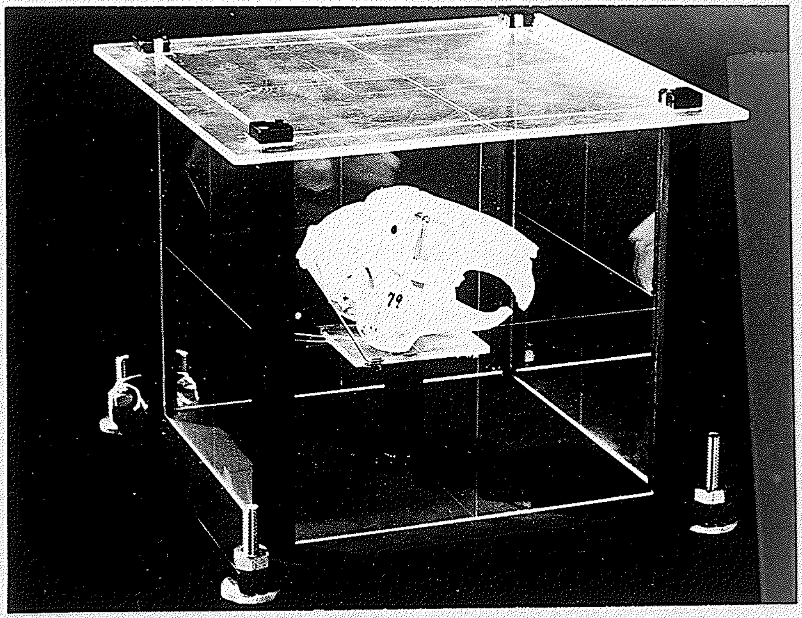


Figure 20. Dry skull mounted in a craniostat prior to a photographic record

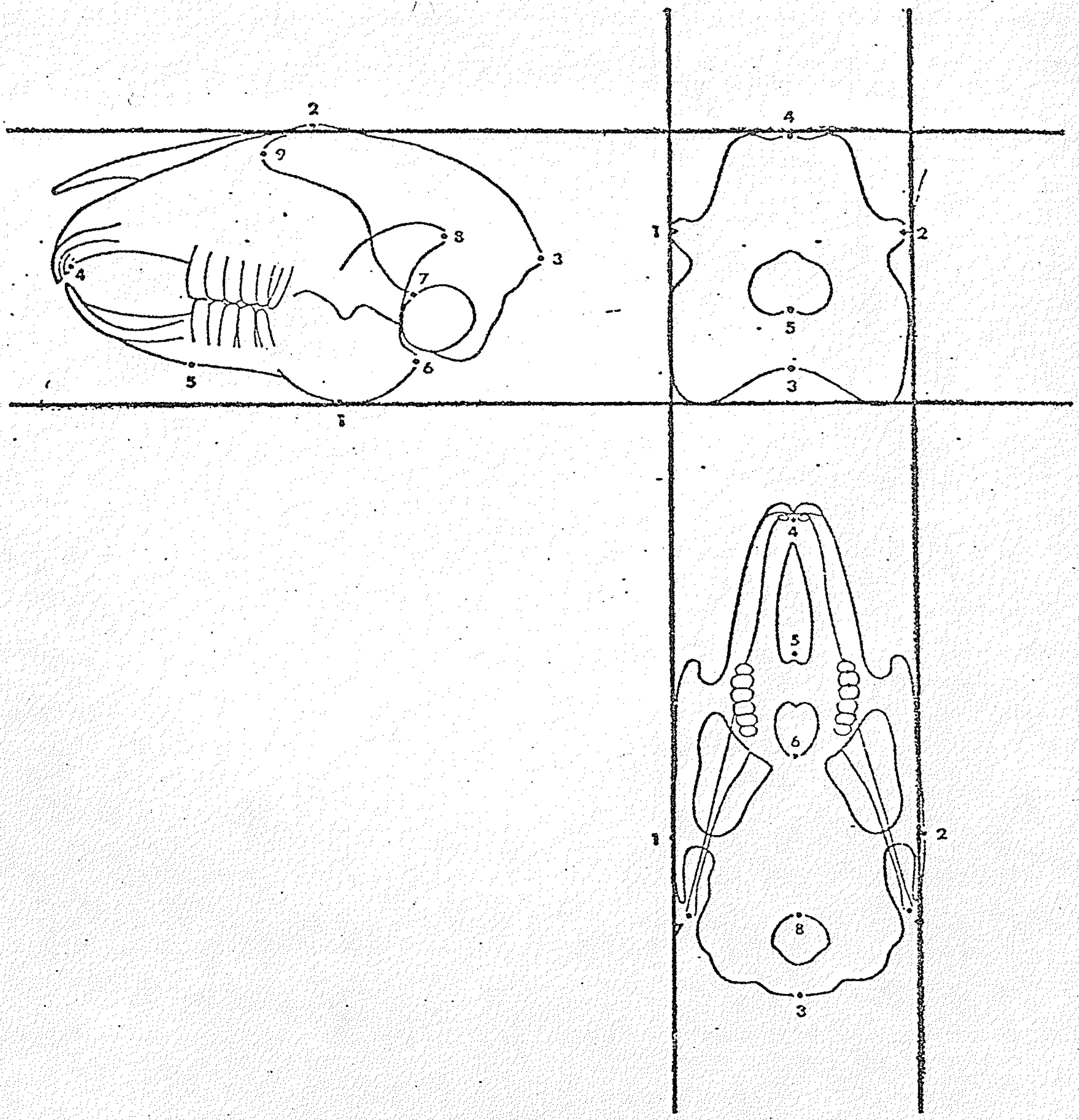


Figure 21. The parallaxing principle, common to both the radiographic and photographic cephalometry

Recording Points

Films taken in the radiographic study were labelled with the litter and animal number and the age. The photographs of the skulls were divided into one of six groups and each skull was assigned a number. The films and photographs were individually mounted on a Ruscom logistics strip chart digitizer (Figure 22) and the X and Y co-ordinates of each landmark were recorded in a predetermined order and punched on IBM cards (Cleall and Chebib, 1971) (Figure 23). These cards were used in a co-ordinate analysis and SPSS computer program to analyze the data. IBM cards and information from the punch cards was then loaded into the University of Manitoba IBM 360-65 computer system which mathematically computed all the linear and angular measurements used in this study. The magnification factor on the live animals was 97.09 and the magnification factor on the dry skulls was 107.55. The co-ordinate analysis program converted these magnifications to actual size so that all the linear data is based on the true dimensions.

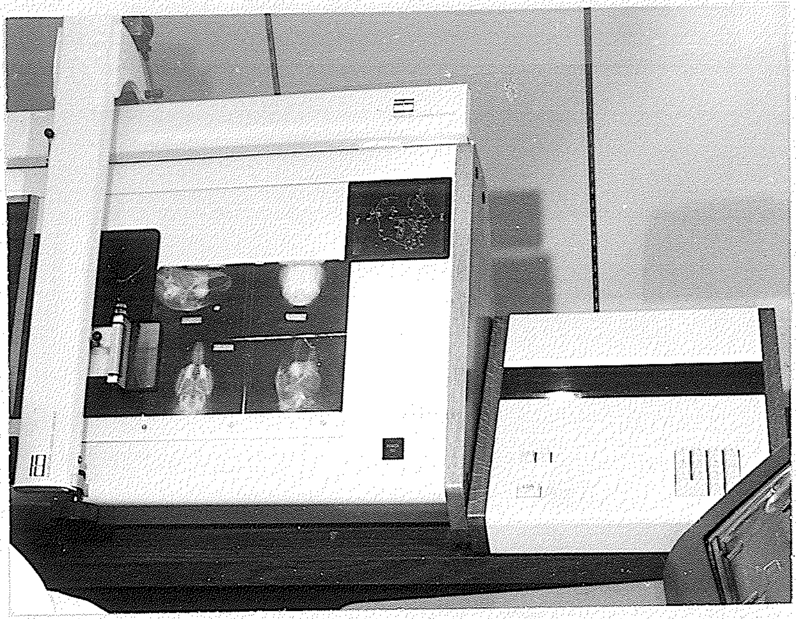


Figure 22. Ruscom logistics strip chart digitizer.

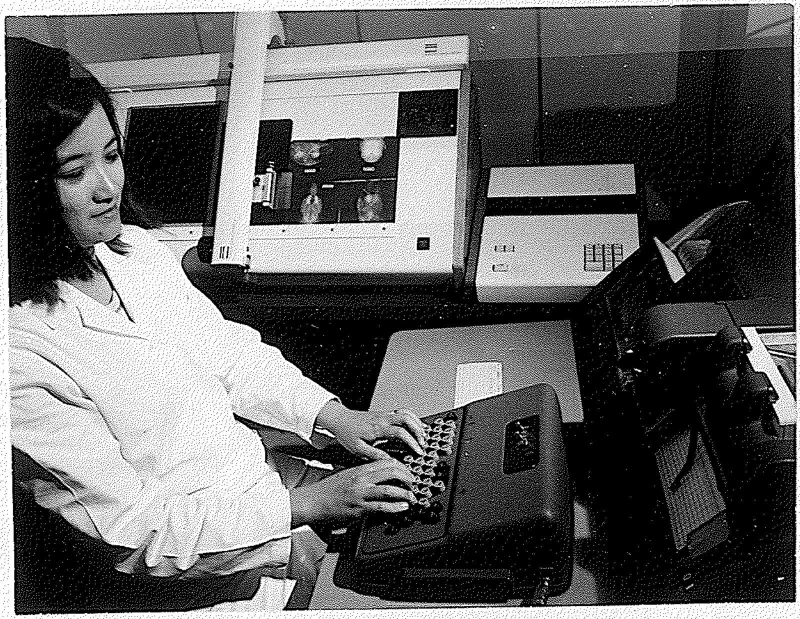
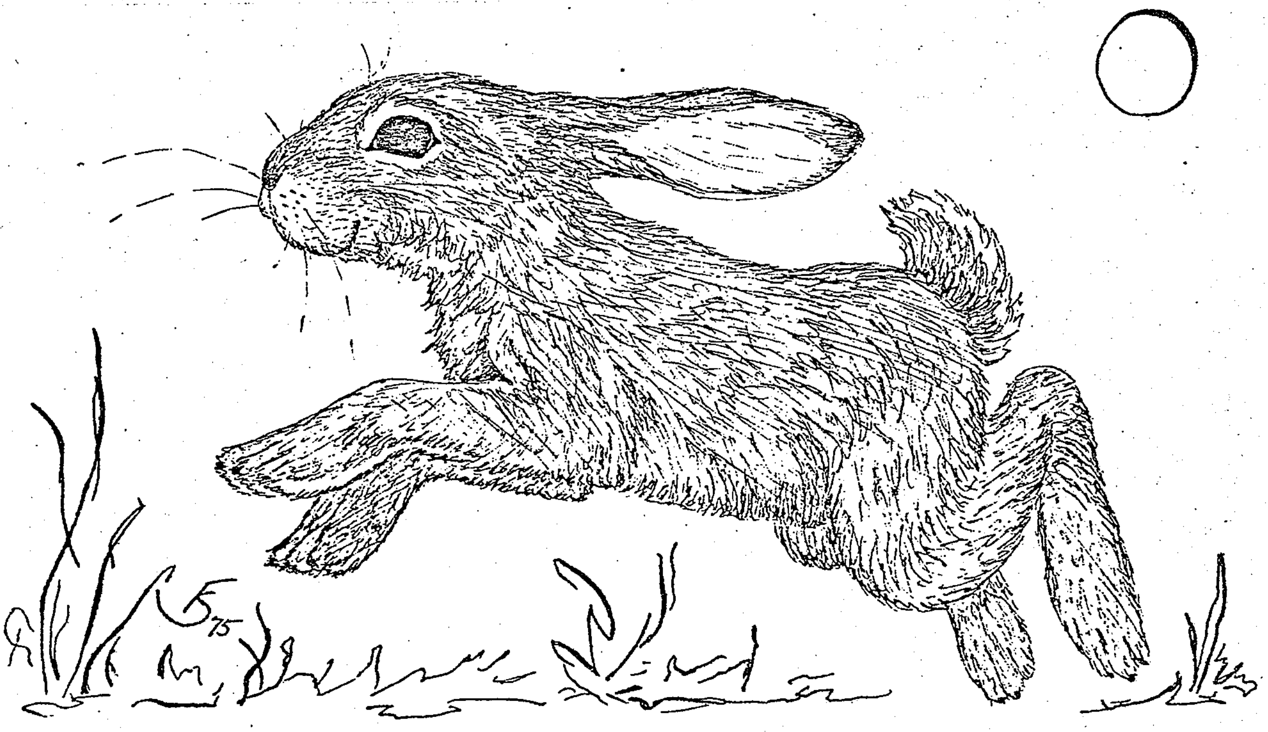


Figure 23. Digitizer and IBM Key Punch used to record the coordinates of the landmarks from the lateral cephalometric radiographs.

RESULTS



Growth Change Analysis

Figures 24 and 25 show the points and angles which were used in the analysis of the lateral and basilar views of the mature skulls in the radiographic and photographic studies. The description of the angles in the Tables give points which are not in a logical sequence. This is due to the nature of the analysis program, so when referring to Figures 24 and 25, refer to the angles as they appear on Tables VIII and X in the section on Variability. The points listed on Tables VII and IX in the section on Variability, are linear measurements given in centimeters.

Weights of the animals in the live study were recorded at 3, 5, 7, 10, 13, 17, 21 and 25 weeks. Table I and Table II show the mean weights in grams of the two live groups during the eight stages of growth. Also shown on these Tables are the growth changes in skull lengths in graph form. Notice the extremely high standard deviations in the weight columns in Tables I and II. These are quite high as compared to the standard deviations in the cranial measurements as shown in the second two columns of both Tables. The standard

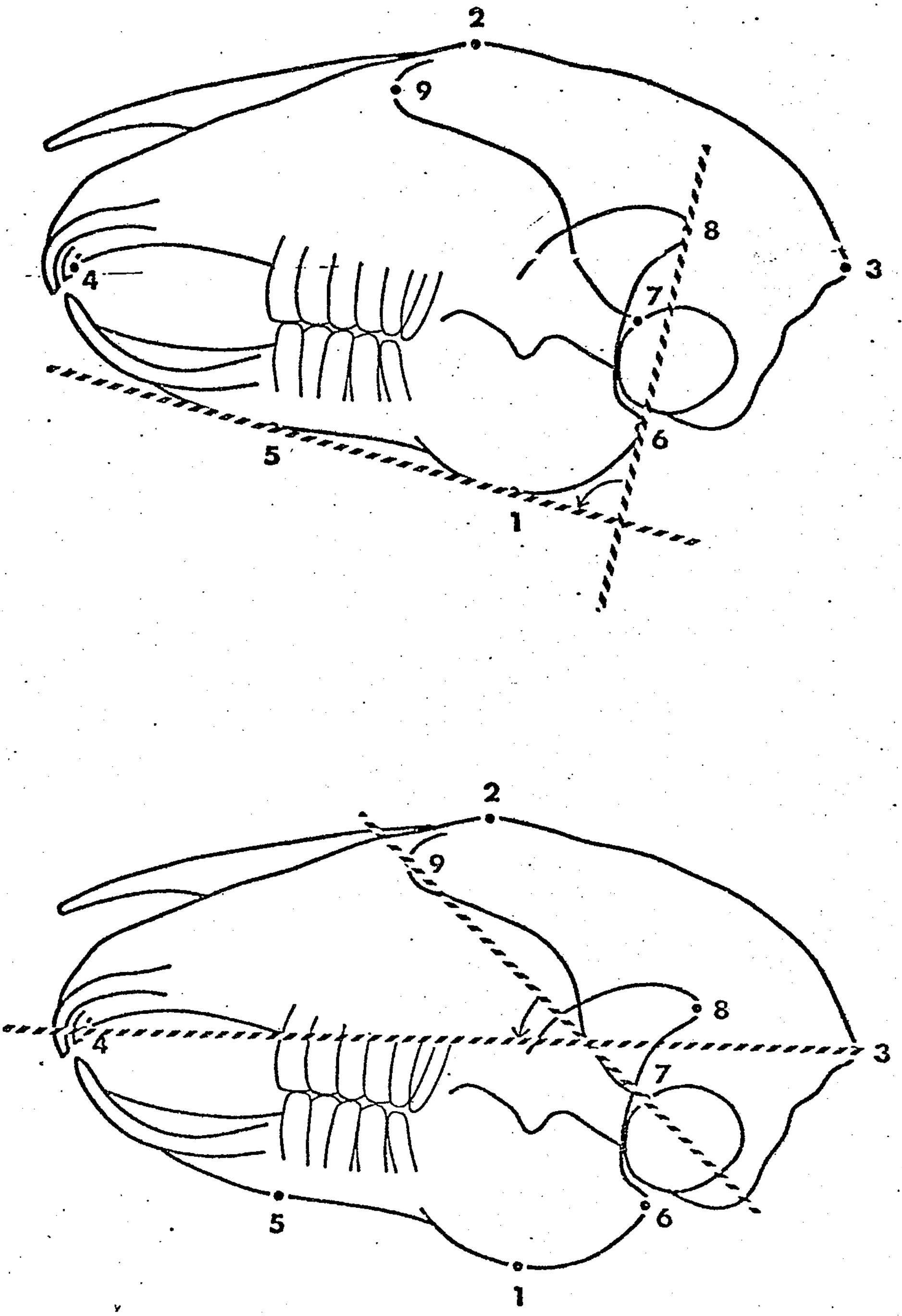


Figure 24. Points and angles used in analysis of lateral view

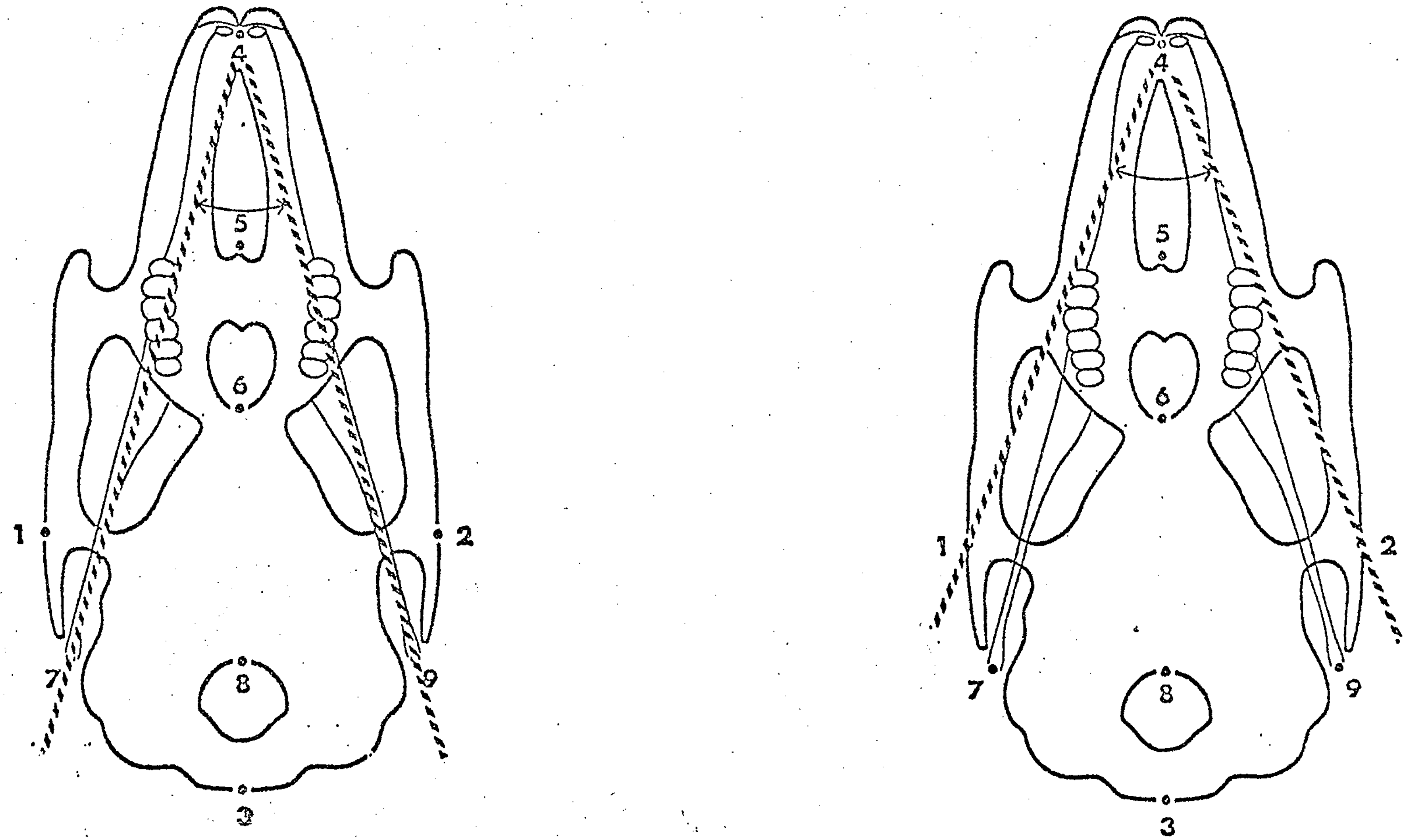


Figure 25. Points and angles used in analysis of basilar view

DUTCH

	WEIGHT grams	SKULL LENGTH centimeters	SKULL HEIGHT centimeters
Stage 1			
Means	296.4	4.596	3.115
SD	37.1	0.222	0.039
Stage 2			
Means	388.6	4.946	3.334
SD	126.1	0.281	0.227
Stage 3			
Means	578.7	5.485	3.613
SD	107.3	0.259	0.288
Stage 4			
Means	905.2	6.113	4.009
SD	141.2	0.264	0.186
Stage 5			
Means	1134.0	6.597	4.220
SD	188.0	0.203	0.186
Stage 6			
Means	1409.5	7.010	4.434
SD	227.1	0.230	0.205
Stage 7			
Means	1550.3	7.145	4.583
SD	320.8	0.230	0.175
Stage 8			
Means	1853.7	7.380	4.670
SD	366.3	0.270	0.206

Table I. Weight in grams and skull length and height in centimeteres at eight stages of Dutch growth- 3,5,7,10,13,17,21 and 25 weeks.

NEW ZEALAND

	WEIGHT grams	SKULL LENGTH centimeters	SKULL HEIGHT centimeters
Stage 1			
Means	323.7	4.766	3.093
SD	93.7	0.256	0.121
Stage 2			
Means	738.9	5.994	3.724
SD	202.7	0.388	0.206
Stage 3			
Means	971.7	6.509	4.065
SD	284.7	0.307	0.176
Stage 4			
Means	1627.1	7.400	4.528
SD	426.3	0.390	0.243
Stage 5			
Means	2065.4	7.902	4.802
SD	505.6	0.466	0.287
Stage 6			
Means	2446.5	8.398	5.092
SD	561.3	0.395	0.227
Stage 7			
Means	2958.4	8.652	5.215
SD	435.6	0.282	0.194
Stage 8			
Means	3243.7	8.954	5.396
SD	727.9	0.381	0.253

Table II. Weight in grams and skull length and height in centimeters at eight stages of New Zealand growth- 3,5,7,10,13,17,21 and 25 weeks.

deviations vary from 0.039 in the first stage of the skull height in the Dutch, to a larger standard deviation of 0.395 in the skull length at stage 6 in the New Zealand. The important thing to notice about the figures in Tables I and II is that there seems to be a poor relationship between body weight and skeletal measurements. Figure 31 shows the means of the weights and skull measurements plotted against time. Both the Dutch and New Zealand show rather poor fitting curves on the weight graph while the graph which shows skull length, as taken from the second column in Tables I and II, shows a smooth fitting curve in both groups of animals.

Table III shows changes in the gonial angle during the eight stages of growth. In both the Dutch and New Zealand varieties the gonial angle is greatest at three weeks. It is almost the same at five weeks and in the Dutch it remains within one degree of the angle recorded at three weeks throughout the entire growth of the skull. The New Zealand continues to become more acute reaching 82 degrees at the age of 7 weeks and remains constant until adult size is obtained.

The angle shown in the first stage might possibly be a result of an inability to see all of the head of the condyle, because of burnout on the films of the very young rabbits. The skull had developed sufficiently after

Changes in the Gonial Angle (8-6-5-1) During 8 Stages of Growth

	DUTCH	NEW ZEALAND
Stage 1		
Means	93.664	94.532
SD	3.900	7.489
Stage 2		
Means	88.941	88.215
SD	10.817	5.033
Stage 3		
Means	87.634	82.462
SD	4.282	6.990
Stage 4		
Means	89.939	82.701
SD	6.474	5.434
Stage 5		
Means	89.747	82.597
SD	6.407	6.088
Stage 6		
Means	91.998	82.958
SD	4.372	5.006
Stage 7		
Means	92.828	82.915
SD	7.110	6.263
Stage 8		
Means	90.562	82.370
SD	6.467	6.381

Table III

stage 3 to see all of the landmarks. Notice that the gonial angle of the Dutch at stage 8 (mature skull) is approximately 8 degrees more obtuse than the New Zealand. This would be a reflection of a definite shape difference between the two types of rabbits.

Curve Fitting

Growth curves in this study were found by fitting the growth of anatomical points in each individual rabbit and doing the same with a group. The points plotted for the growth curves were taken from an orientation shown in detail on Figure 28 and described later in the section on the Mode and Prediction of Growth. Growth curves were obtained by superimposing sequential tracings on a fixed point and the reference line 'R' (Figure 28). The series of points are the motion of that point and growth which reaches maturity at point 'P' (Figure 28). Points of growth described as mid-sagittal snout growth were fitted using a regression analysis. Growth curves were fitted with dependent variables, Y and log of Y and variables, log of X and X and log of Y dependent variable to log of X variable. Log of Y, log of X were found to give consistent correlations on all curves fitted. Table IV shows a curve fitting and the constants derived in curves from all rabbits in each group.

The regression analysis results on Table IV are for all of the curves in each group. Figures 26 and 27 show graphic representation of curves where log Y = log a + n log X in some of the New Zealand and Dutch animals. These graphs represent the straight-line description of the curves of the first four animals in each group using constants N for slope and log a for the Y intercept. Each graph was constructed using figures from the first four sets of constants on Table IV.

Copies of SPSS print-out sheets can be found at the end of the Appendix. These were used to find best fit curves on the original data. Multiple R, which is the multiple regression for each curve for an individual animal, is shown on the left side of the table and is an indication of the degree to which the points adhere to the best fit curve. A multiple R of 1.000 would be perfect fit and the multiple R's should be close to that figure if growth is a strictly logarithmic phenomenon and has been accurately recorded. The points which are plotted close to the Y axis might possibly show a good fit using multiple regression because of the relationship between the rate of change of X and Y with growth when using Y to log X, or X to log Y, depending upon the coordinate. However, as a general rule, log Y-log X are the most consistent dependent and independent variables to use.

Graphic Representation of Curves
Where $\log Y = \log a + n \log X$
in DUTCH Group

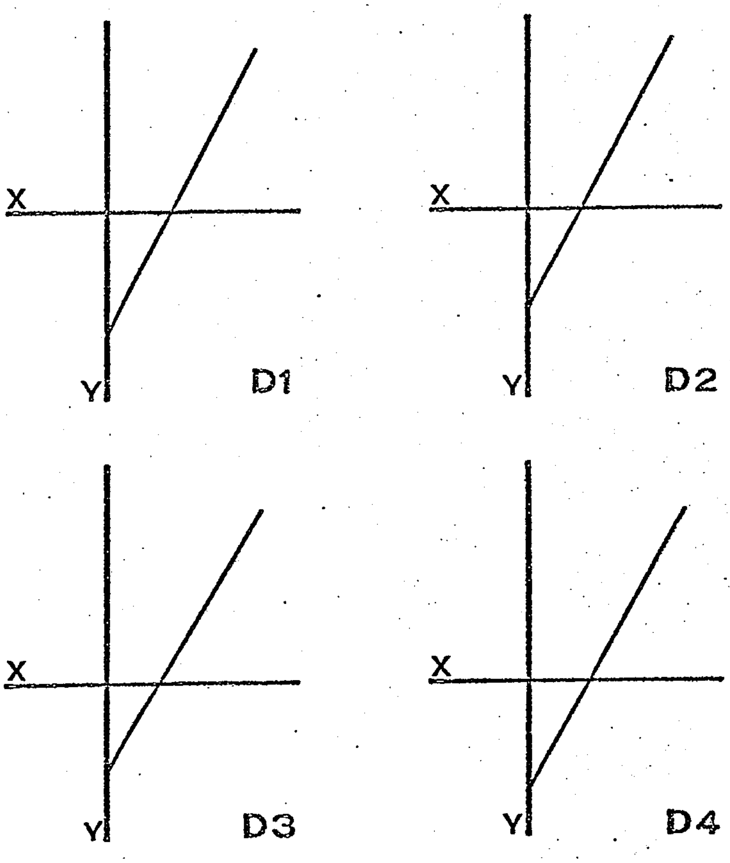


Figure 26. Graphic representation of curves obtained from values found on Table IV.

Graphic Representation of Curves
Where $\log Y = \log a + n \log X$
in NEW ZEALAND Group

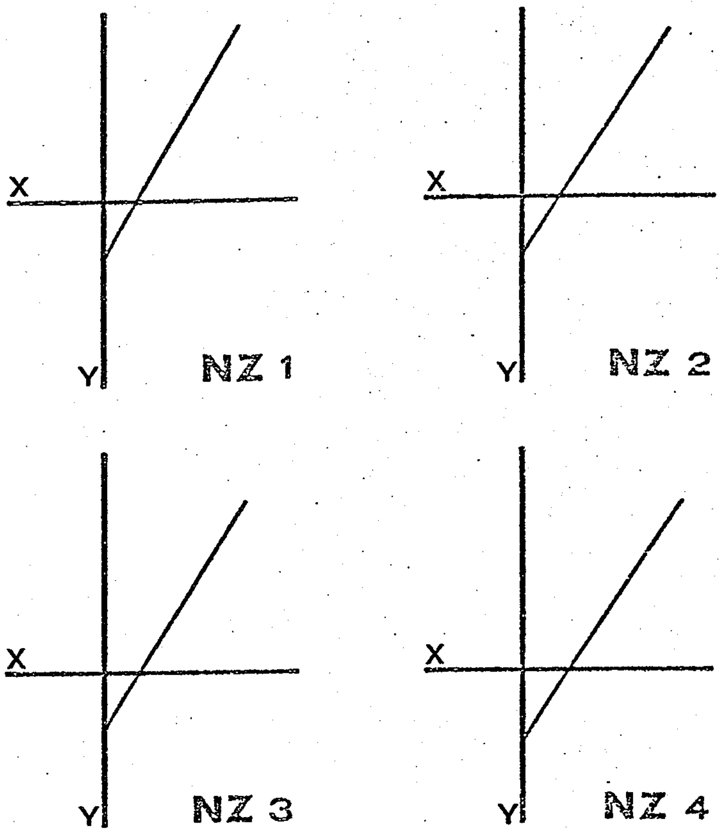


Figure 27. Graphic representation of curves obtained from values found on Table IV.

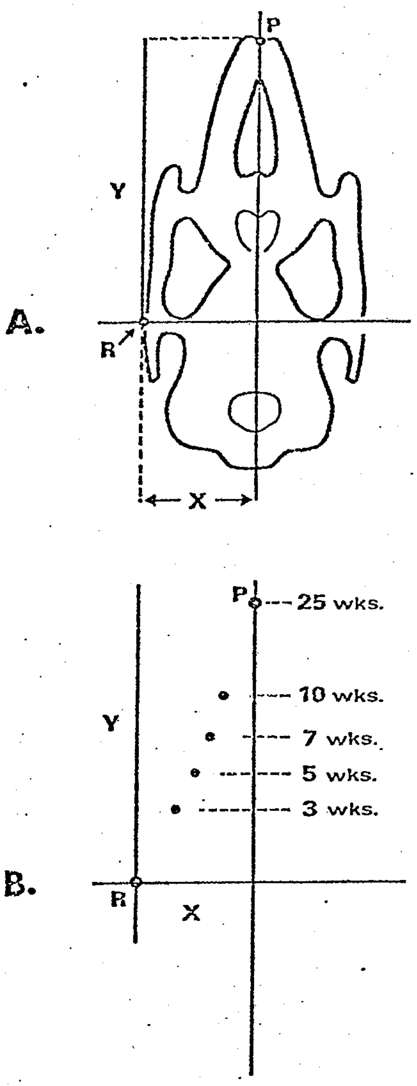


Figure 28. Method of orientation for the superimposition of growth records on point "R" along line "X"(as described anatomicaly in the text) for the registration of points of mid-sagital snout growth in relation to an X-Y axis.

Constants Derived From Curve Fitting Where $\log Y = \log a + n \log X$

DUTCH

Number	Y INTERCEPT (log a)	SLOPE (n)
1.	-1.847	1.997
2.	-2.051	2.063
3.	-1.323	1.705
4.	-1.694	1.907
5.	-0.388	1.313
6.	-1.204	1.731
7.	-1.064	1.626
8.	-0.935	1.588
9.	-1.458	1.576

CHI^2 (PER DF)=0.38

NEW ZEALAND

Number	Y INTERCEPT (log a)	SLOPE (n)
1.	-0.923	1.576
2.	-0.857	1.534
3.	-0.865	1.532
4.	-1.127	1.655
5.	-0.924	1.554
6.	-0.941	1.589
7.	-0.789	1.508
8.	-0.325	1.305
9.	-0.661	1.463
10.	-0.664	1.455
11.	-1.404	1.778
12.	-0.764	1.498
13.	-0.414	1.340
14.	-0.904	1.539
15.	-1.939	2.026
16.	-1.858	1.992

CHI^2 (PER DF)=0.08

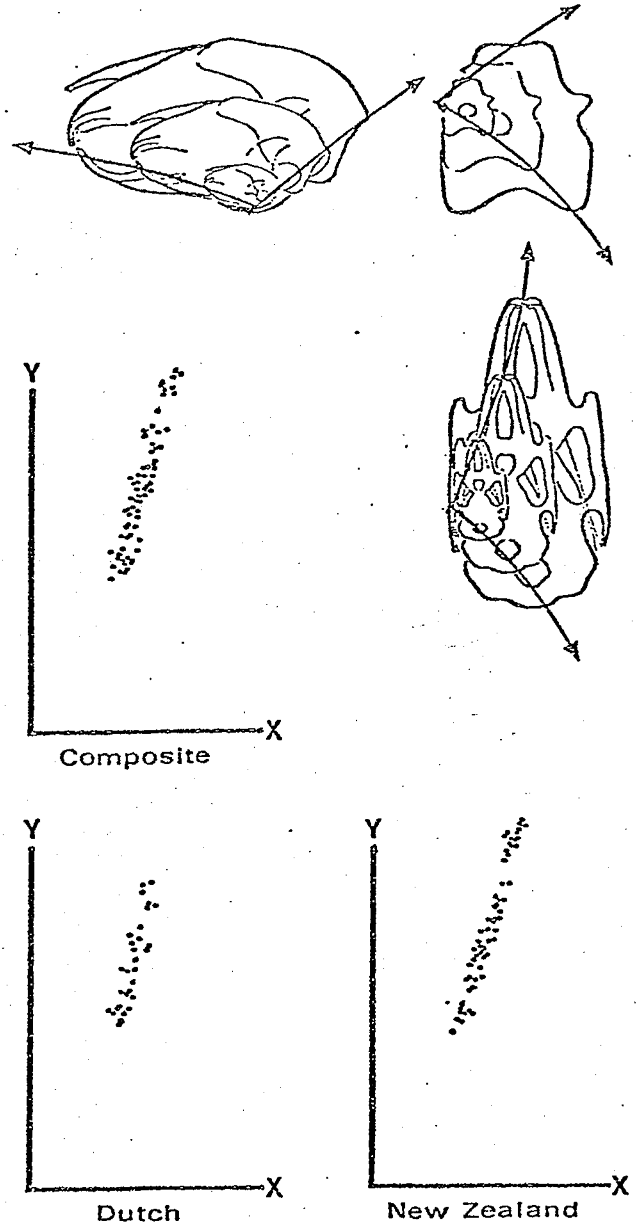
Table IV

The advantage of using log Y-log X in any curve fitting is that the curve can be expressed in straight lines as shown in Figures 26 and 27. All the lines on Figures 26 and 27 for each individual animal when superimposed on the X Y axis will fall almost exactly one on top of another. If the straight lines do fail to fall one upon another, they are still parallel, indicating that the slope is constant. This is true for all the animals in a certain group. However, the lines from the mid-sagittal snout growth of the Dutch cannot be exactly superimposed over the lines from the New Zealand group, but they are close. The straight lines from various animals and groups of animals can be plotted and the growth directions compared. The precise adherence of each curve to a log straight line shows that the relationship between the points during growth is a strictly log process.

Mode and Prediction of Skull Growth

An attempt was made to describe the general mode of skull growth in a longitudinal study and to determine at which age a prediction could be made as to the final adult size of the skull. The points of growth shown on Figure 28 were used for an SPSS program which found correlation coefficients of the distances between the points of growth at 3, 5, 7, 10 and 25 weeks of mid-sagittal snout growth. Growth was represented by registering each record on the most lateral point of the zygomatic bone (Figure 28). The anterior-posterior orientation of this point always coincided with a line drawn through both mid-points of the anterior surface of the zygomatic process of the temporal bones. This was the point of reference which was always used on the basilar view. Points of reference used on the lateral view were drawn from the external occipital protuberance to the most anterior point on the premaxilla. The line of orientation on the A-P view was between the two most lateral points on the zygomatic bones.

At the top of Figure 29 is the tracings of the 90 degree right lateral cephalogram at several ages and at adulthood. On the right side you see the basilar and A-P orientations and on the left, the lateral growth trajectories. The graphs in Figure 29 represent direct plots of mid-sagittal snout growth in the two varieties and a composite of the two varieties. It was found that the equation $Y = aX^n$ fitted all the curves taken at a variety of points selected. This allometric growth equation, Huxley (1929 and 1924) demonstrates that the ratio of the rate of growth in the Y axis to that in the X axis is logrithmitically constant.



Direct Plots of Snout Growth Made During 8 Stages of Growth

Figure 29. Direct plots of mid-sagittal snout growth with Y axis representing anterior growth and XY intercept representing point R. (Figure 28).

Figure 28 shows a method of analysis of growth changes on the basilar view. The plotting of the points of growth on the 90 degree basilar view were all in relation to registration point R. The mid-sagittal plane of the skull was used as an indirect reference line and all stages of growth which originated approximately from point R were recorded along this line. With this orientation it is possible for the growth of the chosen point such as P, to be recorded by tracing the path of this point directly from a series of tracings of radiographic records.

Figure 30 shows direct plots from radiographs of rabbits, taken in the lateral view. Because three of the rabbits in the Dutch group developed malocclusions, and the plots of the mandibular growth showed two definite growth trajectories, the Dutch were separated into two groups for the investigation of mandibular growth. As this was a normal growth study complete analysis of these growth trajectories in the malocclusion rabbits was not pursued. However, for illustrative purposes, Figure 30 shows points of growth on the mandible for the New Zealand, the normal Dutch, and the three Dutch which had the malocclusion. Notice how much different the growth trajectory is for the Class III Dutch. It is evident in Figure 30 that the difference in shape did exist.

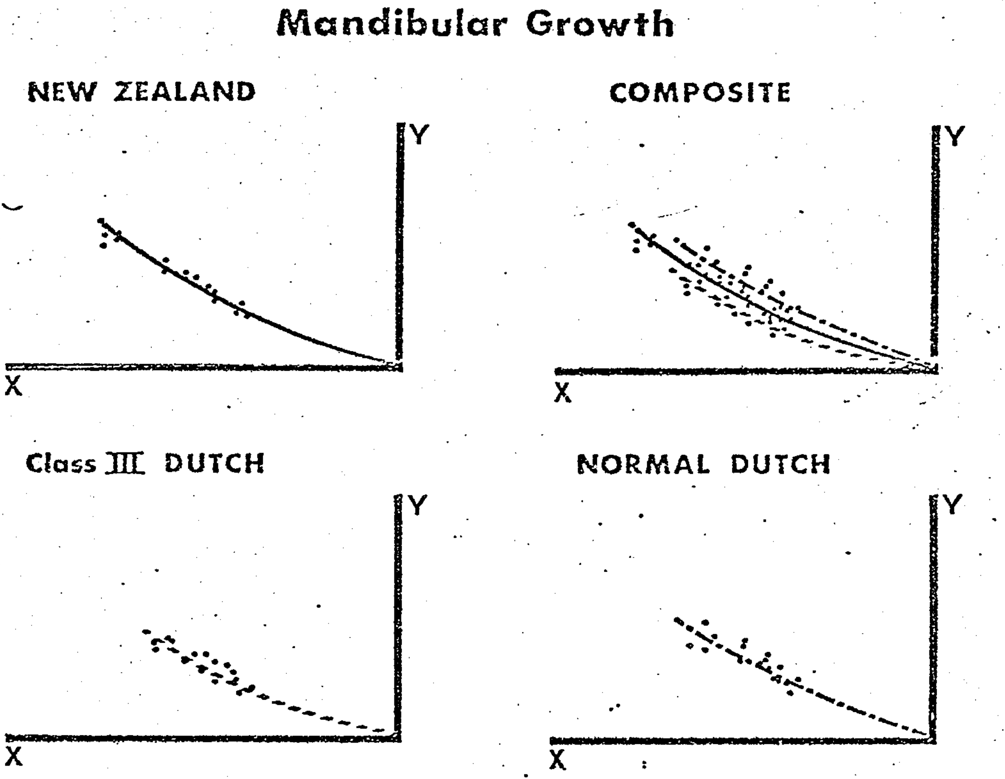


Figure 30. Direct plots of mandibular growth (lateral view) with anterior growth represented on X axis and vertical growth on Y axis. XY intersect represents point 1 as described in the Appendix.

Body Weight and Skull Length Plotted Against Time

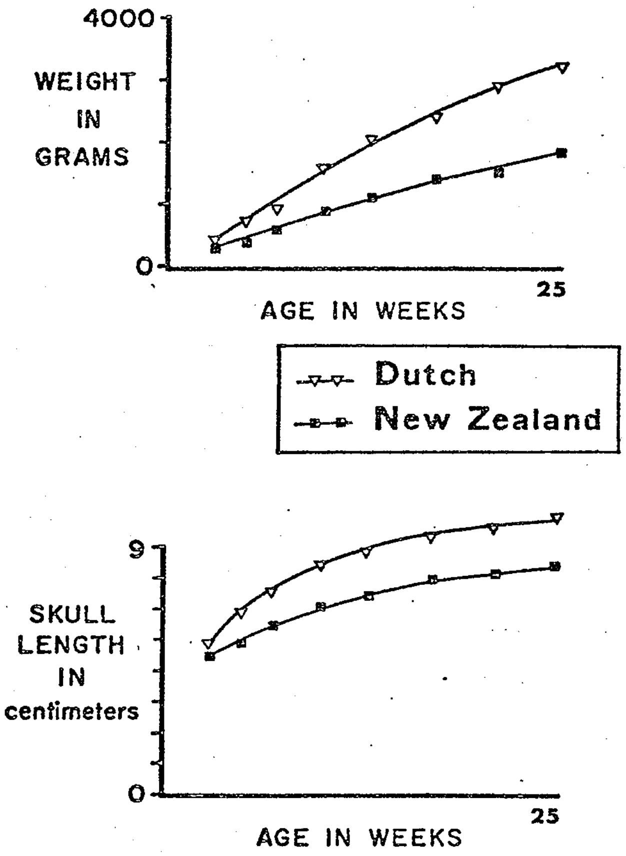


Figure 31

An SPSS program was used to determine correlation coefficients between points of mid-sagittal snout growth. Tables V and VI show correlation coefficients based on analysis of points of growth recorded at 3, 5, 7, 10 and 25 weeks. The program was designed to correlate distances between points shown on Figure 28, with the distance travelled between point R and P. Initial evaluation showed very little correlation at the 13, 17, and 21 week periods, and so the earlier growth periods were used to establish correlations of size at various stages of growth. The data was handled in two different manners--linear and cumulative linear. Correlations were derived between distances of growth at four stages and the distance travelled between point R and point P (Figure 28). Table V shows a method of handling the data in a linear fashion. The correlations on this Table represent straight line distances from point R to each of the growth points and from those points to the adult size. These are composites of the two groups of rabbits. It might be well to point out that each rabbit was treated as an individual and was analysed separately. The final correlations are based on composites of the two groups. The data was again analysed, but as a cumulative linear change, as shown on Table VI. This represents the

```
D3T25,REMAINING LINEAR SNOUT GROWTH AT 3 WEEKS
D5T25,REMAINING LINEAR SNOUT GROWTH AT 5 WEEKS
D7T25,REMAINING LINEAR SNOUT GROWTH AT 7 WEEKS
D10T25,REMAINING LINEAR SNOUT GROWTH AT 10 WEEKS

                 SURFILE     LAB1         LAB2
          STATISTICS..

         CORRELATION (R)   0.23534      0.56296
D3T25    STD ERR OF FST    0.21484      0.21033
          SIGNIFICANCE     0.27107      0.01159

         CORRELATION (R)   0.09388      0.09865
D5T25    STD ERR OF EST.   0.04902      0.03628
         SIGNIFICANCE      0.40507      0.35812

         CORRELATION (R)   0.86715      0.73945
D7T25    STD FRR OF EST    0.23688      0.25766
          SIGNIFICANCE     0.00123      0.00053

         CORRELATION (R)   0.35556      0.41430
D10T25   STD ERR OF EST    0.18219      0.33018
         SIGNIFICANCE      0.17385      0.05531

         PLOTTED VALUES    9            16
```

Table V. SPSS regression analysis

LAB 1 (Dutch)

LAB 2 (New Zealand)

```
C3T25,REMAINING CUMULATIVE LINEAR SNOUT GROWTH 3 TO 25 WEEKS
C5T25,REMAINING CUMULATIVE LINEAR SNOUT GROWTH 5 TO 25 WEEKS
C7T25,REMAINING CUMULATIVE LINEAR SNOUT GROWTH 7 TO 25 WEEKS
C10T25,REMAINING CUMULATIVE LINEAR SNOUT GROWTH 10 TO 25 WEEKS

              SUBFILE   LAB1        LAB2
         STATISTICS..
          CORRELATION (R) 0.17669     0.15650
C3T25     STD ERR OF EST  0.21757     0.25135
          SIGNIFICANCE    0.32464     0.28136

          CORRELATION (R) 0.15352     0.04938
C5T25     STD ERR OF EST  0.20480     0.25630
          SIGNIFICANCE    0.34666     0.42795

          CORRELATION (R) 0.93368     0.84277
C7T25     STD ERR OF EST  0.17577     0.21195
          SIGNIFICANCE    0.00012     0.00002

          CORRELATION (R) 0.40813     0.31840
C10T25    STD ERR OF EST  0.89436     0.65072
          SIGNIFICANCE    0.13775     0.11470

          PLOTTED VALUES  9           16
```

Table VI. SPSS regression analysis

LAB 1 (Dutch)

LAB 2 (New Zealand)

correlation of the sum of each growth period with the sums of the growth periods remaining. In this way, the data on Table VI is handled measuring the distance more closely along the curve. In both groups the most significant correlations were in the 7 week stage. When referring to Tables V and VI, note that subfile lab 1 is the Dutch variety of rabbit and subfile lab 2 is the New Zealand variety. The plotted values at the bottom of each Table represent the number of rabbits in each group. On Table V the correlations at the 5 week stage were higher than those at the 7 week stage, but the level of significance, 0.4 for the dutch, and 0.3 for the New Zealand group, was not acceptable. A correlation of 0.9 and a significance level of 0.0 makes the remaining cumulative linear snout growth, 7 to 25 weeks, the best correlation in the Dutch group. The correlation 0.8 and a better level of significance, 0.0 in the New Zealand group at 7 weeks, is also better than the correlations on Table V which list the remaining linear snout growth at 7 weeks. Thus, in both groups, the best correlations were based on cumulative linear measurements which are those measurements which adhere more closely to the growth curve than the linear measurements.

The enlarged superimpositions shown on Figure 31 were drawn from two series of x-ray records taken at 8 stages of growth. They represent the changing size of two New Zealand rabbits from the age of three weeks until 25 weeks. This illustration points out some of the things which have already been shown in the results. One of the things to notice is that the rabbit which started as a smaller rabbit, the rabbit whose growth stages are traced with dotted lines, ended up being the smallest rabbit at maturity. This was true in all the rabbits studied in the longitudinal portion of this work. In the case of these two rabbits illustrated, only during the 17th week did the smaller rabbit seem to catch up to the larger rabbit. Figure 31 shows that the change in size from the 21st to the 25th week was minimal and the rabbit which began as the smallest ended with the smallest adult size. This illustration also shows the skull expanding somewhat like a balloon which is being blown up. One can notice that the early stages of growth show a projected future shape of the skull. The plotting of the movement of defined anatomical points will describe a series of smooth curvatures and these curvatures adhere closely to the general expression $Y = aX^n$. This allometric principle was consistent throughout the entire period of growth.

Variability

Tables VII through X show the results of the angular and linear measurements of the points on the basilar and lateral views of the mature skulls in both the radiographic and photographic study. Figures 32, 33 and 34 show comparisons of the cranial lengths, heights and widths of both the domestic and wild adult rabbits. The numerical values for Figures 32, 33 and 34 can be found on column 1 and 2 on Table VII and column 1 on Table IX. The standard deviations are greatest in the two domestic rabbits in all adult dimensions of the cranium. The standard deviation in the cranial length of the Pigmy rabbit is rather high. The cranial lengths of the wild groups were available on both the basilar and lateral views, however the lateral view was more reliable due to the fact that plasticine was used to stabilize the skull in the craniostat for the basilar view and it was necessary to sometimes cover the external occipital protuberance, thus reducing the accuracy of location of that point. A precise

GROUP	GENERIC	COMMON NAME	DISTANCES 1-2	DISTANCES 3-4	
1	Oryctolagus cuniculus	Dutch (Domestic rabbit)	4.670 0.206 9	7.380 0.270 9	Means Stnd. Dev. No. of Sam.
2	Oryctolagus cuniculus	New Zealand (Domestic rabbit)	5.396 0.253 16	8.959 0.381 16	Means Stnd. Dev. No. of Sam.
3	Lepus californicus californicus	Black-tailed Jack Rabbit	5.015 0.158 38	9.342 0.263 38	Means Stnd. Dev. No. of Sam.
4	Lepus townsendi townsendi	White-tailed Jack Rabbit	5.225 0.132 20	8.958 0.223 20	Means Stnd. Dev. No. of Sam.
5	Lepus californicus Deserticola	Black Jack Rabbit	4.903 0.175 45	8.801 0.240 45	Means Stnd. Dev. No. of Sam.
6	Sylvilagus bachmani Tehemae	Brush rabbit	3.543 0.170 29	6.018 0.230 29	Means Stnd. Dev. No. of Sam.
7	Sylvilagus idahoensis	Pygmy rabbit	3.017 0.111 38	4.890 0.253 38	Means Stnd. Dev. No. of Sam.
8	Lepus gaillardi	Gaillard's Jack rabbit	5.384 0.149 9	9.091 0.211 9	Means Stnd. Dev. No. of Sam.

Table VII. Linear distances on the lateral view.

GROUP	GENERIC	COMMON NAME	ANGLES			
			8-6-5-1	1-5-3-4	7-9-3-4	
1	Oryctolagus cuniculus	Dutch (Domestic rabbit)	90.562 6.469 9	14.833 3.528 9	44.503 2.995 9	Means Stnd. Dev. No. of Sam.
2	Oryctolagus cuniculus	New Zealand (Domestic rabbit)	82.370 6.381 16	16.407 4.246 16	43.958 3.324 16	Means Stnd. Dev. No. of Sam.
3	Lepus californicus californicus	Black-tailed Jack Rabbit	82.249 5.028 37	14.220 3.165 38	57.507 5.490 38	Means Stnd. Dev. No. of Sam.
4	Lepus townsendi townsendi	White-tailed Jack Rabbit	80.597 4.824 20	15.931 1.957 20	63.822 4.930 20	Means Stnd. Dev. No. of Sam.
5	Lepus californicus Deserticola	Black Jack Rabbit	79.665 4.220 45	13.841 3.223 45	60.821 2.900 45	Means Stnd. Dev. No. of Sam.
6	Sylvilagus bachmani Tehemae	Brush rabbit	76.148 3.871 29	14.831 3.546 29	58.914 2.652 29	Means Stnd. Dev. No. of Sam.
7	Sylvilagus idahoensis	Pygmy rabbit	81.325 5.070 38	14.779 4.300 38	58.307 6.417 38	Means Stnd. Dev. No. of Sam.
8	Lepus gaillardi	Gaillard's Jack rabbit	79.838 3.215 9	16.895 2.947 9	64.645 2.162 9	Means Stnd. Dev. No. of Sam.

Table VIII. Angular measurements on the lateral view.

GROUP	GENERIC	COMMON NAME	DISTANCES			
			1-2	4-5	4-6	
1	Oryctolagus cuniculus	Dutch (Domestic rabbit)	3.910 0.233 9	2.156 0.183 9	3.835 0.162 9	Means Stnd. Dev. No. of Sam.
2	Oryctolagus cuniculus	New Zealand (Domestic rabbit)	4.427 0.236 16	2.698 0.206 16	4.597 0.261 16	Means Stnd. Dev. No. of Sam.
3	Lepus californicus californicus	Black-tailed Jack Rabbit	4.291 0.169 38	2.908 0.155 38	4.789 0.228 38	Means Stnd. Dev. No. of Sam.
4	Lepus townsendi townsendi	White-tailed Jack Rabbit	4.436 0.085 20	2.792 0.132 20	4.616 0.182 19	Means Stnd. Dev. No. of Sam.
5	Lepus californicus Deserticola	Black Jack Rabbit	4.063 0.124 45	2.699 0.138 45	4.457 0.205 45	Means Stnd. Dev. No. of Sam.
6	Sylvilagus bachmani Tehemae	Brush rabbit	3.146 0.116 29	1.629 0.145 29	2.819 0.198 29	Means Stnd. Dev. No. of Sam.
7	Sylvilagus idahoensis	Pygmy rabbit	2.722 0.097 37	1.332 0.091 37	2.115 0.137 37	Means Stnd. Dev. No. of Sam.
8	Lepus gaillardi	Gaillard's Jack rabbit	4.272 0.086 9	2.971 0.064 9	4.886 0.146 9	Means Stnd. Dev. No. of Sam.

Table IX. Linear distances on the basilar view.

GROUP	GENERIC	COMMON NAME	ANGLES			
			7-4-9-4	1-4-2-4	3-4-9-4	
1	Oryctolagus cuniculus	Dutch (Domestic rabbit)	31.337 2.377 9	44.704 3.559 9	15.952 1.754 9	Means Stnd. Dev. No. of Sam.
2	Oryctolagus cuniculus	New Zealand (Domestic rabbit)	27.719 1.244 16	42.947 1.462 16	13.844 1.136 16	Means Stnd. Dev. No. of Sam.
3	Lepus californicus californicus	Black-tailed Jack Rabbit	27.041 1.024 38	38.904 1.397 38	13.523 0.591 38	Means Stnd. Dev. No. of Sam.
4	Lepus townsendi townsendi	White-tailed Jack Rabbit	27.725 0.916 20	41.050 1.272 20	13.980 0.676 20	Means Stnd. Dev. No. of Sam.
5	Lepus californicus Deserticola	Black Jack Rabbit	26.739 0.917 45	39.451 1.494 45	13.474 0.753 45	Means Stnd. Dev. No. of Sam.
6	Sylvilagus bachmani Tehemae	Brush rabbit	33.482 1.401 29	46.690 2.265 29	17.361 0.941 29	Means Stnd. Dev. No. of Sam.
7	Sylvilagus idahoensis	Pygmy rabbit	39.131 1.740 37	50.315 1.977 37	19.470 1.059 37	Means Stnd. Dev. No. of Sam.
8	Lepus gaillardi	Gaillard's Jack rabbit	25.221 1.015 9	37.822 0.685 9	12.487 0.482 9	Means Stnd. Dev. No. of Sam.

Table X. Angular measurements on the basilar view.

Figure 32

Graphic representation of the means and standard deviations of the cranial lengths of adult animals in the live study (groups 1 and 2) and the wild study (groups 3 through 8) as obtained from column 2 on Table VII. (Linear distances on the lateral view)

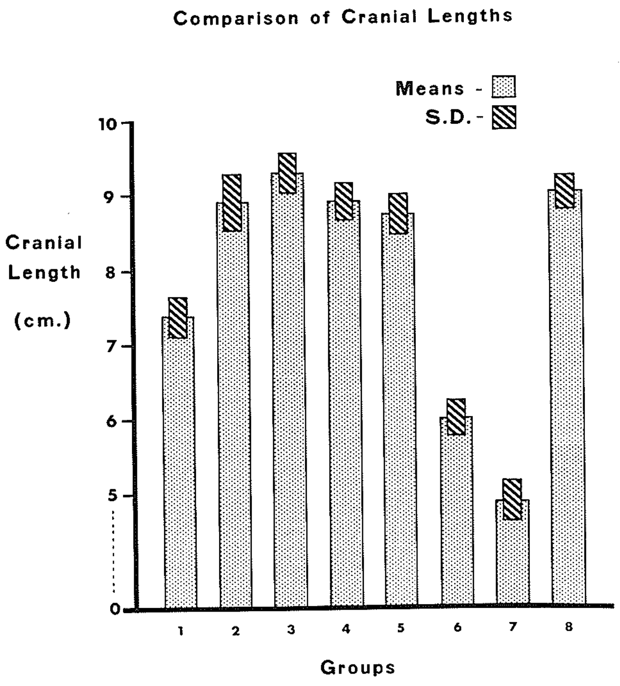

Comparison of Cranial Lengths
Means -
S.D. -
Cranial Length (cm.)
10
9
8
7
6
5
0
1
2
3
4
5
6
7
8
Groups

Figure 32

Figure 33

Graphic representation of the means and standard deviations of the cranial heights of adult animals in the live study (groups 1 and 2) and the wild study (groups 3 through 8) as obtained from column 1 on Table VII (Linear distances on the lateral view)

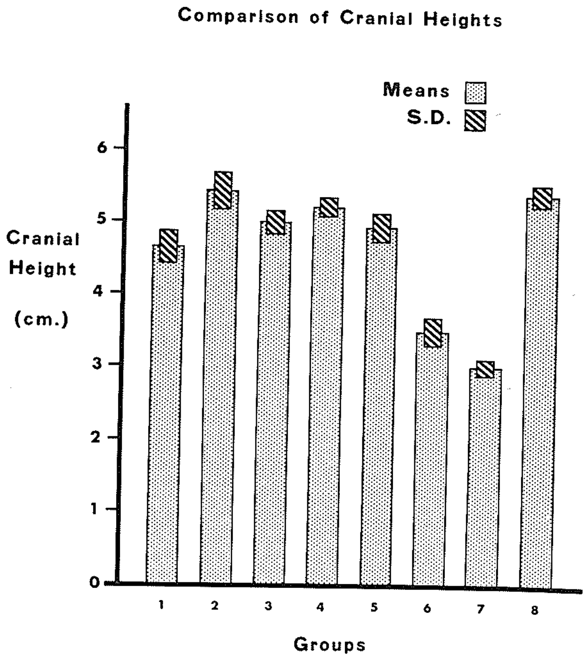

Comparison of Cranial Heights
Means
S.D.
Cranial Height (cm.)
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
Groups

Figure 33

Figure 34

Graphic representation of the means and standard deviations of the cranial widths of adult animals in the live study (groups 1 and 2) and the wild study (groups 3 through 8) as obtained from column 1 on Table IX (Linear distances on the lateral view)

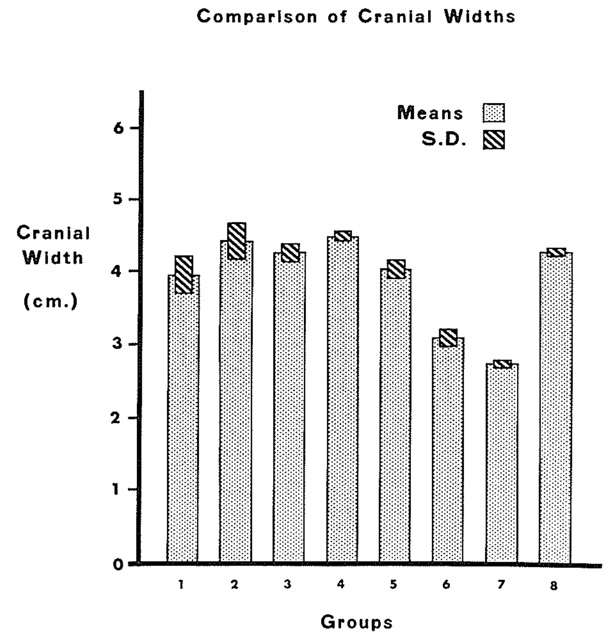

Comparison of Cranial Widths
Means
S.D.
Cranial Width (cm.)
0
1
2
3
4
5
6
1
2
3
4
5
6
7
8
Groups

Figure 34

description of all the anatomical points used is available in the Appendix.

Two other linear measurements of the basilar view are shown on Table IX. Distance 4-5 is from the most anterior point of the premaxilla between the central and lateral incisor on the mid-sagittal suture and the most anterior point on the mid-palatine suture. Point 6 is the midline point of the synchondrosis between the anterior and posterior portions of the basi-sphenoid. Of the three points, point 6 is the most difficult to locate. Point 4 is found between the centrals and laterals on the mid-sagittal plane. Point 5 is visible on both the radiograph and the photograph, while point 6 is hard to distinguish especially in the radiograph. Referring again to Table IX notice that in all cases except one the standard deviation of distance 4-5 is less than the standard deviation of distance 4-6. The standard deviation of distance 4-5 in the Dutch is 0.183 and the standard deviation of distance 4-6 is 0.162.

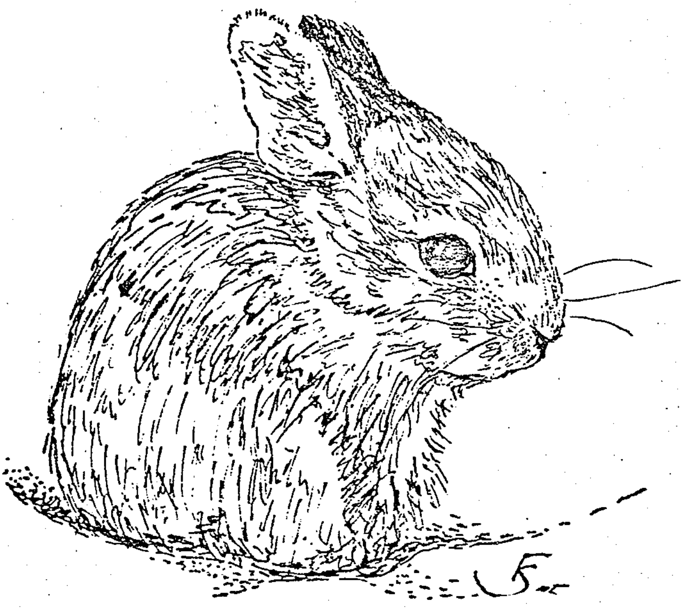
The results of angular measurements as described on Figure 24 of the lateral view are shown on Table VIII. Angle 8-6-5-1 (gonial angle) shows a great similarity in all groups except the Dutch which have a gonial angle approximately 10 degrees greater than the New Zealand or the wild groups. The variation in the angle is also high. The Brush rabbit has the most acute gonial angle and is a small rabbit. The smallest rabbit, the Pigmy, has a gonial angle which is similar to most of the other groups. Angle 1-5-3-4 on Table VIII is the angle which roughly approximates to a clinical mandibular plane angle in relation to some predetermined axis on the skull. In this case it is the angle represented by the lower border of the mandible and a point between the external occipital protuberance and the most anterior point on the premaxilla. This is a somewhat acute angle and is shown in column 2 with rather high standard deviations, considering its absolute magnitude. The position of the mandible in the last study is often affected by the stage of anesthesia that the animal is under. It the animal is in deep anesthesia it will often try to protrude its tongue. This changes the mandibular plane angle to a significant degree. Likewise, in the photographic cephalometric study, the precise positioning of the mandible in the dry skull is often a difficult procedure and again, an explanation is available for the wide variation of this angle. Column 3, Table VIII shows angle 7-9-3-4 which corresponds closely to the cranial base and the long axis of the skull. While in the radiographs of younger rabbits both of these points, 7 and 9 are hard to see, in the mature rabbit the spheno-occipital synchondrosis is quite visible as is the most anterior point of the cranial vault on the endocranial surface. This angle, however, in the dry material presents a problem of approximating anatomical points and this is reflected in the rather high standard deviations which are shown on Table VIII.

Figure 25 shows the angles used in the analysis of the basilar view. Points 1 and 2 are defined as the most external points on the zygomatic bone. The location of points 1 and 2 are described in detail in the section on Mode and Prediction of Skull Growth. Angle 7-4-9-4 is the intercondylar angle and angle 1-4-2-4 will be called the zygomatic angle. Angle 3-4-9-4 should be half of the intercondylar angle. These angles showed a great similarity in both the domestic and wild with the exception of the Pigmy rabbit. This is because the Pigmy is small and these angles vary with absolute size. Also, the variation is very similar in all the groups except the Dutch in which it is much greater.

A multi-variate analysis was done on the angles and linear distances of the rabbits in the eight adult groups.

This was done in an attempt to arrive at an index which could be used to separate these various groups in some sort of classification. IBM punch cards were prepared for each animal in the study and each angle and distance is represented. If an indexing were possible the multi-variate analysis program would show certain trends and groupings indicative of this possibility. However, there was so much similarity between many of the angles and distances that no such classification was found possible.

DISCUSSION



Growth Change Analysis

Most animals raised in a controlled environment are used as an adjunct to the main part of an experiment. The animals in the live portion of this study showed a consistent pattern of growth which was extended without mishap to the entire portion of the study. Tables I and II give evidence of consistent changes in overall skull dimensions with very low standard deviations. The weight records showed no evidence of temporary changes in the environment or other possible insults to the growing animals. The consistency and parallel nature of change shown in the gonial angle in Table III might be a further indication of the consistency of the growth through the eight stages.

Thus, it appears that both groups in the live study appeared to grow in a generally similar manner as their body weights and linear measurement increases were well proportioned and as a group, their range of variation (within groups) was generally the same. They grew up in substantially uniform environments, and there is no reason to suspect any pathological influences in the growth of their skulls. There is no reason to believe that this study does not reflect a normal and usual manner of growth.

Curve Fitting

In the longitudinal portion of this study an attempt was made to produce records which could be used to describe mathematically the precise direction of growth. Describing the growth of the skull is difficult because of the complexity of its shape and form, the many areas of growth, and the difficulty of obtaining accurate landmarks and biologically meaningful reference points.

The curve fitting constants shown in Table IV show that we were dealing with a precise direction of growth and the analysis indicated that there was a pathway toward an adult form which was definable within certain limits of variation. These growth pathways can be expressed in the form $Y = aX^n$ and enables one, mathematically, to predict future growth pathways of any animal which has an established a and n value. The reliability of this mathematical expression (Huxley, 1932 and McKeown, 1972) is demonstrated in Tables XIV through XXIII in the Appendix. The multiple regression program which was used to find best fit curves for each animal shows multiple regressions on log Y to log X, as high as 0.9, significant to the 99% level (Table XIV). This is shown in both the graphic analysis of the Dutch and New Zealand groups and the pathways which are shown in Figure 29.

Following the direction of motion of a point with respect to a fixed reference point finds that the points describe a curve and as we have seen ,the curve can be fitted to the mathematical expression $Y = aX^n$. These values for the slope are given in the results Table IV. This was the case for all of the animals. In each group the curves lay very close together and when comparisons of the two groups were made there was little difference between them and they were quite similar. This suggests that the direction of the point in each group was remarkably consistent, and that since the animals in a group had similar pathways described mathematically, that the skulls retained similar shapes. This is not to say that size and shape are the same, since there was a variation in the mature dimensions of the skulls; only the pathways were almost identical. These animals were raised in a controlled environment and whatever small influence environment and litter size may have had on the skull size, it did not seem to affect the shape.

Describing changes with growth curves and relating growth curves to the total shape is a way to arrive at an understanding of growth. The fact that the general overall shape of the head expands in an obviously orderly way suggests that if we choose other points it would also grow along precise curves in a variety of directions. These results support the studies of McKeown's (1972) thesis on the growth of the skull in domestic dogs. He showed that genetic factors predominated over environmental factors in skull growth.

Mode and Prediction of Growth

The data necessary to determine if growth prediction is possible for a certain variety of animal must come from longitudinal data, which affords a precise method of following growth allometrically. The method of analysis shown on Figure 28 allows points to be plotted and a curve fitted using a regression analysis. The animals within a group are used to find a pattern of growth particular to the theory of allometric growth. The correlations made between points (Tables V and VI) supported the predictability of that particular point along the curve. By superimposing tracings (Figure 28) made of each individual animal at the designated time intervals until maturity, there is a remarkably consistent, three-dimensional and apparently orderly change of form. The basilar view was examined in more detail because of the length of the curves which could be obtained. The orderly and consistent changes were detected in every animal, and when the two groups were compared it became apparent that one was, in general a smaller version of the other. In other words, the smaller breed, the Dutch started off smaller and reached a smaller adult size when compared to the larger New Zealand rabbit, yet both breeds appeared to have a generally similar mode of growth. When describing this mode of growth it is, of course, necessary to apply some simple mathematical definitions to this expansive growth.

The results found in this live study do not support the concept of differential growth, as a prediction method. Differential growth merely describes the relation of one part to another and its growth and change in relation to the opposing member. If we look at the organism as a whole and think of the organism as beginning with one cell, we are operating within a 'holism' philosophy (Huxley, 1932) considering the organism as one cohesive unit and the growth of the total rather than the individual and separate parts. Then we are not dependent on small changes within the organism. Too much data on growth is handled with univariate statistics which are used to describe central tendencies and variability of the velocity of each part and by bivariate statistics to express the association of the other variables. The results of such statistics produce scattergrams, clusters and trends which are often statistically significant, but afford little practical application, because they are not precisely applicable to the individual.

The high correlations found in Table VI show possibilities for growth prediction which do not depend on time, such as Hirschfeld (1970) who applied time series and exponential smoothing methods to the analysis and prediction of growth. He concluded that a time series approach has a greater application and could yield a more accurate prediction than a regression method.

The fact is that the close adherence to the general formula $Y = aX^n$ means that if it is expressed logarithmically $\log Y = \log A + \log X$, the ratio of the rate of growth of log X to log Y is constant and that the value "n" is, therefore, constant throughout the observed period of growth for that individual. It must therefore, approximate the genotypic expression of shape. The fact that growth rates vary substantially in individuals was pointed out by McCance (1968). He has pointed out that individuals can obtain the same adult size by growing so that their rates differ at various chronological points. This implies that the way in which rate changes may vary,might also be substantially genotypic. In these circumstances one would not, of course, obtain the perfect correlation by comparing achieved values at fixed time points with that achieved in the adult. This fact can be observed on Table VI in the results of the longitudinal portion of this study.

We can use growth data of this type to project future growth since a point grows in a predetermined manner. We also need other data to anticipate the point which it will have reached as an adult. The comparison was made between sizes achieved at various chronological post-natal times and the size achieved by the adult in an attempt to obtain a close relation between size achieved at some early point in post-natal growth and that eventually reached by the adult. If a perfect correlation were obtained, then its invariate nature would indicate that adult size was completely genotypic and that environmental contributions were constant in all animals. This unlikely event did not, of course, occur but we found correlations shown on Tables V and VI which were of substantial strength to support our conclusions. Values obtained from various stages on correlation tables can be used as a future basis for the prediction of adult size.

Variability

The photographic portion of this study compared the variability of a group of animals grown in a controlled environment with a group of animals which grew in the wild. The study was a comparison of groups of animals measuring various linear and angular measurements of the mature skulls of these eight different varieties (Tables VII through X). Figures 32, 33 and 34 show that there was not a significantly different amount of variability between the wild groups and this reflects on whether environment plays a role in this variability. When an animal in one of the groups seems to vary significantly from all the other animals in that group, you can suspect the cause of this to be from many different things. **Genetics**, environmental insults (nutritional or thermal) and many other factors which play an important role in variability.

In this experimental design, the live group was used and all but genetics were hopefully brought under control. It was hoped to determine the influence of environment in variability. The temperatures in the animal house were well monitored. Roubicek, et al. (1971) found a definite influence in growing rats at two different environmental temperatures.

The animals in this study were fed at regular times and it seems that this would be the best way to ensure a controlled growth area. However, Harker (1964) found that altering the feeding pattern of laboratory animals had very little effect on the growth of the animal and, apparently, animals are able to adapt to changes in feeding patterns in the laboratory just as animals who grow with the changes of season in wild environments, are able to adapt to these changing feeding times.

Animals which grow in a wild environment are most likely all subjected to periods of diminished nutrition. A period of low feed intake would first alter the amount and distribution of fat in the body. When fat is in excess, it has no direct role in the growth and it merely acts as a storer of energy. While its deposition is influenced by the quality and level of nutrition, fat in itself has very little structural stability. Tables I and II which show the mean weights in grams of the two live groups during the eight growth stages show high standard deviations. Figure 24 shows a weight curve which lacks the consistency of the curves of the changes in bony dimensions. Bryden (1968), in a study of the southern elephant seal found that although periods of starvation will certainly give a differential growth on a selective depletion of certain parts and tissues, the earlier developing parts of the body, muscular, skeletal and circulatory system are least affected by these insults. This supports work done by McCance (1968) in which he describes various tissues of more structural stability.

Catch-up growth is certainly a factor when considering variability. The potential for a complete catch-up growth after a form of growth arrest may depend upon the state of the cellular multiplication at the time of the insults to growth. The low standard deviations of the linear measurements on Table I and II and the angular measurements shown on Table III agree with Prader et al. (1963) who suggests that within each body there is a mechanism which monitors the growth rates of the organism, accelerating and decelerating the growth as is necessary for the body to meet its genetic potential.

Figures 32, 33 and 34 show the variability of various cranial measurements on all of the animals in the study. These Figures, along with Tables VII through X show very low standard deviations in the wild group. The sample of the wild animals was collected over a period of 60 years and certainly wide diversions from the optimum environmental conditions to which the animals were genetically adaptable might cause retardation in some weaker animals and, certainly have an effect on the variability. However, this did not seem to be the case.

Since the rabbits in the live portion of the study were grown in a controlled environment, we must decide if this growth projection is an artificial premise. If we compare the variations in adult size of a variety of linear skull measurements in a number of groups of wild lagomorphs of very different adult sizes, we find that their variation in most cases is less than the laboratory counterparts. In fact, the total variation in many measurements is very limited and leaves little room for any substantial environmentally induced adult variation. It seems, therefore, that adult form is probably very much less influenced by environmental variables than growing form in which growth rates are well known to be very susceptible to such alterations. A study by McKeown (1975) of wild and domestic adults has shown little variation in skull form, thus hopefully the adult variation in other species, including man, which is environmentally induced, could be very limited.

SUMMARY

(1) A method for examining the mode of growth for the rabbit skull was developed. This involved a longitudinal, three-dimensional radiographic study of a group of large and small rabbits. Also included in the investigation was a three-dimensional photographic study of six groups of wild rabbits.

(2) The basic nature of variation in the adult form of the different rabbit groups was demonstrated.

(3) Growth occurring in three dimensions can be described as a precise logarithmic process involving changes in size and shape. The process is basically a *cohesive phenomenon involving the entire head.

(4) Points on the rabbit skull can be represented as closely adhering to the allometric growth equation $Y = aX^n$, thus the direction of movement for any given point throughout growth on an individual animal is constant and is represented by the two invariates "a" and "n".

(5) A precise mode of growth, if described mathematically, affords a method of projecting the future shape of the skull.

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*-cohering, or sticking together, as in a mass.
Webster's New International Dictionary, Second Edition, (unabridged).

(6) After examining the relationship between attained adult size and the size at specific ages during growth, it was found that a strong correlation existed between the size at seven weeks and that at maturity. The method of measurement was found to be important as measurement in a traditional linear manner yielded lower correlation values than measurements made along the growth curvatures.
(7) High correlations permitted a relatively accurate prediction of "final" adult size to be made from the seven week records.
(8) The strong size correlations in combination with the dependability of the growth predictions confirm the contention that genetics and not environmental factors are dominant in growth under controlled environmental conditions.
(9) The similar magnitude of variation in wild and domestic groups, suggest that no substantially greater environmentally induced variation occurs in adult wild animals.
(10) The application of similar techniques to man might eventually lead to a clinically valuable method of predicting the adult dimensions of the human cranium.

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APPENDIX

Description of Points Used:

<u>Basilar View as Described in Materials and Methods - Section of Positioning of the Live Rabbit</u>

1. & 2. Most lateral point on zygomatic bone

3. External occipital protuberance

4. Most anterior point of the premaxilla between the central and lateral incisor on the mid-sagittal suture

5. Most anterior point on the mid-palatine suture

6. Synchondrosis between the anterior and posterior portions of the basi-sphenoid

7. & 9. Most posterior point of head of condyle

8. Posterior aspect of basi-occipitalis as it forms the anterior of the foramen magnum

Description of Points Used:

<u>Lateral View as Described in Material and Methods - Section of Positioning of the Live Rabbit</u>

1. Lowest point on the inferior border of the posterior part of the mandible
2. Most superior point on the frontal bone
3. Most posterior point on the external occipital protuberance
4. Most anterior point of the premaxilla between the central and lateral incisors
5. Inferior border of mandible at prominence below the masseteric ridge
6. Most posterior point on the angle of the mandible
7. Most superior point on the spheno-occipital synchondrosis
8. Most posterior point of head of condyle
9. Most anterior point of cranial vault on the endocranial surface

Description of Points Used:

<u>Antero-Posterior View as Described in Material and Methods - Section of Positioning of the Live Rabbit</u>

1. & 2. Most lateral point on zygomatic bone

3. Inferior aspect of basi-occipitalis on the mid-sagittal plane

4. Superior aspect of the frontal bone on the mid-sagittal plane

5. Inferior border of the foramen magnum

MATERIALS AND METHODS

Error of the Method

The error of the method in the Radiographic Cephalometry section of this study was determined by taking four separate x-rays of the same animal in the same stage and view. The four films were then digitized four times and each animal was then run through the coordinate analysis program as 16 separate animals. Tables XI, XII and XIII show the results of the error of the method. Animal No. 7 from the second Dutch litter was used at stage 5, for 13 weeks. Table XI shows the results of the basilar view; Table XII shows the results of the lateral view. Animal No. 14 from the New Zealand group was used at stage 6, for 17 weeks. Table XIII shows the results of the error of the method of the lateral view. It is possible to compare the error of the method between the two live groups and, also, between two views from the same animal of the same group at the same stage. The very small differences in the standard deviations of animal No. 7 on the length of the skull (points 3-4) show the reliability of the positioning in both the basilar and the A-P view. If the animal is tipped in the basilar view, or rotated in the lateral view, there would be a considerable difference in the same measurements taken in two dimensions. The error of the method on the angular measurements is similar between the two groups. The error of the method is slightly greater in the linear measurements on the smaller group of animals taken at a slightly younger age. These animals are harder to anesthestise and smaller animals are somewhat harder to position. The landmarks are not quite as easy to see on the x-rays; many of the bony landmarks are not dense on a smaller animal. One could assume that the error of the method would improve directly proportional to the age of the animal no matter which group you were working with.

Measuring the condylar angle 5-1-8-6 (Table XII) shows a very similar standard deviation regardless of the type of animal and the stage. This appears to be true in all the groups observed. The difficulty here would be involved in accurately locating the head of the condyle on the lateral view. This problem exists in any lateral radiographic view of the skull of any mammal.

Many observations of radiographs involve the discernment of contrast and the landmarks within the border of the skull often demand a rather objective impression to give a constant result when digitizing these landmarks. Ratliff, (1972) did a study on contour and contrast and pointed out the difficulty of being objective when observing contrast. It is much more difficult to determine contrast in an object that also has contour. Deciding upon the edge of a straight line is not nearly as difficult as determining the edge of a curve. This might well explain the dependability in low standard deviations in our study when we deal with the bizygomatic width on the basilar view. The problem of seeing points on x-rays is compounded when you have contrast, curve and also juxtapositioning of two bony parts, one on top of another as you find when looking for the head of the condyle on the lateral view. Metelli, (1974) in a study on the perception of transparency worked with various semi-transparent shapes which were laid one on top of another. He found that when one object affects the degree of transparency of the other object, various sectors take on an entirely different appearance, thus the problem of contour and the juxtapositioning and its effect on what we see inside the outline of a basilar or lateral x-ray can give an error which cannot be entirely eliminated.

McKeown, (1972), in his three dimensional study of Boxers and Pointers, found that the position of the head was a greater source of error than distortion. An example of this is the fact that plotting of points of growth from one stage to another on the A-P view will be affected to a greater degree by points which are in a vertical growth relationship since these points fall on the longer axis of the skull. Transverse measurements on the A-P view do not result in as much error. This is a good reason to choose widely separated points on the basilar view. Richardson, (1966) did a study on the reproducibility of cephalometric landmarks. He found that some landmarks were more reproducible vertically than horizontally and vice versa, and this factor should be taken into account in assessing the suitability of points, planes, or angles for a particular investigation.

Kremenak, et al. (1969) did a comparison of the osteometry of facial bones and the reliability of a radiographic versus a direct method. He found that a direct method is a reliable method where practical, an indirect method such as we have with radiographic cephalometry or photographic cephalometry yields a very small additional component of error. The error of the method in photographic cephalometry has been examined by McKeown, (1972) and Smith, (1975).

Output of Multiple Regressions -- New Zealand Group

Table XIV - log Y to log X and log of Y to exponential of X - animal no. 2
Table XV - log Y to log X and log of Y to X to the fifth power - animal no. 2
Table XVI - Y to log X and Y to exponential of X - animal no. 2
Table XVII - Y to X and log Y to X - animal no. 2
Table XVIII - Y to X^2 and Y to X - animal no. 3
Table XIX - log Y to log X and log Y to X - animal no. 3
Table XX - log Y to X and log Y to log X - animal no. 4
Table XXI - log Y to X and log Y to log X - animal no. 12
Table XXII - log Y to X and log Y to log X - animal no. 13
Table XXIII - log Y to X and log Y to log X - animal no. 14

LAB 1 BASILAR STAGE 5: ERROR OF METHOD

DISTANCES	1- 2	4- 5	7- 4- 8- 4	1- 4- 2- 4	3- 4- 8- 4
SAMPLE 1 FM11075	3.584	1.612	34.922	49.791	17.833
SAMPLE 2 FM11075	3.593	1.583	34.214	49.884	17.036
SAMPLE 3 FM11075	3.594	1.583	34.386	49.525	16.761
SAMPLE 4 FM11075	3.525	1.651	34.255	48.367	17.044
SAMPLE 5 FM11075	3.632	1.632	34.150	49.708	17.198
SAMPLE 6 FM11075	3.603	1.554	33.846	50.072	17.558
SAMPLE 7 FM11075	3.631	1.612	33.866	50.687	16.998
SAMPLE 8 FM11075	3.602	1.621	33.601	49.444	16.789
SAMPLE 9 FM11075	3.592	1.563	33.591	49.855	17.041
SAMPLE 10 FM11075	3.612	1.564	34.003	50.128	16.761
SAMPLE 11 FM11075	3.651	1.623	33.736	50.105	16.772
SAMPLE 12 FM11075	3.633	1.545	33.588	50.564	16.591
SAMPLE 13 FM11075	3.612	1.690	29.758	44.601	14.510
SAMPLE 14 FM11075	3.565	1.663	30.404	44.280	15.498
SAMPLE 15 FM11075	3.583	1.671	29.822	43.954	15.677
SAMPLE 16 FM11075	3.554	1.710	29.629	43.861	14.748
NUMBER OF SAMPLES	16	16	16	16	16
MEANS	3.598	1.617	32.986	48.427	16.551
STANDARD DEVIATIONS	0.033	0.050	1.875	2.590	0.948

Table XI

```
LAB VAR1 LATERAL STAGE 5 ERROR OF METHOD

DISTANCES                    1- 2        3- 4      5- 1- 8- 6

SAMPLE   1 FM12075          4.115       6.032        84.223
SAMPLE   2 FM12075          4.136       6.063        87.510
SAMPLE   3 FM12075          4.055       6.098        85.290
SAMPLE   4 FM12075          4.208       6.127        81.872
SAMPLE   5 FM12075          4.046       6.098        84.535
SAMPLE   6 FM12075          4.037       6.063        82.136
SAMPLE   7 FM12075          4.056       6.107        78.842
SAMPLE   8 FM12075          4.060       6.061        79.684
SAMPLE   9 FM12075          4.041       6.040        93.567
SAMPLE  10 FM12075          4.033       6.023        86.101
SAMPLE  11 FM12075          4.050       6.015        94.206
SAMPLE  12 FM12075          4.082       6.055        93.125
SAMPLE  13 FM12075          4.071       6.661        82.451
SAMPLE  14 FM12075          4.082       6.633        84.800
SAMPLE  15 FM12075          4.052       6.573        88.564
SAMPLE  16 FM12075          4.081       6.583        82.349

NUMBER OF SAMPLES             16          16            16

MEANS                       4.075       6.202        85.579

STANDARD DEVIATIONS         0.045       0.247         4.745
```

Table XII

```
LAB VAR2 LATERAL STAGE 6 ERROR OF METHOD

DISTANCES                    1- 2          3- 4      5- 1- 8- 6

SAMPLE   1 EM22146          5.544         8.932         96.420
SAMPLE   2 EM22146          5.492         8.895         95.623
SAMPLE   3 EM22146          5.483         8.874         95.645
SAMPLE   4 EM22146          5.576         8.891         94.375
SAMPLE   5 EM22146          5.537         8.902         88.591
SAMPLE   6 EM22146          5.515         8.960         85.454
SAMPLE   7 EM22146          5.520         8.894         87.205
SAMPLE   8 EM22146          5.520         8.933         87.480
SAMPLE   9 EM22146          5.520         8.928         89.838
SAMPLE  10 EM22146          5.539         8.884         95.664
SAMPLE  11 EM22146          5.547         8.904         94.913
SAMPLE  12 EM22146          5.546         8.885         95.028
SAMPLE  13 EM22146          5.506         8.846         99.669
SAMPLE  14 EM22146          5.538         8.908         98.726
SAMPLE  15 EM22146          5.525         8.837        100.454
SAMPLE  16 EM22146          5.544         8.867         98.675

NUMBER OF SAMPLES             16            16             16

MEANS                       5.528         8.896         93.985

STANDARD DEVIATIONS         0.023         0.032          4.777
```

Table XIII

```
SUBFILE   L11

* * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                 REGRESSION LIST  7
DEPENDENT VARIABLE..    LNY        LOG  Y+1 TO BASE E

VARIABLE(S) ENTERED ON STEP NUMBER  1..    LNX        LOG  X+1 TO BASE E

MULTIPLE R            0.99566                      ANALYSIS OF VARIANCE    DF      SUM OF SQUARES       MEAN SQUARE           F
R SQUARE              0.99133                      REGRESSION               1.          2.14150           2.14150        457.31331
STANDARD ERROR        0.06843                      RESIDUAL                 4.          0.01873           0.00468

----------------- VARIABLES IN THE EQUATION ------------------            ------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE              B         BETA      STD ERROR B       F              VARIABLE       BETA IN      PARTIAL   TOLERANCE        F

LNX               1.64373     0.99566       0.07686      457.313
(CONSTANT)       -0.01326
                                                            SUMMARY TABLE
VARIABLE                                         MULTIPLE R  R SQUARE  RSQ CHANGE   SIMPLE R             B                BETA

LNX         LOG  X+1 TO BASE E                     0.99566    0.99133    0.99133    0.99566          1.64373           0.99566
(CONSTANT)                                                                                          -0.01326

DEPENDENT VARIABLE..    LNY        LOG  Y+1 TO BASE E

VARIABLE(S) ENTERED ON STEP NUMBER  1..    EX         EXPONENTIAL OF X

MULTIPLE R            0.98900                      ANALYSIS OF VARIANCE    DF      SUM OF SQUARES       MEAN SQUARE           F
R SQUARE              0.97811                      REGRESSION               1.          2.11295           2.11295        178.74228
STANDARD ERROR        0.10873                      RESIDUAL                 4.          0.04728           0.01182

----------------- VARIABLES IN THE EQUATION ------------------            ------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE              B         BETA      STD ERROR B       F              VARIABLE       BETA IN      PARTIAL   TOLERANCE        F

EX                0.35839     0.98900       0.02681      178.742
(CONSTANT)       -0.29252
                                                            SUMMARY TABLE
VARIABLE                                         MULTIPLE R  R SQUARE  RSQ CHANGE   SIMPLE R             B                BETA

EX          EXPONENTIAL OF X                       0.98900    0.97811    0.97811    0.98900          0.35839           0.98900
(CONSTANT)                                                                                          -0.29252
```

Table XIV

```
SUBFILE   L11

* * * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                      REGRESSION LIST  9
DEPENDENT VARIABLE..    LNY        LOG  Y+1 TO BASE E

VARIABLE(S) ENTERED ON STEP NUMBER  1..    X ?         LATERAL SNOUT GROWTH

MULTIPLE R           0.99906                       ANALYSIS OF VARIANCE    DF     SUM OF SQUARES      MEAN SQUARE         F
R SQUARE             0.99811                       REGRESSION              1.          2.15616          2.15616       2115.60481
STANDARD ERROR       0.03192                       RESIDUAL                4.          0.00408          0.00102

----------------- VARIABLES IN THE EQUATION ------------------         ------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE              B          BETA      STD ERROR B       F          VARIABLE     BETA IN      PARTIAL    TOLERANCE          F

X                   0.96668    0.99906       0.02102     2115.605       X2           0.14005      0.52691     0.02671         1.153
(CONSTANT)         -0.00525                                             X3           0.07782      0.53992     0.09084         1.234
                                                                        X4           0.05823      0.55297     0.17016         1.321
                                                                        X5           0.04918      0.56599     0.24999         1.414
                                                                        LNX         -0.35491     -0.51528     0.00398         1.084
                                                                        EX           0.14145      0.54311     0.02782         1.255

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
VARIABLE(S) ENTERED ON STEP NUMBER  2..    X5          X POWER 5

MULTIPLE R           0.99936                       ANALYSIS OF VARIANCE    DF     SUM OF SQUARES      MEAN SQUARE         F
R SQUARE             0.99872                       REGRESSION              2.          2.15746          1.07873       1167.98875
STANDARD ERROR       0.03039                       RESIDUAL                3.          0.00277          0.00092

----------------- VARIABLES IN THE EQUATION ------------------         ------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE              B          BETA      STD ERROR B       F          VARIABLE     BETA IN      PARTIAL    TOLERANCE          F

X                   0.92547    0.95647       0.04001      534.919       X2          -1.16119     -0.48569     0.00022         0.617
X5                  0.00488    0.04918       0.00410        1.414       X3          -0.97988     -0.50032     0.00033         0.668
(CONSTANT)          0.00061                                             X4          -1.48671     -0.51492     0.00015         0.722
                                                                        LNX          2.25510      0.47412     0.00006         0.580
                                                                        EX          -1.94855     -0.49258     0.00008         0.641

                                                          SUMMARY TABLE
VARIABLE
                                                 MULTIPLE R   R SQUARE   RSQ CHANGE   SIMPLE R             B               BETA
X          LATERAL SNOUT GROWTH
X5         X POWER 5                               0.99906     0.99811     0.99811     0.99906         0.92547           0.95647
(CONSTANT)                                         0.99936     0.99872     0.00060     0.87751         0.00498           0.04918
                                                                                                       0.00061
```

Table XV

```
SUBFILE  L11
* * * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                    REGRESSION LIST  3
DEPENDENT VARIABLE..    Y          MIDSAGITAL SNOUTH GROWTH

VARIABLE(S) ENTERED ON STEP NUMBER  1..     LNX          LOG  X+1 TO BASE E

MULTIPLE R           0.96143                    ANALYSIS OF VARIANCE     DF       SUM OF SQUARES        MEAN SQUARE            F
R SQUARE             0.92435                    REGRESSION                1.            13.56700           13.56700        48.87317
STANDARD ERROR       0.52687                    RESIDUAL                  4.             1.11038            0.27760

---------------- VARIABLES IN THE EQUATION -----------------          ------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE              B         BETA      STD ERROR B       F             VARIABLE      BETA IN      PARTIAL   TOLERANCE         F

LNX                4.13726    0.96143      0.59180      48.873
(CONSTANT)        -0.10614

VARIABLE                                          MULTIPLE R   R SQUARE   RSQ CHANGE   SIMPLE R          B                BETA

LNX         LOG  X+1 TO BASE E                     0.96143     0.92435     0.92435     0.96143        4.13726           0.96143
(CONSTANT)                                                                                            -0.10614

FILE    CURVES    (CREATION DATE = 22/04/75)
SUBFILE   L11
* * * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                    REGRESSION LIST  4
DEPENDENT VARIABLE..    Y          MIDSAGITAL SNOUTH GROWTH

VARIABLE(S) ENTERED ON STEP NUMBER  1..     EX           EXPONENTIAL OF X

MULTIPLE R           0.99638                    ANALYSIS OF VARIANCE     DF       SUM OF SQUARES        MEAN SQUARE            F
R SQUARE             0.99278                    REGRESSION                1.            14.57134           14.57134       549.64625
STANDARD ERROR       0.16282                    RESIDUAL                  4.             0.10604            0.02651

---------------- VARIABLES IN THE EQUATION -----------------          ------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE              B         BETA      STD ERROR B       F             VARIABLE      BETA IN      PARTIAL   TOLERANCE         F

EX                 0.94115    0.99638      0.04014     549.646
(CONSTANT)        -0.98420

VARIABLE                                          MULTIPLE R   R SQUARE   RSQ CHANGE   SIMPLE R          B                BETA

EX          EXPONENTIAL OF X                       0.99638     0.99278     0.99278     0.99638        0.94115           0.99638
(CONSTANT)                                                                                            -0.98420
```

Table XVI

```
SUBFILE    L11
* * * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                    REGRESSION LIST  1
DEPENDENT VARIABLE..    Y          MIDSAGITAL SNOUTH GROWTH

                                                    SUMMARY TABLE

VARIABLE                                        MULTIPLE R  R SQUARE  RSQ CHANGE  SIMPLE R          B             BETA

X           LATERAL SNOUT GROWTH                 0.97604    0.95265    0.95265    0.97604         2.46169        0.97604
(CONSTANT)                                                                                       -0.12493

FILE   CURVES    (CREATION DATE = 22/04/75)
SUBFILE   L11
* * * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                    REGRESSION LIST  6
DEPENDENT VARIABLE..     LNY        LOG  Y+1 TO BASE E

VARIABLE(S) ENTERED ON STEP NUMBER  1..     X          LATERAL SNOUT GROWTH

MULTIPLE R          0.99906                  ANALYSIS OF VARIANCE    DF     SUM OF SQUARES      MEAN SQUARE            F
R SQUARE            0.99811                  REGRESSION              1.        2.15616            2.15616       2115.60481
STANDARD ERROR      0.03192                  RESIDUAL                4.        0.00408            0.00102

---------------- VARIABLES IN THE EQUATION -----------------      ------------ VARIABLES NOT IN THE EQUATION ------------

VARIABLE             B          BETA     STD ERROR B      F            VARIABLE      BETA IN     PARTIAL   TOLERANCE        F

X                 0.96668     0.99906     0.02102     2115.605
(CONSTANT)       -0.00525
                                                    SUMMARY TABLE

VARIABLE                                        MULTIPLE R  R SQUARE  RSQ CHANGE  SIMPLE R          B             BETA

X           LATERAL SNOUT GROWTH                 0.99906    0.99811    0.99811    0.99906         0.96668        0.99906
(CONSTANT)                                                                                       -0.00525
```

Table XVII

```
SUBFILE    L12

* * * * * * * * * * * * * * * * * * * * * * * *.*  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                      REGRESSION LIST  2
DEPENDENT VARIABLE..     Y          MIDSAGITAL SNOUTH GROWTH

VARIABLE(S) ENTERED ON STEP NUMBER  1..     X2         LATER SNOUTGROWTH SQUARED

MULTIPLE R           0.99614                         ANALYSIS OF VARIANCE     DF      SUM OF SQUARES       MEAN SQUARE          F
R SQUARE             0.99229                         REGRESSION               1.           14.25528          14.25528      514.74208
STANDARD ERROR       0.16642                         RESIDUAL                 4.            0.11078           0.02769

----------------- VARIABLES IN THE EQUATION ------------------          ------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE                B          BETA      STD ERROR B        F               VARIABLE       BETA IN      PARTIAL   TOLERANCE          F

X2                  1.30330     0.99614        0.05744      514.742            X              -0.40274     -0.84973     0.03433       7.793
(CONSTANT)         -0.09555                                                    X3              0.45307      0.85452     0.02743       8.119
                                                                               X4              0.24772      0.85493     0.09184       8.148
                                                                               X5              0.18191      0.85413     0.16999       8.092

SUBFILE    L12

* * * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                      REGRESSION LIST  1
DEPENDENT VARIABLE..     Y          MIDSAGITAL SNOUTH GROWTH

VARIABLE(S) ENTERED ON STEP NUMBER  1..     X          LATERAL SNOUT GROWTH

MULTIPLE R           0.96507                         ANALYSIS OF VARIANCE     DF      SUM OF SQUARES       MEAN SQUARE          F
R SQUARE             0.93135                         REGRESSION               1.           13.37989          13.37989       54.27000
STANDARD ERROR       0.49653                         RESIDUAL                 4.            0.98617           0.24654

----------------- VARIABLES IN THE EQUATION ------------------          ------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE                B          BETA      STD ERROR B        F               VARIABLE       BETA IN      PARTIAL   TOLERANCE          F

X                   2.29781     0.96507        0.31191       54.270
(CONSTANT)         -0.17213
                                                         SUMMARY TABLE

VARIABLE                                           MULTIPLE R  R SQUARE  RSQ CHANGE  SIMPLE R          B               BETA

X           LATERAL SNOUT GROWTH                     0.96507    0.93135    0.93135    0.96507       2.29781          0.96507
(CONSTANT)                                                                                         -0.17213
```

Table XVIII

```
SUBFILE   L12
* * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARI'BLE LIST   1
                                                                                                                  REGRESSION LIST  6
DEPENDENT VARIABLE..     LNY          LOG  Y+1 TO BASE E
VARIABLE(S) ENTERED ON STEP NUMBER   1..     X            LATERAL SNOUT GROWTH

MULTIPLE R              0.99877                     ANALYSIS OF VARIANCE     DF        SUM OF SQUARES         MEAN SQUARE            F
R SQUARE                0.99755                     REGRESSION               1.             2.09054             2.09054       1628.14897
STANDARD ERROR          0.03583                     RESIDUAL                 4.             0.00514             0.00128

------------------ VARIABLES IN THE EQUATION ------------------         -------------- VARIABLES NOT IN THE EQUATION --------------

VARIABLE               B          BETA       STD ERROR B        F            VARIABLE        BETA IN       PARTIAL    TOLERANCE          F

X                   0.90827     0.99877        0.02251      1628.149
(CONSTANT)         -0.01090
                                                          SUMMARY TABLE
VARIABLE                                             MULTIPLE R   R SQUARE   RSQ CHANGE   SIMPLE R              B                BETA

X           LATERAL SNOUT GROWTH                       0.99877     0.99755     0.99755     0.99877           0.90827           0.99877
(CONSTANT)                                                                                                  -0.01090

* * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARIABLE LIST   1
                                                                                                                  REGRESSION LIST  7
DEPENDENT VARIABLE..     LNY          LOG  Y+1 TO BASE E
VARIABLE(S) ENTERED ON STEP NUMBER   1..     LNX          LOG  X+1 TO BASE E

MULTIPLE R              0.99314                     ANALYSIS OF VARIANCE     DF        SUM OF SQUARES         MEAN SQUARE            F
R SQUARE                0.98632                     REGRESSION               1.             2.06701             2.06701        288.39624
STANDARD ERROR          0.08466                     RESIDUAL                 4.             0.02867             0.00717

------------------ VARIABLES IN THE EQUATION ------------------         -------------- VARIABLES NOT IN THE EQUATION --------------

VARIABLE               B          BETA       STD ERROR B        F            VARIABLE        BETA IN       PARTIAL    TOLERANCE          F

LNX                 1.56935     0.99314        0.09241       288.396
(CONSTANT)         -0.01854
                                                          SUMMARY TABLE
VARIABLE                                             MULTIPLE R   R SQUARE   RSQ CHANGE   SIMPLE R              B                BETA

LNX         LOG  X+1 TO BASE E                         0.99314     0.98632     0.98632     0.99314           1.56935           0.99314
(CONSTANT)                                                                                                  -0.01854
```

Table XIX

```
SUBFILE   L13
* * * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                   REGRESSION LIST  6
DEPENDENT VARIABLE..   LNY        LOG  Y+1 TO BASE E
VARIABLE(S) ENTERED ON STEP NUMBER  1..    X          LATERAL SNOUT GROWTH

MULTIPLE R          0.99902                        ANALYSIS OF VARIANCE    DF      SUM OF SQUARES        MEAN SQUARE            F
R SQUARE            0.99803                        REGRESSION              1.             1.88366            1.88366       2028.14876
STANDARD ERROR      0.03048                        RESIDUAL                4.             0.00372            0.00093

----------------- VARIABLES IN THE EQUATION ------------------           ------------- VARIABLES NOT IN THE EQUATION -------------
VARIABLE               B        BETA     STD ERROR B       F             VARIABLE      BETA IN     PARTIAL   TOLERANCE          F

X                  0.81463   0.99902       0.01809    2028.149
(CONSTANT)         0.01089
                                                                   SUMMARY TABLE
VARIABLE                                                   MULTIPLE R  R SQUARE  RSQ CHANGE   SIMPLE R          B             BETA

X           LATERAL SNOUT GROWTH                             0.99902    0.99803    0.99803    0.99902       0.81463         0.99902
(CONSTANT)                                                                                                  0.01089


* * * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                   REGRESSION LIST  7
DEPENDENT VARIABLE..   LNY        LOG  Y+1 TO BASE E
VARIABLE(S) ENTERED ON STEP NUMBER  1..    LNX        LOG  X+1 TO BASE E

MULTIPLE R          0.99775                        ANALYSIS OF VARIANCE    DF      SUM OF SQUARES        MEAN SQUARE            F
R SQUARE            0.99550                        REGRESSION              1.             1.87888            1.87888        884.53494
STANDARD ERROR      0.04609                        RESIDUAL                4.             0.00850            0.00212

----------------- VARIABLES IN THE EQUATION ------------------           ------------- VARIABLES NOT IN THE EQUATION -------------
VARIABLE               B        BETA     STD ERROR B       F             VARIABLE      BETA IN     PARTIAL   TOLERANCE          F

LNX                1.44964   0.99775       0.04874     884.535
(CONSTANT)        -0.01154
                                                                   SUMMARY TABLE
VARIABLE                                                   MULTIPLE R  R SQUARE  RSQ CHANGE   SIMPLE R          B             BETA

LNX         LOG  X+1 TO BASE E                               0.99775    0.99550    0.99550    0.99775       1.44964         0.99775
(CONSTANT)                                                                                                 -0.01154
```

Table XX

```
SUBFILE   L21
* * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                  REGRESSION LIST  6
DEPENDENT VARIABLE..    LNY        LOG  Y+1 TO BASE E

VARIABLE(S) ENTERED ON STEP NUMBER  1..    X            LATERAL SNOUT GROWTH

MULTIPLE R           0.99730                   ANALYSIS OF VARIANCE     DF      SUM OF SQUARES       MEAN SQUARE            F
R SQUARE             0.99460                   REGRESSION               1.             2.29475           2.29475     736.93593
STANDARD ERROR       0.05580                   RESIDUAL                 4.             0.01246           0.00311

----------------- VARIABLES IN THE EQUATION ------------------           ------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE             B        BETA      STD ERRCR B        F             VARIABLE        BETA IN      PARTIAL    TOLERANCE          F

X                0.91685   0.99730       0.03377      736.936
(CONSTANT)       0.03025
                                                    SUMMARY TABLE

VARIABLE                                          MULTIPLE R   R SQUARE  RSQ CHANGE   SIMPLE R               B                BETA

X          LATERAL SNOUT GROWTH                     0.99730     0.99460   0.99460     0.99730           0.91685            0.99730
(CONSTANT)                                                                                              0.03025

* * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                  REGRESSION LIST  7
DEPENDENT VARIABLE..    LNY        LOG  Y+1 TO BASE E

VARIABLE(S) ENTERED ON STEP NUMBER  1..    LNX          LOG  X+1 TO BASE E

MULTIPLE R           0.99831                   ANALYSIS OF VARIANCE     DF      SUM OF SQUARES       MEAN SQUARE            F
R SQUARE             0.99663                   REGRESSION               1.             2.29942           2.29942    1181.90367
STANDARD ERROR       0.04411                   RESIDUAL                 4.             0.00778           0.00195

----------------- VARIABLES IN THE EQUATION ------------------           ------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE             B        BETA      STD ERROR B        F             VARIABLE        BETA IN      PARTIAL    TOLERANCE          F

LNX              1.63431   0.99831       0.04754     1181.904
(CONSTANT)      -0.01585
                                                    SUMMARY TABLE

VARIABLE                                          MULTIPLE R   R SQUARE  RSQ CHANGE   SIMPLE R               B                BETA

LNX        LOG  X+1 TO BASE E                       0.99831     0.99663   0.99663     0.99831           1.63431            0.99831
(CONSTANT)                                                                                             -0.01585
```

Table XXI

```
SUBFILE   L22

* * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                  REGRESSION LIST  6
DEPENDENT VARIABLE..    LNY        LOG  Y+1 TO BASE E

VARIABLE(S) ENTERED ON STEP NUMBER  1..    X           LATERAL SNOUT GROWTH

MULTIPLE R          0.99724                       ANALYSIS OF VARIANCE    DF      SUM OF SQUARES       MEAN SQUARE            F
R SQUARE            0.99448                       REGRESSION              1.           2.37762           2.37762       720.79235
STANDARD ERROR      0.05743                       RESIDUAL                4.           0.01319           0.00330

----------------- VARIABLES IN THE EQUATION ------------------          ------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE              B         BETA      STD ERROR B        F          VARIABLE      BETA IN     PARTIAL   TOLERANCE          F

X                 0.87279     0.99724      0.03251       720.792
(CONSTANT)        0.03091
                                                              SUMMARY TABLE

VARIABLE                                            MULTIPLE R   R SQUARE  RSQ CHANGE   SIMPLE R             B               BETA

X           LATERAL SNOUT GROWTH                      0.99724     0.99448    0.99448     0.99724         0.87279          0.99724
(CONSTANT)                                                                                               0.03091


* * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                  REGRESSION LIST  7
DEPENDENT VARIABLE..    LNY        LOG  Y+1 TO BASE E

VARIABLE(S) ENTERED ON STEP NUMBER  1..    LNX         LOG  X+1 TO BASE E

MULTIPLE R          0.99890                       ANALYSIS OF VARIANCE    DF      SUM OF SQUARES       MEAN SQUARE            F
R SQUARE            0.99780                       REGRESSION              1.           2.38555           2.38555      1814.72164
STANDARD ERROR      0.03626                       RESIDUAL                4.           0.00526           0.00131

----------------- VARIABLES IN THE EQUATION ------------------          ------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE              B         BETA      STD ERROR B        F          VARIABLE      BETA IN     PARTIAL   TOLERANCE          F

LNX               1.59368     0.99890      0.03741      1814.722
(CONSTANT)       -0.01225
                                                              SUMMARY TABLE

VARIABLE                                            MULTIPLE R   R SQUARE  RSQ CHANGE   SIMPLE R             B               BETA

LNX         LOG  X+1 TO BASE E                        0.99890     0.99780    0.99780     0.99890         1.59368          0.99890
(CONSTANT)                                                                                              -0.01225
```

Table XXII

```
SUBFILE   L13

* * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                 REGRESSION LIST  6
DEPENDENT VARIABLE..    LNY         LOG  Y+1 TO BASE E

VARIABLE(S) ENTERED ON STEP NUMBER  1..    X          LATERAL SNOUT GROWTH

MULTIPLE R           0.99902                        ANALYSIS OF VARIANCE    DF      SUM OF SQUARES       MEAN SQUARE          F
R SQUARE             0.99803                        REGRESSION              1.           1.88366           1.88366     2028.14876
STANDARD ERROR       0.03048                        RESIDUAL                4.           0.00372           0.00093

----------------- VARIABLES IN THE EQUATION -----------------          ------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE             B          BETA      STD ERROR B        F          VARIABLE      BETA IN     PARTIAL   TOLERANCE          F

X                  0.81463    0.99902        0.01809     2028.149
(CONSTANT)         0.01089
                                                               SUMMARY TABLE

VARIABLE                                           MULTIPLE R  R SQUARE  RSQ CHANGE   SIMPLE R            B               BETA

X          LATERAL SNOUT GROWTH                     0.99902    0.99803    0.99803     0.99902          0.81463          0.99902
(CONSTANT)                                                                                              0.01089


* * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                 REGRESSION LIST  7
DEPENDENT VARIABLE..    LNY         LOG  Y+1 TO BASE E

VARIABLE(S) ENTERED ON STEP NUMBER  1..    LNX        LOG  X+1 TO BASE E

MULTIPLE R           0.99775                        ANALYSIS OF VARIANCE    DF      SUM OF SQUARES       MEAN SQUARE          F
R SQUARE             0.99550                        REGRESSION              1.           1.87888           1.87888      884.53494
STANDARD ERROR       0.04609                        RESIDUAL                4.           0.00850           0.00212

----------------- VARIABLES IN THE EQUATION -----------------          ------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE             B          BETA      STD ERROR B        F          VARIABLE      BETA IN     PARTIAL   TOLERANCE          F

LNX                1.44964    0.99775        0.04874      884.535
(CONSTANT)        -0.01154
                                                               SUMMARY TABLE

VARIABLE                                           MULTIPLE R  R SQUARE  RSQ CHANGE   SIMPLE R            B               BETA

LNX        LOG  X+1 TO BASE E                       0.99775    0.99550    0.99550     0.99775          1.44964          0.99775
(CONSTANT)                                                                                             -0.01154
```

Table XX

Figure 35

Superimpositions of two New Zealand rabbits at eight stages of growth.(true relationship shown, but enlarged for illustrative purposes)

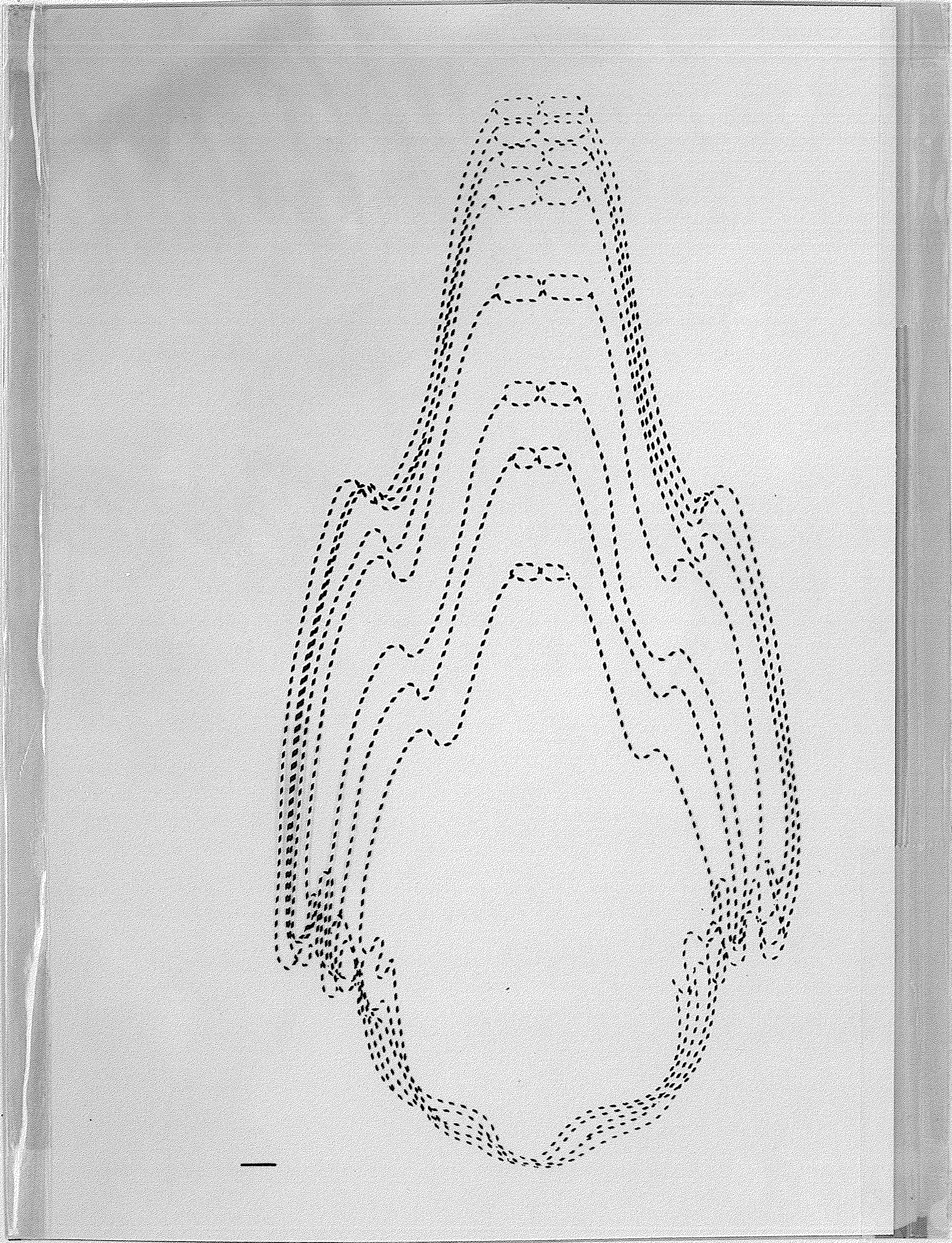

Figure 35