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The Course of Skeletal Growth in the Dairy Cow

SAMUEL BRODY AND A. C. RAGSDALE*

Abstract.—The course of skeletal growth of Jersey and Holstein heifers is presented in the form of 23 charts. The charts give (1) the absolute value of 21 skeletal measurements from birth to 60 months of age, (2) monthly gains in the measurements for each of the 60 months, (3) *rational* equations for each of the 21 curves relating the course of growth with age, and the monthly gains with age. The physiological significance of the growth equations is discussed. The numerical data on the course of skeletal growth as represented by 21 measurements are also presented.

C. H. Eckles, in 1906, then Professor of Dairy Husbandry, University of Missouri College of Agriculture undertook an investigation for the purpose of determining the effect of age of first calving and the effect of the plane of nutrition on the course of growth of the dairy heifer. The change in the live weight of the animal with age was taken for the principal index of growth. This principal index was supplemented by 21 linear or skeletal measurements¹. Wagner, in Germany, employed substantially the same skeletal measurements to measure the course of growth of some dairy animals in Germany during 1907-10 and described them in detail in 1910.²

The 21 linear measurements and the numbers by which they have become known are given in Table 1 and are graphically illustrated in Fig. A. The number of animals measured at the various ages and the averages of all the animals for each of the 21 measurements are given in Table 2 for the Jersey heifers and Table 3 for the Holstein heifers. The averages for all the animals are given rather than the averages of the six separate subgroups (normal fed early calving, normal fed late calving, low fed early calving, low fed late calving, high fed early calving, and high fed late calving) for two reasons. In the first place, the animals represented in each of the six sub-groups were two few to

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make the average for each subgroup statistically significant—at least from the viewpoint of this investigation. In the second place, none of the six subgroups could be considered as representing abnormal animals; each subgroup merely represented a type of management which is practiced by different dairymen in different localities and under different economic conditions. The averages of all animals probably represent a greater degree of normalcy than the average of any one of the six subgroups.

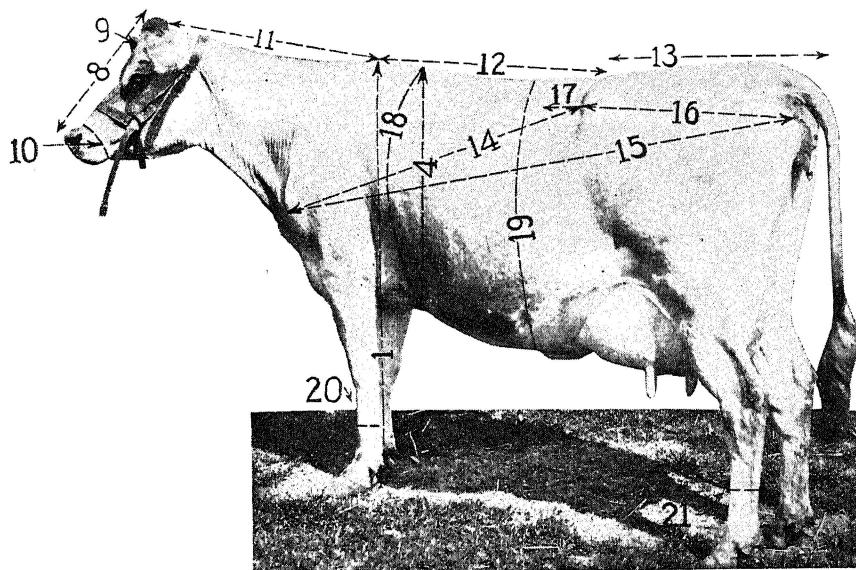


Fig. A.—The points of anatomy and the measurements taken of the cows referred to in Table 1 and in the charts.

The course of growth as measured by each of the 21 linear measurements is represented graphically in 22 charts (Figs. 1 to 22). The light circles represent the observed values for the Jersey heifers and the dark circles for the Holstein heifers. While no values for variability and degree of precision of the measurements are given, the distribution of the circles in the charts will serve to give the reader some idea concerning the variability of the data. In addition to the variability inherent in this type of work, several personal equations also entered into these measurements inasmuch as the measurements have been taken by several members of this Department. (Acknowledgment of the contribution of each person is given in our references).

The data on growth in weight and height of withers were averaged and presented by Eckles³. The other linear measurements, however,

TABLE I.—THE MEASUREMENTS, THE NUMERALS BY WHICH THE MEASUREMENTS HAVE COME TO BE KNOWN, THE ORDER IN WHICH THE CHARTS APPEAR IN THIS PAPER, THE VALUES OF THE CORRESPONDING MEASUREMENTS AT MATURITY (A), THE *Rates* OF GROWTH (P AND K), AND THE EMPIRICAL CONSTANTS (B) REFERRED TO IN THE TEXT.

Numbers and names of measurements	The numerical values of the measurements at maturity (A)		Monthly percentage persistency (ratio of gain during any month to the gain of the preceding month times 100) (100 p)		Monthly percentage decline in growth (100 k)		Empirical Constant (B)	
	Jersey cm	Holstein cm	Jersey	Holstein	Jersey	Holstein	Jersey	Holstein
1. Height at withers	125.9	134.7	91.0	91.5	9.0	8.5	137	139
2. Height at highest point of croup	125.0	133.0	89.0	89.0	11.0	11.0	156	168
3. Height at hip points	123.0	132.0	87.8	89.0	12.2	11.0	178	164
4. Depth of chest just behind elbow joint	65.3	69.0	90.5	91.3	9.5	8.7	96	92
5. Width of chest just behind elbow joint	40.0	44.4	92.0	93.5	8.0	6.5	57	50
6. Width of hips (hip points)	50.0	55.0	93.3	94.2	6.7	5.8	66	66
7. Width of loin (center)	35.7	39.0	93.5	94.0	6.5	6.0	44	44
8. Length from poll to point of muzzle	49.3	54.6	88.5	89.8	11.5	10.2	86	82
9. Width of forehead	19.2	21.0	85.0	89.0	15.0	11.0	33	25
10. Circumference of muzzle at opening of mouth	41.0	45.2	90.0	89.8	10.0	10.2	54	45
11. Length from horns to base of withers	54.5	57.5	89.0	90.0	11.0	10.0	96	88
12. From highest point of withers to a line between hips	86.0	98.0	90.5	93.2	9.5	6.8	130	112
13. From a line between hips to tail								
14. From point of shoulders to point of hips	109.0	119.0	88.5	91.3	11.5	8.7	191	153
15. From point of shoulders to ischium	155.0	164.0	91.2	90.8	8.8	9.2	205	226
16. From point of hips to ischium	46.0	47.0	90.9	90.9	9.1	9.1	62	61
17. From point of hips directly forward to last rib	35.0	35.0	92.4	91.3	7.6	8.7	44	49
18. Heart girth just below elbow joint	170.0	185.0	91.7	92.6	8.3	7.4	220	215
19. Girth of paunch just behind last rib	200.0	216.0	91.4	92.1	8.6	7.9	268	260
20. Smallest circumference of shin bone of fore leg	15.5	17.8	89.0	91.2	11.0	8.8	21	18
21. Smallest circumference of shin bone of hind leg	17.2	19.9	89.0	90.0	11.0	10.0	24	24
11 + 12 + 13	173 cm	185 cm.	87.4	89.5	12.6	10.5	376	311
22. Weight	420 kgs.	550 kgs.	94.6	95.8	5.4	4.2	680	805

are presented here for the first time. The responsibility for the development of the viewpoint presented in this paper and for the compilation of the data from the original data sheets, as well as all computations, charting, and interpretations, rests with the authors.

The purpose of averaging the 20 sets of data was to derive numerical values which would represent the *rates* of growth of the parts of the body represented by each of the sets of measurements. It is, of course, evident that each part of the body has a characteristic rate of growth which is different from the rates of growth of most of the other parts of the body; if this were not so, growth would not be accompanied by change of form, and the mature animal would be as spherical as the egg from which it was developed.

It is believed that this purpose of obtaining quantitative indices of the rates of growth of each set of skeletal measurements was accomplished. The rates of growth are presented in Table 1 in two forms. The first form is that of monthly percentage persistency of growth which is merely the ratio of the increment of the given month to the increment of the immediately preceding month. Thus, in the case of height at withers for the Jersey heifer, the average ratio of each month's increment to the immediately preceding month's increment is 0.946 and the percentage persistency of growth in height at withers per month is therefore 94.6. Secondly, the rates of growth are presented in the form of constants representing monthly percentage decline in growth. Thus, if the increment during a given month is 9 units, and in the immediately preceding month it was 10 units, then the growth of the given month declined by one-tenth of the preceding month, or the decline was 10 per cent. Of course, in this case, the persistency is nine-tenths or 90 per cent. Thus it comes about that the sum of the percentage persistency and percentage decline add up to 100. In other words, knowing one, the other may be obtained by subtracting the one from 100. The values in column 2 of Table 1, when added to the corresponding values in column 3, give the sum of 100.

In addition to the specific rates of growth, the theoretical mature values of each of the 21 skeletal measurements are also given in Table 1.

In Table 1, the *rate* of growth of each set of measurements is presented by one numerical value. In other words, it is assumed that the rates of growth, as above defined in terms of persistency or decline, are the same during the entire period of growth. Now while this constancy of rate of growth is not absolutely true, it is not far from being true for the extrauterine period of growth. If the constancy of rates of growth (as above defined) were absolutely true, and if no experimental errors were involved in this work, the observed values in the charts (Figs. 1 to 23) would absolutely coincide with the smooth curves passing through

the observed values; for the smooth curves in the chart were computed on the assumption that the constancy of the rates as given in Table I is absolutely true for the whole period of extrauterine growth.

The mathematically-minded physiologist will perceive the importance of the constancy of the rates of growth for the whole period of extrauterine growth. The senior author has developed the following equation from which the smooth curves passing through the observed values in the charts were computed.

$$Y = A - Be^{-k(t+9.4)}$$

In this equation, Y represents the value of the given measurements at the age t , A is (practically) the value of the measurement at maturity, and k is the *rate* of growth as above defined and as represented in the third column of Table 1. From Table 1, the height at withers of the Jersey cow at maturity was found from the above equation to be 125.9 cms; and the value of $k=0.09$ or 9 per cent. e is the base of natural logarithms. (The period of gestation was taken to be 9.4* months.)

The charts are self explanatory and but little other explanation is called for. The curves are arranged from 1 to 23 in the order in which they are given in Table 1. Each chart bears the name of the measurement on the axis of ordinates and this is followed by the serial number (as given in Table 1) in parenthesis. The columns in the charts represent the actual monthly gains or monthly increments. The solid curves (Jersey breed) and the broken curves (Holstein breed) passing through these columns, represent the theoretical gains; that is, gains on the assumption that the rate of growth declines in a constant manner as previously explained. The scale of ordinates for the increment curves is given in the right side of the charts.

The curves for weight, given in Fig. 23 are based on summaries by Eckles¹. They are included here for the sake of completeness and to show how the conception of constancy of *rate* of growth applies to weight data.

Some of the curves show rather strange peculiarities which the reader, no doubt, will attempt to explain. In his attempt to explain these peculiarities, the reader may be aided by the charts in a recent bulletin by the authors on the change of form with age³, and by a discussion on cyclic growth⁴. Robertson's monograph⁵ would also prove helpful to the reader in his attempt to formulate a philosophy of growth.

*B is a constant whose value compensates for the fact that the phase of growth having a constant rate of growth does not begin until sometime after conception. The 9.4 in the exponent stand for the age of the animal (in months) at birth.

TABLE II.—DATA OF SKELETAL GROWTH IN JERSEY CATTLE

Age	1		2		3		4		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20 21	
	Height at withers		Height at highest point of croup		Height at hip points		Depth of chest just behind elbow joint		Width of chest just behind elbow joint	Width of hips	Width of loins	Length from poll to point of muzzle	Width of forehead	Circumference of muzzle at opening of mouth	Length from base of horns to withers	From highest point of withers to a line between the hips	From a line between hips to the tail	From point of shoulders to point of hips	From point of shoulders to ischium	From point of hips to ischium	From point of hips directly forward to last rib	Heart girth just behind elbow joint	Girth of paunch at end of last rib	Smallest circumference of shin bone Fore leg Hind leg	
mos.	No. Animals	cm.	No. Animals	cm.	No. Animals	cm.	No.* Animals	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.
Birth.	10	66.8	7	69.5	5	69.4	5	26.5	13.5	14.2	11.2	22	11.4	21.4	20.4	34.0	14.6	48.6	64.6	20.0	12.2	68.2	71.6	8.5	9.0
1	14	71.1	8	75.4	6	75.0	6	29.6	15.7	16.3	13.9	22	12.8	22.5	23.8	38.5	15.8	53.6	72.7	21.6	14.3	75.2	86.1	8.9	9.5
2	17	75.9	9	79.8	11	78.3	7	32.6	17.2	18.2	14.1	26	13.2	24.1	26.6	43.1	15.7	58.6	79.7	23.6	16.0	82.3	97.9	9.5	10.2
3	18	80.4	9	84.9	11	82.9	7	35.9	19.2	20.8	15.9	28	13.7	25.8	29.0	46.6	19.0	63.2	83.2	25.6	18.4	91.5	112.0	9.7	10.7
4	20	84.9	9	90.0	11	88.7	7	38.6	20.6	23.1	17.6	30.1	14.6	26.7	31.6	51.0	20.0	67.7	90.8	27.7	19.6	98.6	119.5	10.5	11.4
5	22	89.6	11	94.1	11	92.5	7	41.9	23.9	25.2	18.9	32.0	14.9	30.4	33.0	55.6	22.1	72.6	99.1	29.4	21.9	106.9	133.6	11.1	12.4
6	24	93.6	15	97.4	14	96.1	11	43.3	24.2	26.7	19.9	35.2	15.6	29.2	37.1	58.3	24.0	78.5	106.8	30.7	21.5	110.8	132.7	11.4	12.8
7	29	96.8	23	98.8	21	99.5	17	44.3	24.9	29.5	20.6	35.6	15.7	30.4	33.3	59.8	28.5	81.1	109.8	31.9	23.2	115.1	140.7	11.7	13.2
8	35	98.5	25	101.8	22	101.4	19	46.4	25.4	29.6	22.3	37.0	15.8	31.3	40.2	61.0	28.9	81.4	111.8	32.8	23.5	118.5	142.7	12.1	13.5
9	34	100.8	29	104.2	24	103.5	21	47.9	27.9	31.0	22.2	38.9	16.6	32.2	42.3	62.1	30.7	84.6	115.6	34.0	24.6	122.5	147.6	12.4	14.0
10	37	102.9	30	106.4	27	105.9	22	49.4	28.0	32.2	22.6	40.0	17.2	32.9	42.9	65.2	32.2	87.7	120.5	35.1	25.2	125.9	149.5	12.8	14.6
11	39	104.9	32	108.6	28	107.8	24	50.5	29.7	33.5	23.2	41.9	17.9	33.4	45.5	65.9	34.0	90.4	123.7	36.2	26.0	129.9	155.3	13.2	15.0
12	41	106.5	32	110.2	28	108.9	24	51.3	29.8	34.2	23.9	42.2	17.6	34.1	46.8	66.8	34.0	91.9	126.1	36.8	26.1	132.1	155.4	13.4	15.2
13	41	108.3	33	111.1	26	109.9	24	51.7	29.9	35.2	24.7	42.6	17.9	34.5	47.1	68.6	34.4	92.4	127.1	37.7	27.0	135.2	156.8	13.7	15.4
14	40	109.7	30	112.3	27	111.9	23	53.4	30.3	35.9	25.4	43.6	17.9	35.1	47.2	69.1	35.0	93.7	129.1	38.1	26.7	137.2	160.1	14.0	15.6
15	42	111.0	32	113.3	27	113.1	24	54.5	31.7	36.5	25.6	43.6	18.4	35.3	48.5	70.3	35.5	95.1	131.6	38.3	27.4	140.2	163.2	14.1	15.6
16	40	111.8	35	114.7	28	113.9	24	55.6	32.2	37.1	26.6	45.0	18.3	35.8	49.2	70.9	36.0	96.5	133.5	38.9	27.6	141.5	165.3	14.1	15.8
17	36	113.2	33	115.4	28	114.7	24	55.8	32.8	38.3	26.7	45.7	18.5	36.0	49.1	72.9	36.8	98.2	135.4	39.3	28.5	145.9	168.6	14.4	16.0
18	41	113.9	34	115.5	29	115.3	26	56.7	33.6	38.7	27.1	45.7	18.7	36.6	49.3	73.9	36.7	99.3	136.9	40.2	29.0	145.5	170.4	14.5	16.3
19	43	115.3	37	116.7	28	115.9	26	57.6	33.2	39.2	27.7	46.4	18.4	36.9	49.6	73.8	36.9	100.3	138.0	40.5	28.9	147.0	170.6	14.7	16.4
20	39	116.1	40	118.3	30	116.8	28	58.5	33.8	40.1	28.1	46.5	18.9	36.9	51.4	75.9	37.0	101.4	139.7	41.5	29.5	148.8	175.1	14.7	16.4
21	40	116.8	43	119.3	32	117.7	30	59.3	34.0	40.8	28.6	46.8	18.6	37.5	50.9	76.6	36.6	102.7	140.5	42.0	29.6	151.1	175.9	14.8	16.3
22	41	117.4	42	115.1	32	118.2	29	59.4	34.4	41.2	28.6	47.5	18.9	38.2	51.9	76.7	36.8	103.6	143.2	42.5	29.8	153.0	177.5	14.9	16.4
23	41	118.7	42	120.1	34	118.9	30	60.5	34.6	42.2	29.6	47.0	18.6	38.2	51.6	77.9	36.5	104.3	144.3	43.2	29.8	154.9	179.7	15.0	16.5

24	40	119.3	40	121.1	33	119.5	31	61.2	35.3	43.1	30.0	47.4	18.7	38.5	52.1	79.8	36.0	105.1	145.7	43.5	29.8	157.4	183.7	15.0	16.8
25	36	119.8	36	121.8	30	120.4	28	61.9	35.5	43.8	30.9	47.4	18.4	39.0	50.8	81.1	36.2	106.0	146.3	44.0	30.9	158.2	186.1	15.1	16.6
26	35	119.9	33	122.1	28	120.8	26	62.0	36.0	44.2	31.2	47.6	18.6	39.1	50.2	82.3	35.0	105.4	145.7	44.0	30.9	158.5	185.0	15.2	16.8
27	37	120.5	34	122.7	28	121.2	25	62.8	37.4	44.9	31.5	47.5	18.8	39.4	49.9	82.3	34.9	106.9	147.7	44.3	31.5	160.2	188.6	15.2	16.8
28	23	120.4	29	123.4	23	121.2	22	63.0	37.1	45.6	32.4	46.5	18.5	39.6	48.5	84.6	32.0	107.7	148.3	44.6	32.0	161.3	190.1	15.1	16.8
29	24	121.0	27	123.8	22	121.5	21	64.1	37.4	45.9	32.7	46.9	18.8	39.9	47.9	85.7	32.9	107.6	148.1	45.0	31.3	162.6	194.6	15.2	16.8
30	31	121.7	26	124.1	21	121.9	20	63.9	37.1	46.2	32.7	47.0	19.0	39.5	49.2	85.2	32.3	108.0	148.2	45.1	32.8	162.5	194.4	15.1	16.7
31	20	122.1	26	124.9	21	122.6	21	63.9	39.3	46.7	33.3	46.8	18.7	39.8	49.5	86.3	32.5	107.5	148.9	45.7	32.7	164.7	196.6	15.1	16.8
32	21	122.3	24	124.8	20	122.5	20	64.4	38.9	47.0	33.8	47.2	18.6	40.0	50.5	85.6	32.4	109.2	150.4	45.5	33.2	166.1	198.8	15.1	16.6
33	30	122.8	21	124.9	17	122.7	18	64.8	39.3	47.8	33.8	47.0	18.5	40.3	52.5	85.5	33.0	110.5	152.1	45.6	32.6	166.7	198.7	15.1	16.6
34	20	122.6	23	125.0	19	122.8	18	64.8	39.2	47.4	33.9	47.1	18.7	39.9	51.6	86.1	33.0	109.4	150.4	46.3	32.9	165.8	194.9	15.1	16.7
35	19	122.8	23	124.9	19	122.9	19	65.1	39.2	47.8	33.9	47.1	18.4	40.2	51.5	86.6	32.7	108.8	150.8	46.0	33.0	166.2	196.4	15.1	16.7
36	31	123.3	22	125.4	18	123.4	19	65.0	41.1	47.6	33.7	47.6	18.6	40.4	52.4	86.5	32.5	108.6	151.0	46.2	33.6	165.5	192.9	15.3	16.8
37	18	123.0	22	125.6	18	123.5	17	64.7	40.0	48.0	33.8	47.5	18.8	41.2	51.8	86.8	32.6	109.0	152.6	46.2	33.6	166.1	195.2	15.2	16.8
38	16	122.7	20	125.2	16	122.8	16	65.2	40.1	47.9	33.7	47.8	18.6	40.3	51.2	87.2	32.7	106.1	151.1	46.2	33.6	165.8	193.5	15.2	16.8
39	17	123.0	20	125.4	15	123.6	16	64.9	39.0	47.8	34.1	48.0	18.5	40.5	51.2	87.2	32.7	109.4	152.2	46.0	34.0	166.1	193.6	15.2	16.7
40	16	123.4	20	125.6	16	123.5	17	65.3	37.6	48.2	34.2	47.2	18.7	40.8	52.9	87.4	33.1	109.9	152.2	46.6	33.7	165.6	195.6	15.2	16.9
41	16	123.1	21	126.0	16	123.8	15	65.2	39.3	48.4	34.5	48.1	18.8	40.7	52.5	88.5	33.6	110.1	151.9	46.6	33.8	167.4	196.6	15.4	16.9
42	26	124.0	19	125.9	14	123.7	14	65.4	39.5	48.2	34.5	48.2	19.0	40.8	53.2	88.3	33.2	109.7	151.9	46.7	33.8	166.8	196.5	15.4	17.0
43	15	123.0	17	125.0	15	122.5	15	64.8	36.6	48.4	34.2	48.3	19.4	40.7	53.1	87.0	32.6	109.8	151.5	46.3	34.5	165.5	195.7	15.1	16.7
44	16	123.4	18	125.8	16	124.3	16	65.3	40.5	48.7	34.3	48.5	19.0	40.6	55.3	87.2	32.9	110.0	153.1	46.3	34.3	167.8	197.7	15.3	17.0
45	17	124.0	20	125.7	16	123.6	16	65.3	40.3	48.8	34.4	47.9	19.2	41.1	53.9	87.8	32.8	111.4	154.5	47.1	34.9	167.0	197.6	15.3	17.0
46	12	123.7	14	125.2	12	122.7	12	64.5	38.9	47.8	33.9	48.8	19.2	41.0	54.9	86.1	32.6	110.6	153.4	46.3	34.5	165.5	197.2	15.2	16.9
47	13	124.2	15	125.9	13	123.8	13	65.8	38.9	48.5	34.2	49.0	18.9	41.0	57.2	87.9	32.0	112.0	156.0	47.1	34.4	167.2	196.2	15.3	17.8
48	27	124.4	19	126.6	13	123.6	13	64.8	39.2	48.9	34.1	48.3	19.0	41.0	54.7	88.1	34.5	111.3	155.3	47.0	35.6	166.6	195.6	15.3	17.7
49	13	124.4	13	126.2	12	123.8	11	66.9	38.5	47.9	34.3	50.0	19.0	41.4	56.0	89.2	33.0	113.9	156.4	47.1	36.2	165.2	195.1	15.2	17.7
50	13	123.2	15	124.6	13	122.9	13	65.2	39.6	48.1	34.1	49.0	19.5	41.8	58.3	86.7	32.8	110.4	154.3	46.6	35.5	166.5	197.4	15.2	16.9
51	11	122.9	11	125.2	11	123.1	10	65.3	38.8	46.4	34.4	49.4	18.7	40.8	57.0	85.6	32.7	111.4	154.3	46.2	34.9	166.5	196.9	15.5	17.0
52	9	122.7	9	124.2	9	121.9	9	64.8	38.5	47.4	34.5	49.1	19.2	41.1	57.4	86.6	32.6	111.4	154.4	46.4	35.7	167.2	199.5	15.3	17.0
53	9	122.8	9	124.9	10	122.5	10	65.5	38.6	48.7	33.9	48.9	19.4	41.4	58.5	84.2	35.6	111.5	153.9	46.2	35.4	167.3	204.4	15.3	16.9
54	11	123.9	7	124.1	6	122.4	5	64.7	38.6	48.8	33.6	50.9	19.1	41.7	61.1	83.7	39.4	111.0	154.7	46.7	34.7	164.6	203.0	15.4	17.2
55	6	123.1	5	124.6	4	122.7	5	63.4	36.5	47.4	33.2	52.1	18.9	41.8	60.7	84.7	38.8	110.0	153.7	46.7	33.8	166.0	194.4	15.4	17.1
56	4	120.2	4	124.3	4	121.4	4	63.9	43.0	47.0	33.7	50.4	19.1	42.3	59.8	82.7	33.8	108.7	150.3	45.9	33.9	166.6	198.0	15.2	17.2
57	4	125.6	6	127.9	4	125.5	4	66.7	40.8	48.5	34.0	52.1	19.3	43.4	59.0	81.5	39.5	112.4	158.0	48.8	37.4	172.5	208.5	16.0	17.9
58	2	123.2	4	124.8	2	122.0	2	64.9	36.8	45.5	33.0	51.0	20.3	42.2	60.0	77.0	35.0	112.5	156.8	47.5	34.8	165.0	198.5	15.7	17.5
59	4	123.0	4	124.2	3	121.6	3	64.4	39.3	46.3	30.6	50.4	19.8	42.2	62.5	81.5	36.5	113.7	157.5	46.5	36.5	166.2	206.7	15.8	17.0
60	10	125.8	5	126.2	3	121.7	5	67.1	40.9	48.1	33.4	49.9	19.1	43.2	60.3	82.8	35.0	112.8	154.4	47.6	35.1	171.5	205.4	16.2	17.4

*No. animals for 4 to 21 inclusive.

TABLE III.—DATA OF SKELETAL GROWTH IN HOLSTEIN CATTLE

Age	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15		16		17		18		19		20		21		
	Height at withers		Height at highest point of croup		Height at hip points		Depth of chest just behind elbow joint		Width of chest just behind elbow joint		Width of hips		Width of loins		Length from poll to point of muzzle		Width of forehead		Circumference of muzzle at opening of mouth		Length from base of horns to withers		From highest point of withers to a line between the hips		From a line between hips to the tail		From point of shoulders to point of hips		From point of shoulders to ischium		From point of hips to ischium		From point of hips directly forward to last rib		Heart girth just behind elbow joint		Girth of paunch at end of last rib		Smallest circumference of shin bone		Fore leg		Hind leg
mos.	No. Animals	cm.	No. Animals	cm.	No. Animals	cm.	No. Animals	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.
Birth	11	70.4	6	74.1	6	73.5	6	28.4	16.8	16.2	12.9	23.2	11.8	21.5	22.0	38.5	15.3	50.8	60.0	21.5	13.2	76.2	77.0	10.1	10.7																		
1	20	76.9	8	80.6	13	79.3	8	32.3	18.4	18.3	14.9	25.9	13.1	25.4	26.3	43.0	17.1	55.4	76.0	24.1	14.8	84.6	90.4	10.5	11.2																		
2	23	81.8	7	85.1	14	85.3	7	35.0	21.0	21.0	16.7	29.7	13.9	27.1	30.9	47.9	18.2	62.3	85.5	25.9	17.0	92.9	111.6	11.0	12.0																		
3	25	86.6	7	89.8	14	89.8	7	38.1	23.7	22.9	17.9	31.0	14.5	28.3	30.6	51.3	19.6	66.6	90.4	27.0	18.4	100.7	118.0	11.4	12.5																		
4	23	92.0	8	95.8	15	94.6	8	41.7	24.1	25.8	20.0	32.7	15.5	30.1	33.0	55.9	21.5	71.9	99.5	29.1	20.4	108.4	132.0	12.4	13.5																		
5	29	96.3	8	100.5	15	99.8	8	44.6	26.5	29.1	20.9	34.0	15.9	31.5	35.9	58.3	22.9	76.4	106.0	31.1	21.3	114.0	136.6	13.0	14.4																		
6	36	100.1	14	104.6	20	103.9	14	46.9	27.7	29.8	23.4	37.4	16.4	32.8	40.1	61.9	26.9	83.3	112.9	33.1	22.6	120.8	144.2	13.2	14.7																		
7	37	102.3	19	106.3	25	105.4	20	47.8	28.3	30.5	23.1	39.0	16.8	33.7	42.2	62.9	29.2	85.3	116.2	34.0	23.7	124.1	147.4	13.8	15.5																		
8	39	104.6	23	108.3	25	107.8	22	49.2	28.9	32.1	24.0	40.2	16.9	34.9	44.4	65.4	30.8	88.3	119.6	35.0	24.9	127.8	153.3	13.9	15.7																		
9	41	106.9	22	111.5	27	110.4	23	50.9	30.0	33.6	24.8	41.7	17.5	35.4	44.2	67.1	31.2	91.3	124.3	35.5	25.3	132.1	156.2	14.2	15.9																		
10	41	109.9	22	114.1	23	112.4	22	52.7	31.5	34.6	25.3	42.5	17.6	36.2	45.8	68.5	31.9	91.8	126.1	36.3	26.2	135.1	159.2	14.5	16.2																		
11	44	110.8	24	115.1	26	113.8	25	53.2	31.3	35.6	26.3	43.3	17.6	36.9	46.1	69.8	31.9	94.7	128.8	37.0	27.0	138.0	161.5	14.6	16.6																		
12	47	112.6	24	116.8	27	115.2	25	54.5	32.6	36.3	26.7	44.3	18.1	37.6	46.2	71.1	32.8	95.3	130.0	37.5	27.3	140.6	164.7	15.0	17.0																		
13	48	114.4	24	118.9	27	117.4	24	55.7	32.7	37.2	27.0	45.7	18.6	38.3	48.7	72.3	34.2	98.3	133.7	38.8	28.0	143.7	166.9	15.2	17.4																		
14	46	116.0	26	119.7	28	118.7	26	55.9	33.9	38.3	28.2	46.2	19.1	39.0	49.0	73.8	34.3	99.9	136.1	39.5	28.4	145.2	169.5	15.3	17.4																		
15	46	116.0	26	119.7	28	118.7	26	55.9	33.9	38.3	28.2	46.2	19.1	39.0	49.0	73.8	34.3	99.9	136.1	39.5	28.4	145.2	169.5	15.3	17.4																		
16	47	118.9	28	122.7	30	121.1	28	58.7	34.7	39.9	28.6	49.1	19.7	40.2	50.6	76.1	36.5	102.2	141.3	40.8	29.2	150.7	172.9	15.9	18.0																		
17	47	119.9	29	123.7	31	122.1	29	59.3	35.8	40.8	29.4	49.1	19.6	40.7	52.4	77.0	36.9	103.5	142.8	41.1	29.1	153.6	177.7	16.2	18.4																		
18	47	120.9	27	124.2	29	122.9	27	60.6	36.2	41.5	29.6	49.3	20.1	41.1	53.2	76.6	37.5	103.9	144.2	41.6	29.7	155.6	177.9	16.3	18.5																		
19	49	121.8	30	125.4	31	123.9	29	60.9	36.9	42.2	29.9	50.0	20.0	41.4	52.9	78.4	38.4	105.3	145.2	42.1	29.9	157.4	181.7	16.6	18.7																		
20	49	123.3	30	126.8	30	125.2	29	62.0	37.2	43.1	30.7	50.6	20.0	42.0	53.9	80.3	38.3	106.0	146.7	42.7	30.4	160.1	185.6	16.7	19.0																		
21	50	124.1	28	126.8	30	125.4	28	62.1	37.9	43.5	30.8	51.3	20.3	42.2	54.2	80.2	39.0	108.2	149.4	43.3	30.5	161.3	186.5	16.8	19.1																		
22	49	125.1	27	127.8	30	126.4	27	62.9	37.5	43.4	31.2	51.3	20.2	42.3	53.0	82.7	38.6	108.7	151.0	43.6	30.3	162.2	189.2	16.9	19.1																		
23	46	125.7	26	129.6	29	127.9	26	64.0	39.3	45.3	32.0	52.5	20.5	43.2	54.7	83.5	38.9	109.0	151.6	44.2	30.9	166.1	193.4	17.2	19.5																		

24	43	126.7	25	129.5	28	128.1	25	64.2	39.1	45.8	32.1	52.0	20.1	43.1	53.8	84.6	38.0	111.8	152.6	44.1	31.0	166.3	195.6	17.1	19.4	
25	38	127.4	22	130.1	18	128.7	22	64.9	36.8	46.8	32.8	51.8	20.0	43.0	55.8	85.4	36.9	111.9	153.6	44.5	32.1	167.4	197.1	17.2	19.4	
26	40	127.6	23	130.7	19	128.7	23	65.8	30.9	47.6	33.6	52.5	20.4	43.4	56.7	86.9	38.0	114.7	156.9	45.2	31.9	170.3	201.0	17.2	19.6	
27	38	128.3	23	130.8	18	128.7	23	65.8	40.3	47.6	33.7	52.6	20.3	44.3	55.3	86.6	37.2	113.1	156.1	45.1	32.5	170.7	201.0	17.4	19.6	
28	35	128.9	22	131.9	19	129.3	22	66.3	41.5	48.1	34.2	52.6	20.3	43.9	53.8	88.9	36.8	114.4	157.3	45.3	32.1	171.2	201.7	17.4	19.6	
29	32	129.3	18	131.9	18	129.9	19	66.1	40.6	48.6	34.3	52.0	19.9	44.4	56.0	89.2	36.7	115.1	157.7	45.7	32.4	172.8	203.0	17.3	19.6	
30	34	130.4	19	133.0	19	130.7	19	67.5	41.6	51.1	35.4	52.0	19.8	44.3	55.1	90.5	35.0	114.8	158.1	46.4	33.3	174.9	206.4	17.5	19.6	
31	21	129.9	18	133.0	18	131.2	18	67.7	41.9	49.6	35.8	52.0	19.4	44.1	53.6	90.5	34.0	115.2	158.2	46.6	35.6	175.0	205.5	17.3	19.5	
32	17	130.1	16	133.1	16	131.2	16	68.2	41.9	50.3	36.2	51.8	19.7	44.7	54.5	92.3	33.3	115.5	159.9	46.6	33.9	176.7	211.7	17.3	19.5	
33	29	131.1	17	133.5	17	131.3	17	68.5	42.7	50.7	36.3	52.1	19.8	44.9	53.1	92.9	33.4	115.9	160.2	47.9	35.1	177.8	214.5	17.2	19.7	
34	16	130.7	15	133.3	15	131.4	15	67.9	42.0	50.7	36.2	52.0	19.6	44.7	55.5	92.4	33.3	115.5	159.3	46.9	33.8	176.9	212.6	17.1	19.4	
35	17	130.6	17	133.5	17	131.5	17	68.5	42.7	50.7	36.2	52.3	19.7	44.6	55.4	93.1	34.0	115.8	160.5	47.1	35.3	176.0	211.1	17.2	19.6	
36	30	131.6	15	133.7	15	131.8	15	68.4	40.6	50.7	35.9	52.1	19.7	44.4	53.7	94.9	32.9	117.8	162.6	47.0	35.2	174.7	206.8	17.2	19.6	
37	16	131.0	16	134.1	15	131.7	15	68.5	39.7	50.6	36.1	51.8	19.7	44.4	55.7	93.4	32.5	116.1	160.9	47.3	35.0	175.7	203.4	17.2	19.6	
38	15	131.3	13	133.9	12	131.8	13	68.6	41.5	51.0	36.1	52.0	19.3	44.4	55.1	94.9	32.3	115.0	159.4	47.0	35.1	174.9	204.9	17.0	19.5	
39	17	131.1	13	134.1	13	132.2	14	69.3	42.7	51.6	37.2	51.9	19.4	45.8	54.4	95.5	32.7	116.0	160.8	47.8	34.5	176.7	209.9	17.4	19.6	
40	16	131.4	13	134.0	13	132.1	13	68.6	42.4	51.0	36.4	52.1	19.6	45.1	55.3	94.2	33.0	115.2	161.4	47.6	34.2	176.0	205.5	17.5	19.7	
41	16	131.5	11	133.8	12	131.6	12	69.4	43.2	51.7	36.4	52.3	19.1	45.7	53.4	93.6	33.6	116.8	160.5	47.7	35.5	178.5	209.0	17.5	19.6	
42	29	132.9	13	133.9	13	131.9	13	69.7	42.8	52.2	37.5	52.6	19.5	46.0	55.9	95.7	33.5	117.9	163.1	48.4	34.2	180.4	213.5	17.5	19.6	
43	17	132.2	13	133.8	13	131.9	13	69.0	41.9	51.7	36.6	52.4	19.4	45.2	58.3	92.8	33.6	116.5	161.8	48.2	34.0	177.6	206.7	17.3	19.6	
44	13	131.1	12	133.4	12	131.0	12	69.0	42.8	52.0	36.9	51.9	19.4	46.2	58.2	94.0	34.0	115.0	160.5	48.0	34.9	177.2	210.1	17.4	19.6	
45	13	131.7	12	134.0	13	132.2	13	69.6	42.7	52.9	37.6	52.6	19.1	46.6	60.4	93.5	33.2	116.8	162.8	47.9	34.0	180.1	213.7	17.5	19.6	
46	14	131.9	14	134.7	12	132.0	13	70.0	44.8	51.7	37.9	52.9	19.3	46.7	58.5	94.1	33.3	115.7	162.9	49.1	35.0	183.7	219.8	17.6	19.7	
47	15	131.4	10	132.9	12	131.8	10	69.3	42.9	53.0	38.3	52.2	19.4	45.8	59.4	93.3	34.9	117.1	163.0	49.5	35.7	181.5	220.3	17.4	19.7	
48	26	133.1	12	134.1	12	133.1	12	70.2	44.9	53.3	38.1	52.9	19.4	46.8	60.7	93.9	36.1	116.1	163.8	49.2	34.8	183.0	216.2	17.4	19.8	
49	14	131.2	11	134.8	11	132.1	11	69.7	44.1	52.7	37.9	53.1	19.0	46.4	61.8	93.5	36.6	117.2	163.5	49.2	34.8	181.9	218.0	17.4	19.4	
50	10	131.2	9	133.4	9	136.5	9	69.3	43.7	53.0	38.2	52.5	19.4	45.8	60.7	93.3	36.8	116.7	164.3	49.0	35.5	181.6	212.2	17.2	19.6	
51	10	132.6	9	134.7	9	132.9	9	70.1	44.6	53.7	38.5	52.8	19.4	46.8	62.5	94.8	36.2	119.0	165.0	49.4	34.5	181.7	214.7	17.5	19.7	
52	10	132.9	9	135.9	9	134.7	9	70.8	43.1	53.5	38.1	53.2	19.8	46.3	60.6	96.8	35.4	119.2	166.1	50.0	36.3	183.5	214.7	17.6	20.0	
53	4	130.8	6	133.4	6	131.3	6	69.9	42.9	54.2	39.7	52.7	19.3	45.8	61.5	94.3	36.2	115.7	164.5	48.1	34.6	181.1	211.4	17.5	19.1	
54	14	134.6	5	134.2	5	132.4	5	70.6	44.8	54.1	39.7	52.7	18.7	46.8	62.3	96.4	33.2	118.0	164.3	48.3	35.7	183.4	214.7	17.4	19.5	
55	6	134.4	6	136.2	6	133.4	6	70.8	43.3	54.2	39.9	53.1	20.2	47.1	61.3	97.2	33.7	118.4	165.9	49.4	36.4	184.0	219.4	17.6	20.1	
56	4	132.1	4	133.8	4	132.0	4	70.3	44.4	52.9	39.3	53.3	19.9	47.2	62.7	94.0	34.0	117.1	164.8	50.2	35.7	181.9	213.7	17.5	19.6	
57	3	129.3	3	131.8	3	130.2	3	69.7	45.7	54.4	40.2	52.2	19.3	48.6	66.3	92.5	39.2	121.0	168.2	49.5	34.3	183.5	221.0	17.4	19.3	
58	5	133.3	5	134.0	5	132.0	5	70.8	44.3	55.4	39.5	53.5	19.8	46.6	62.3	93.4	37.0	118.3	165.7	49.3	33.8	182.0	225.5	17.4	19.4	
59	4	135.2	3	136.7	3	134.6	2	69.3	42.2	53.1	38.9	53.2	19.8	48.3	66.3	96.2	40.3	109.0	168.8	49.8	35.2	184.0	218.0	18.1	20.1	
60

*No. animals for 4 to 21 inclusive.

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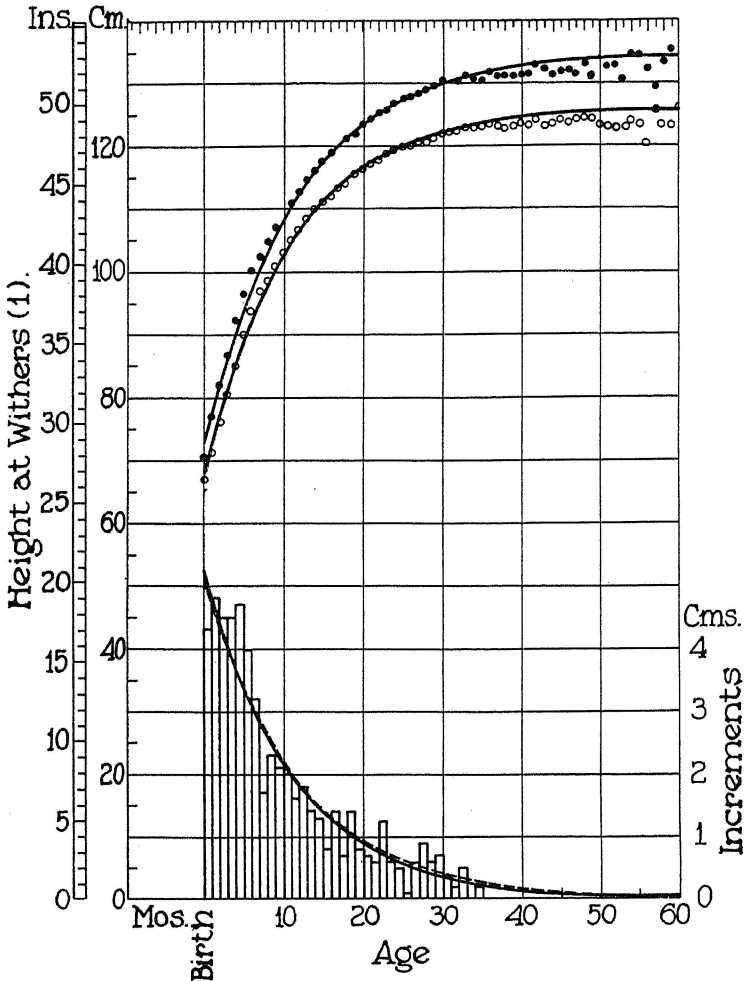


Fig. 1.—Growth in Height at Withers (measurement 1). The light circles represent the mean observed heights at withers of the Jersey group of animals for the ages indicated on the scale of abscissae. The dark circles similarly represent the values for the Holstein group of animals. The smooth curve passing through the Jersey circles was plotted according to the equation $-0.09(t+9.4)$

$$Y = 125.9 - 137e^{-0.09(t+9.4)} \quad (a)$$

in which Y is the height at withers at the age t from birth. The 9.4 in the exponent stands for the age of the animal at birth. The 0.09 is the monthly decline in growth that is k in Table 1. The 125.9 is the computed height at withers at maturity, that is A in Table 1. The value 137 represents the constant B in Table 1. The curve for the Holstein group is computed in the same manner, but, of course, using the constants for the Holstein group as given in Table 1. The columns represent the observed mean monthly gains of the Jersey group of animals. (The observed monthly gains for the Holstein

group were omitted to avoid undue complexity in the chart.) The smooth curve passing through these columns was computed on the assumption that growth takes place according to equation (a). That is

$$dY = 12.3e^{-0.09(t+9.4)} \quad (b)$$

In this equation dY represents the monthly gains at the age (from birth) t as previously explained. The numerical value 12.3 is the product 137 times 0.09, that is, equation (b) is the differential form of equation (a). The broken curve through the columns represents the theoretical monthly gains of the Holstein group of animals.

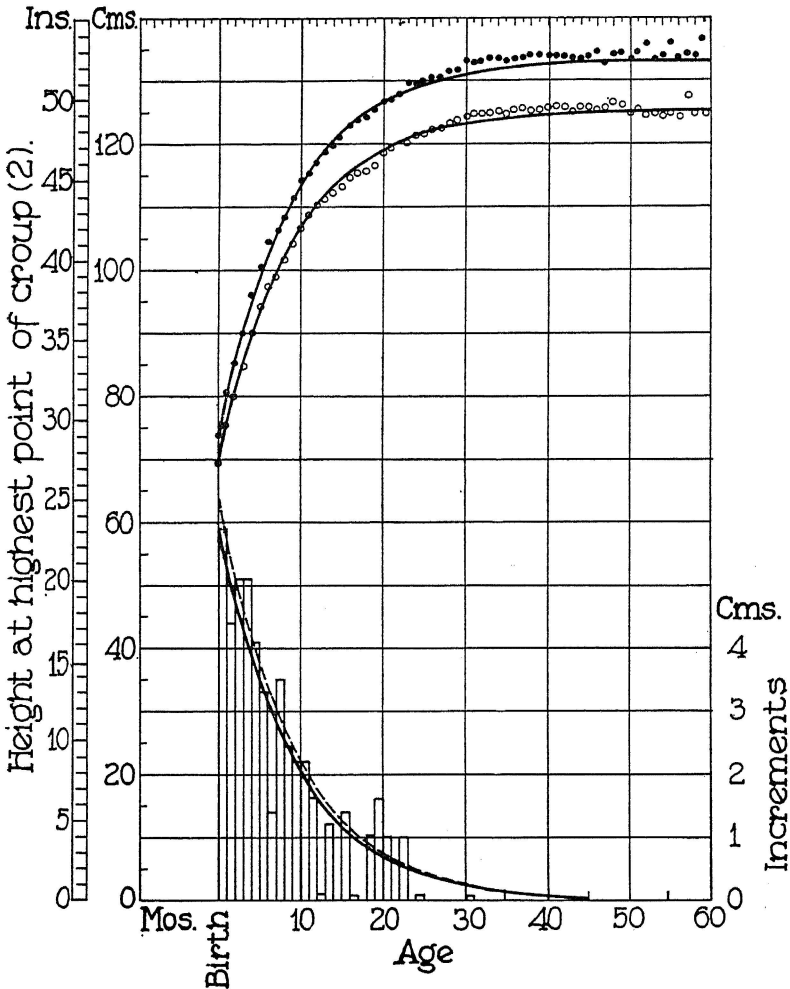


Fig. 2.—The Course of Growth, and Decline of Growth, in Height at Highest Point of Croup (measurement 2). For methods of computation see legend to Fig. 1.

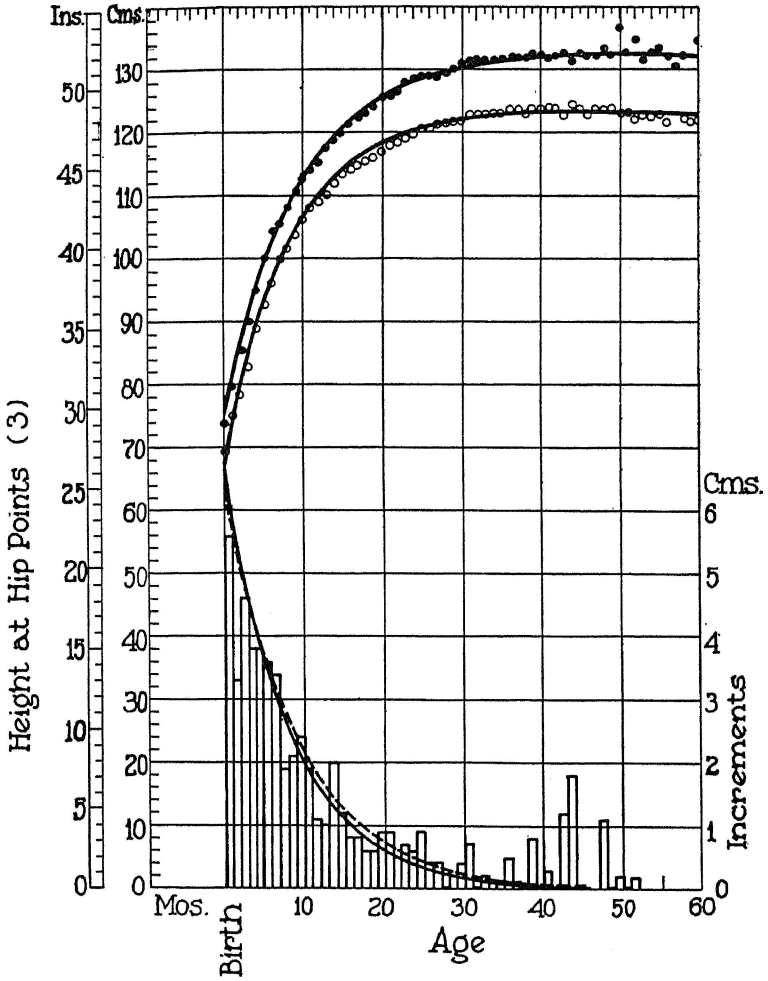


Fig. 3.—Growth in Height at Hip Points.

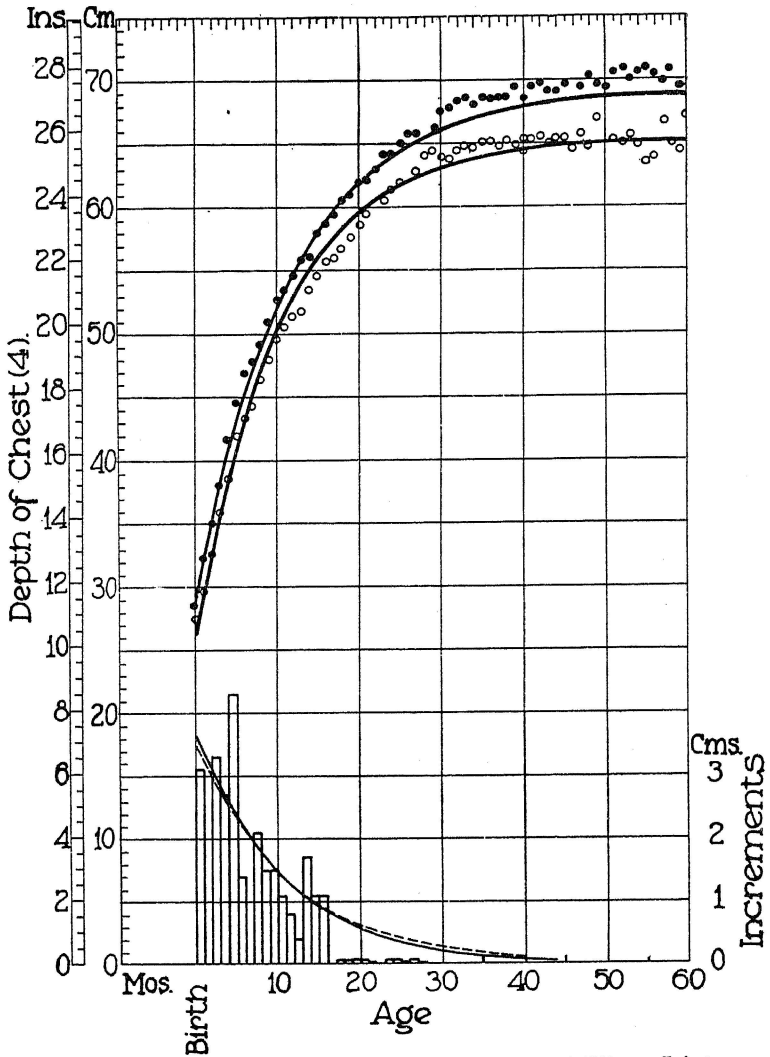


Fig. 4.—Growth of Depth of Chest just Behind Elbow Joint.

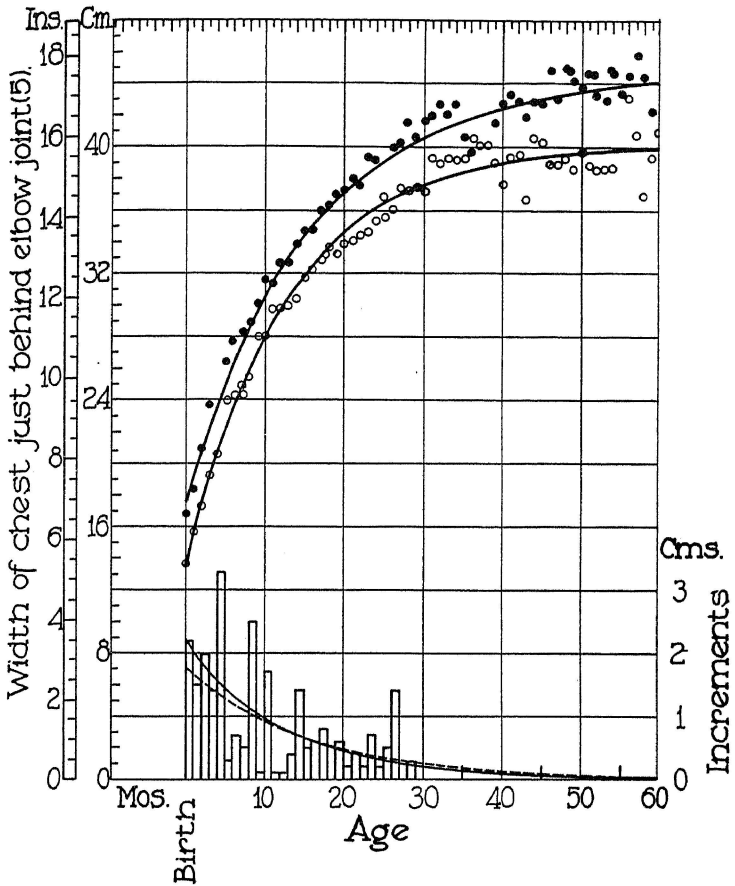


Fig. 5.—Growth of Width of Chest just Behind Elbow Joint.

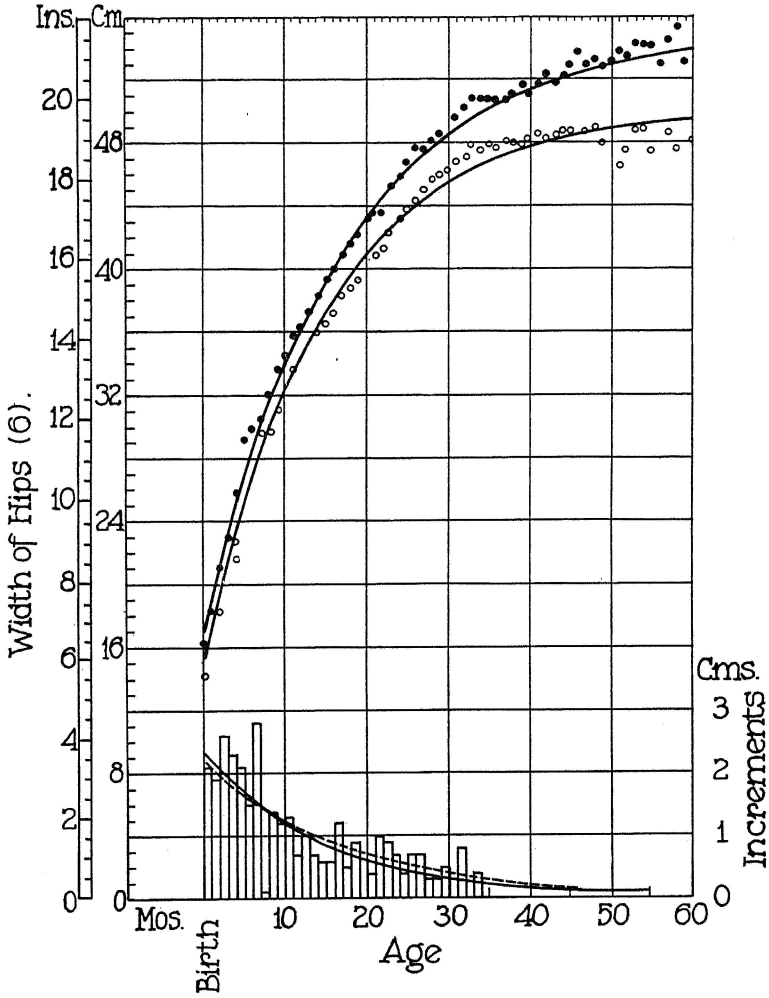


Fig. 6.—Growth of Width of Hips.

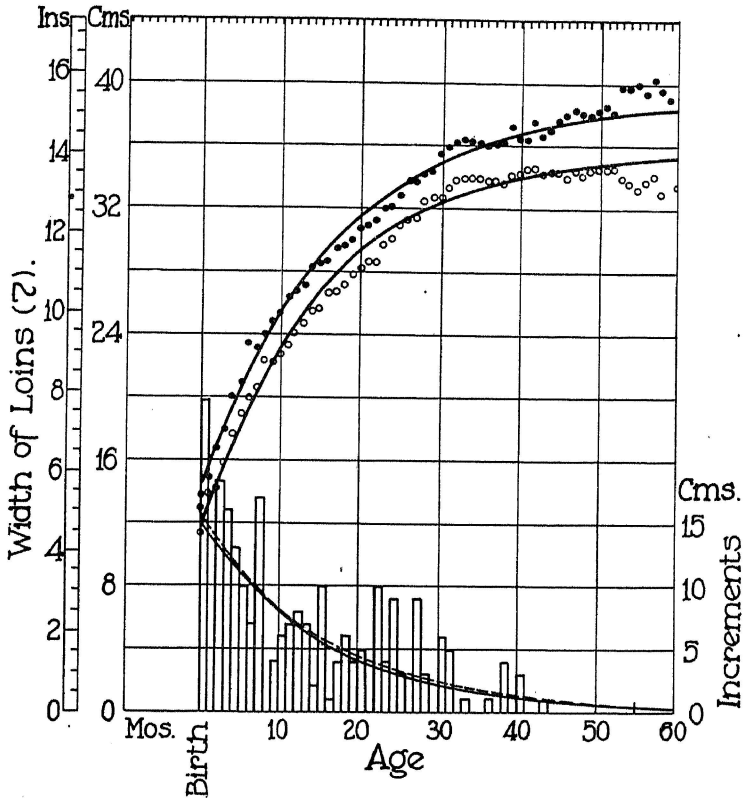


Fig. 7.—Growth of Width of Loins (center).

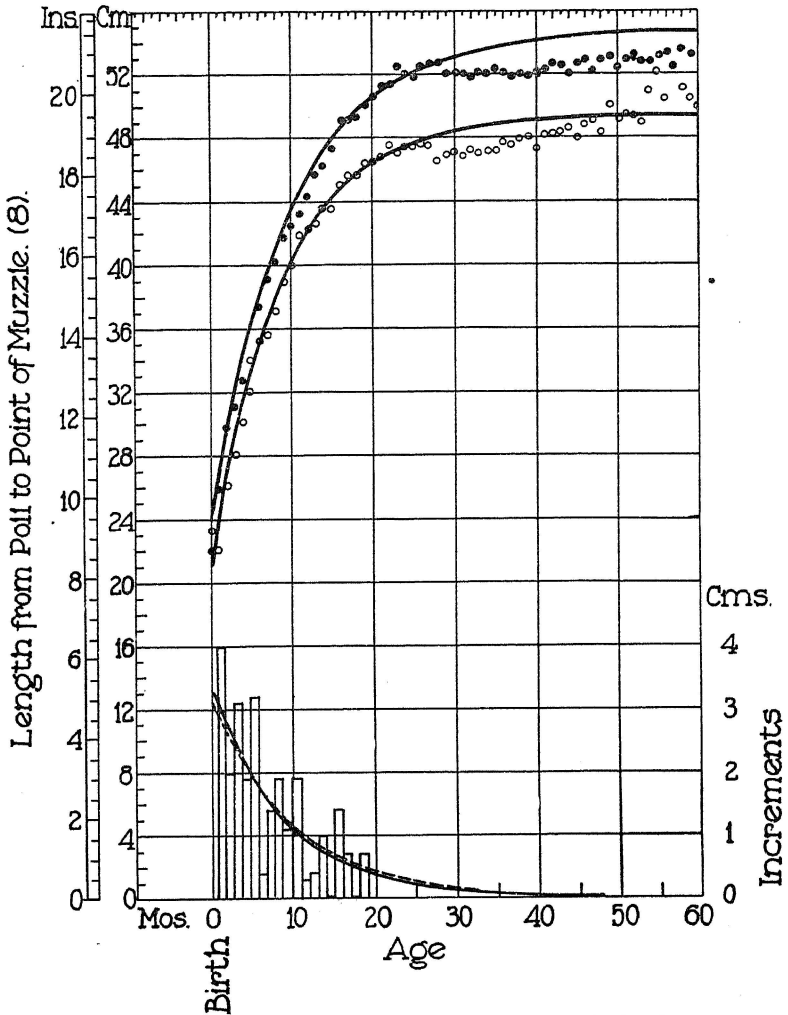


Fig. 8.—Growth in Length from Poll to Point of Muzzle.

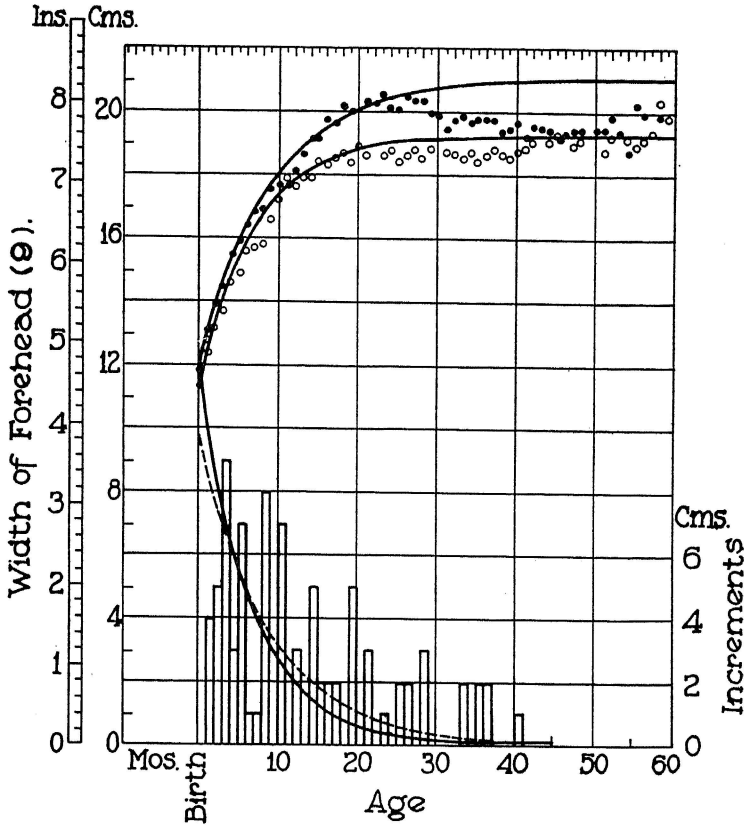


Fig. 9.—Growth in Width of Forehead.

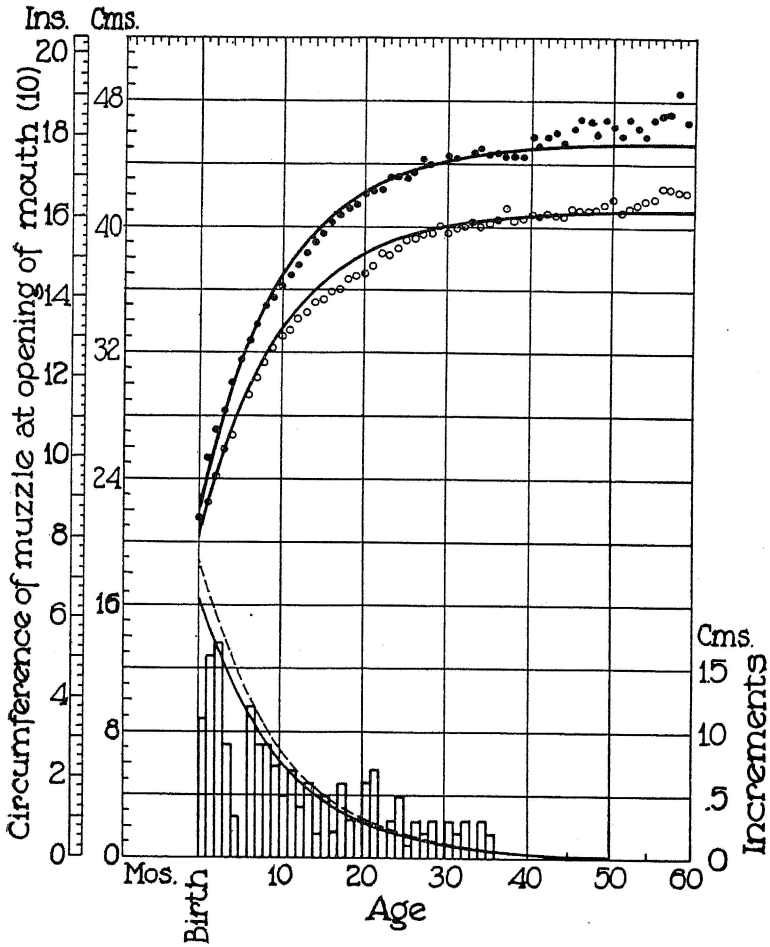


Fig. 10.—Growth in Circumference of Muzzle at Opening of Mouth.

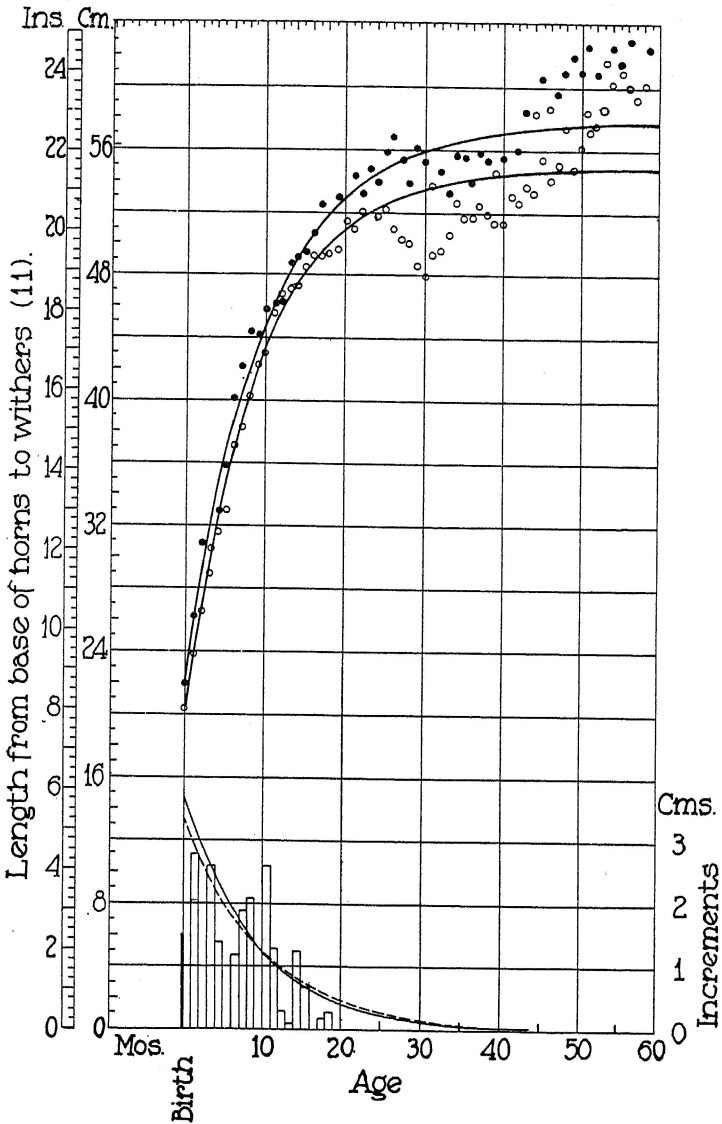


Fig. 11.—Growth in Length from Horns to Base of Withers.

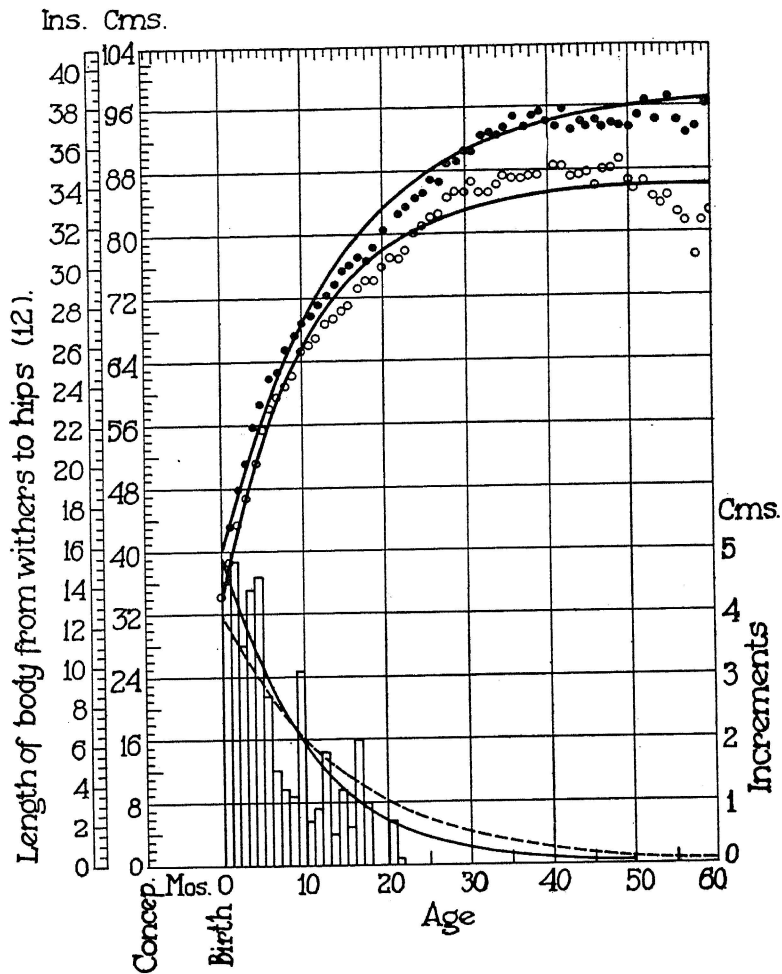


Fig. 12.—Growth in Length from Highest Point of Withers to a Line Between Hips.

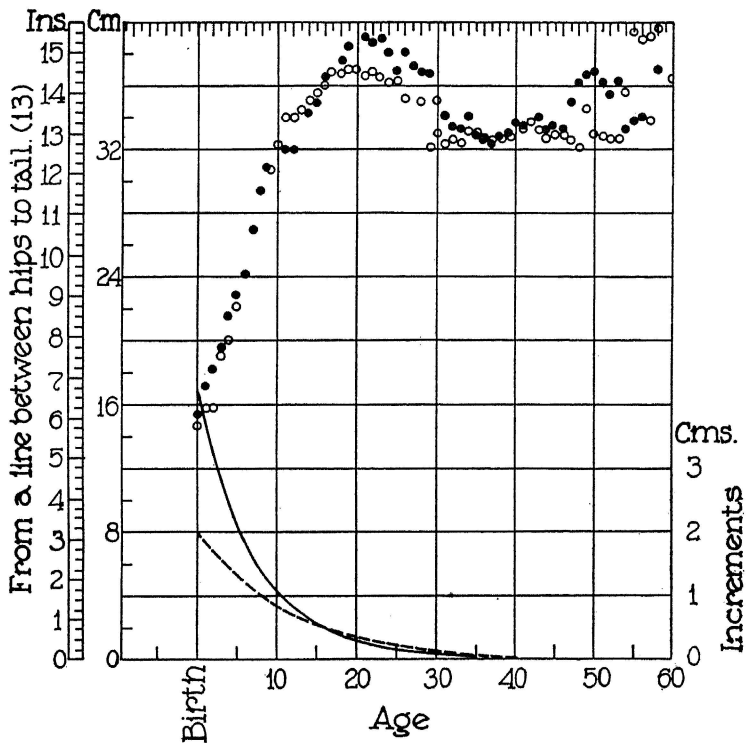


Fig. 13.—Growth in Length from a Line Between Hips to Tail.

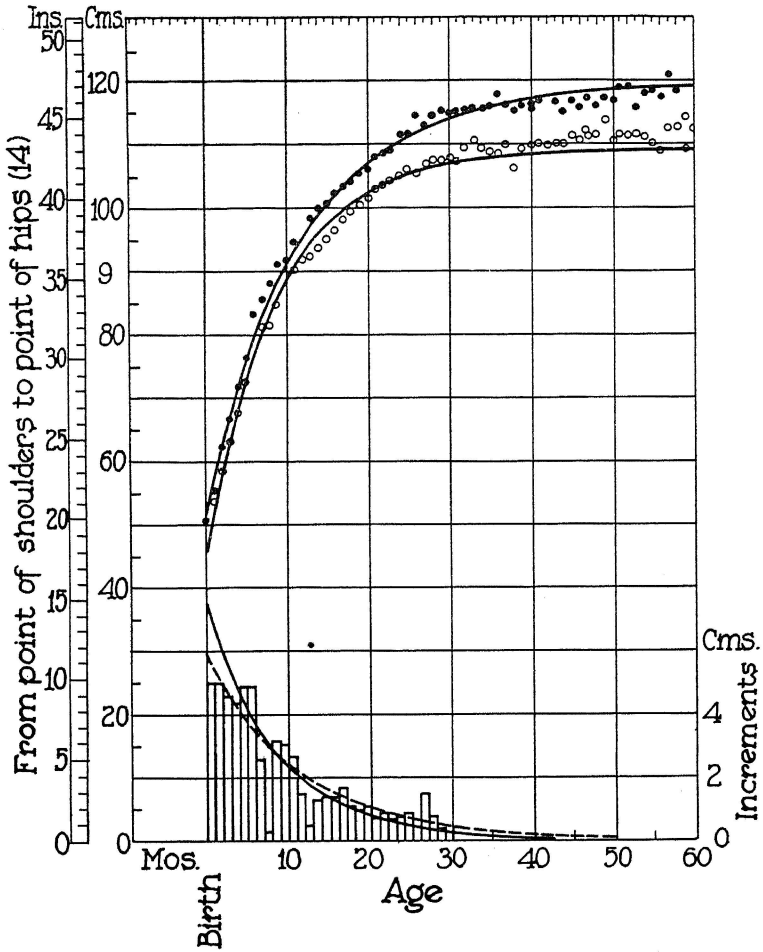


Fig. 14.—Growth from Point of Shoulders to Point of Hips.

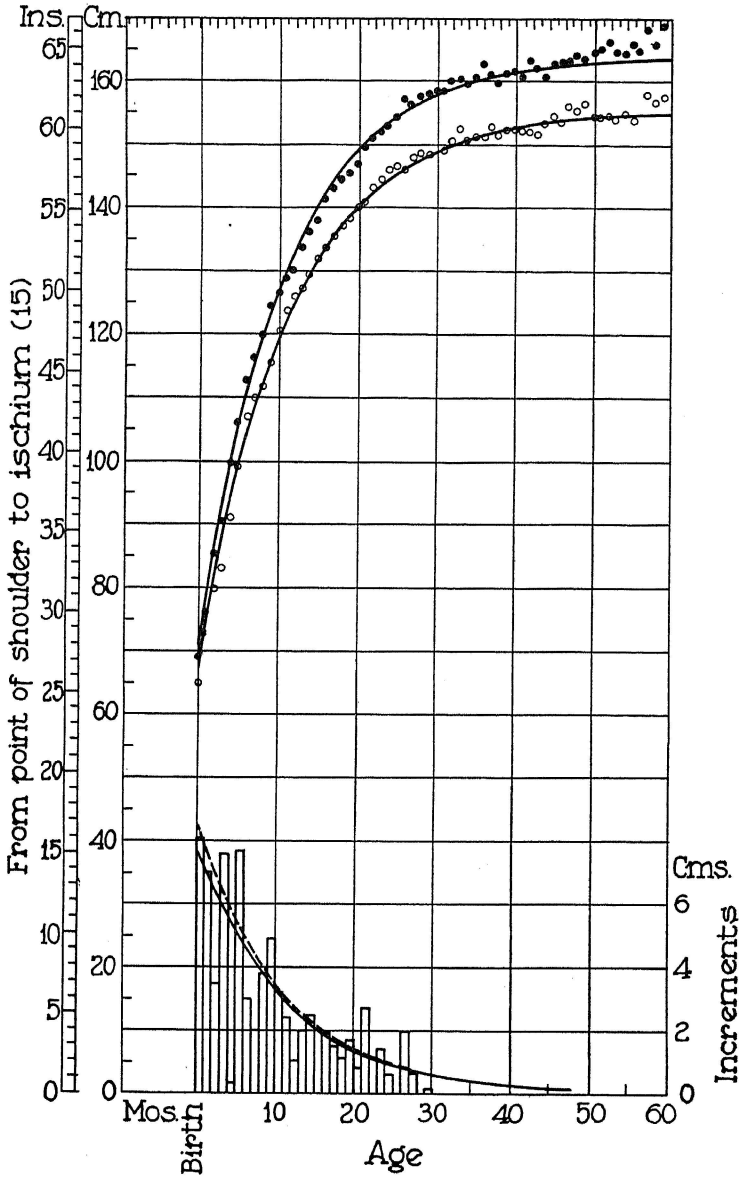


Fig. 15.—Growth from Point of Shoulders to Ischium.

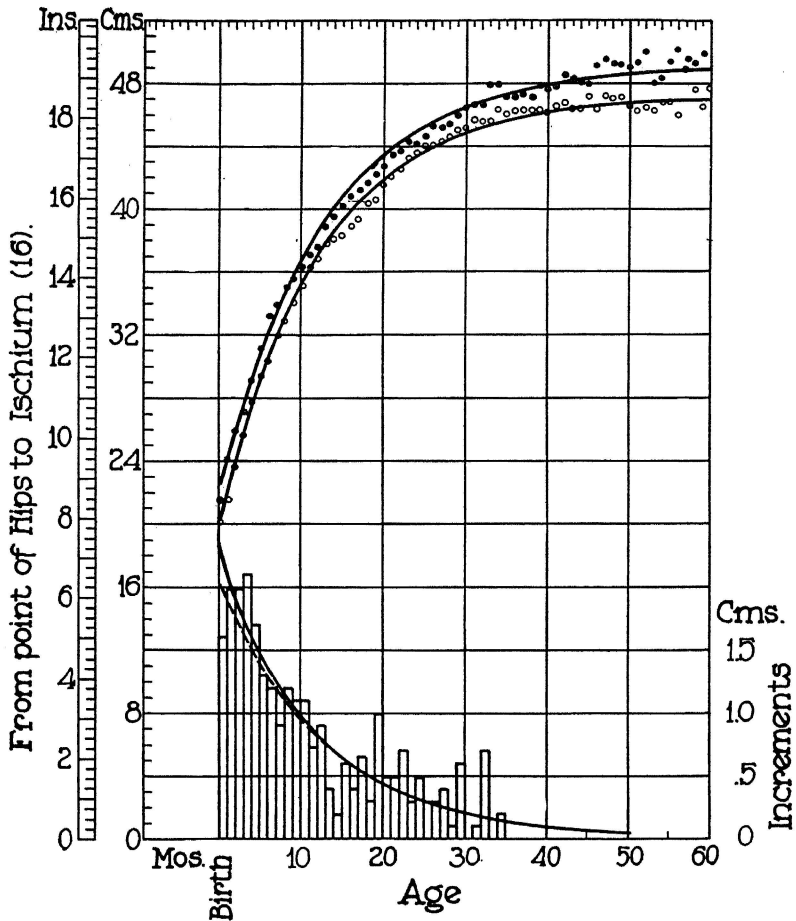


Fig. 16.—Growth from Point of Hips to Ischium.

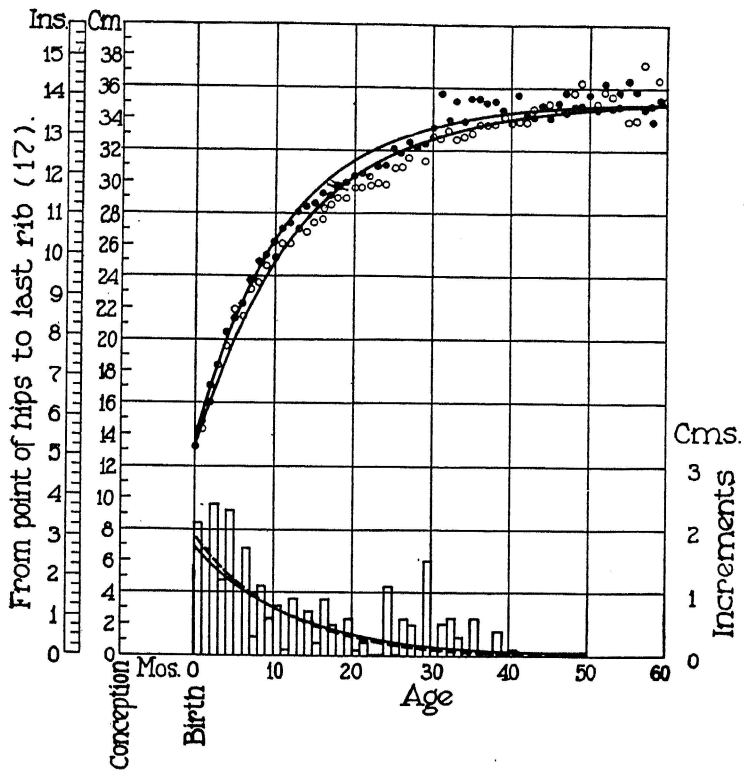


Fig. 17.—Growth from Point of Hips Directly Forward to Last Rib.

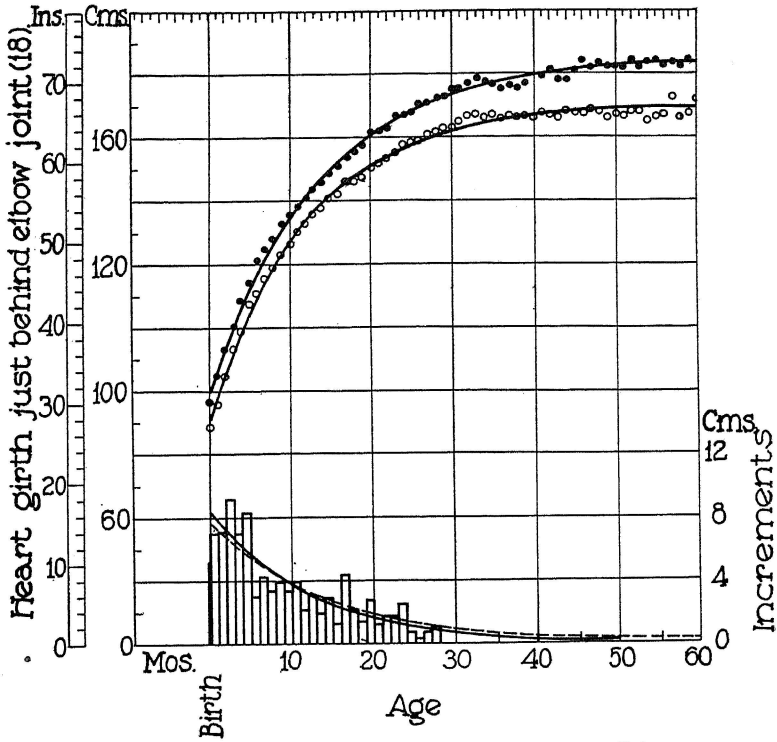


Fig. 18.—Growth in Heart Girth just Behind Elbow Joint.

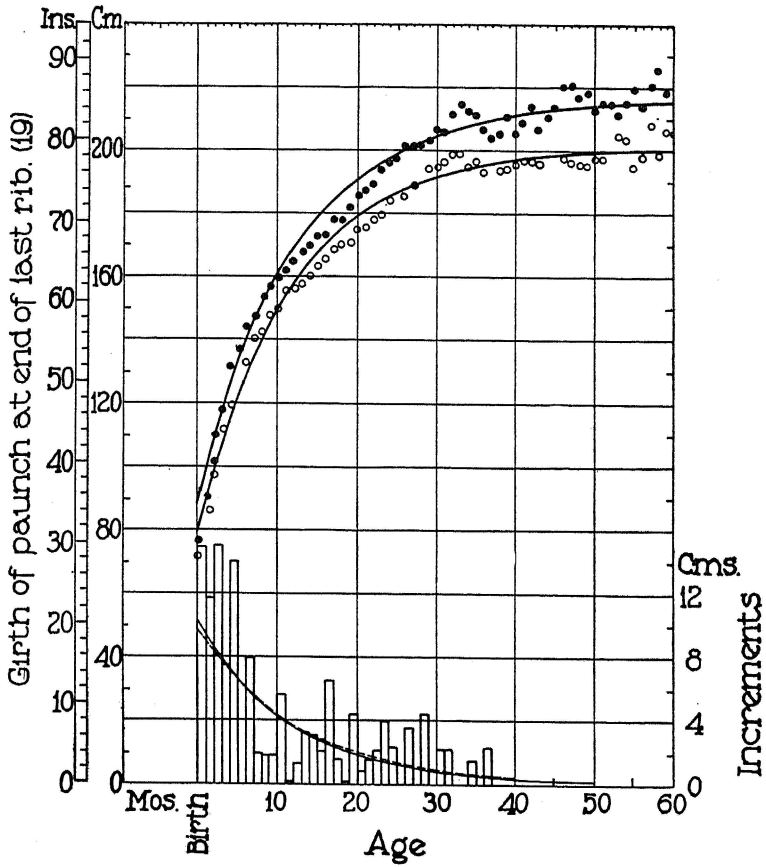


Fig. 19.—Growth in Girth of Paunch just Behind Last Rib.

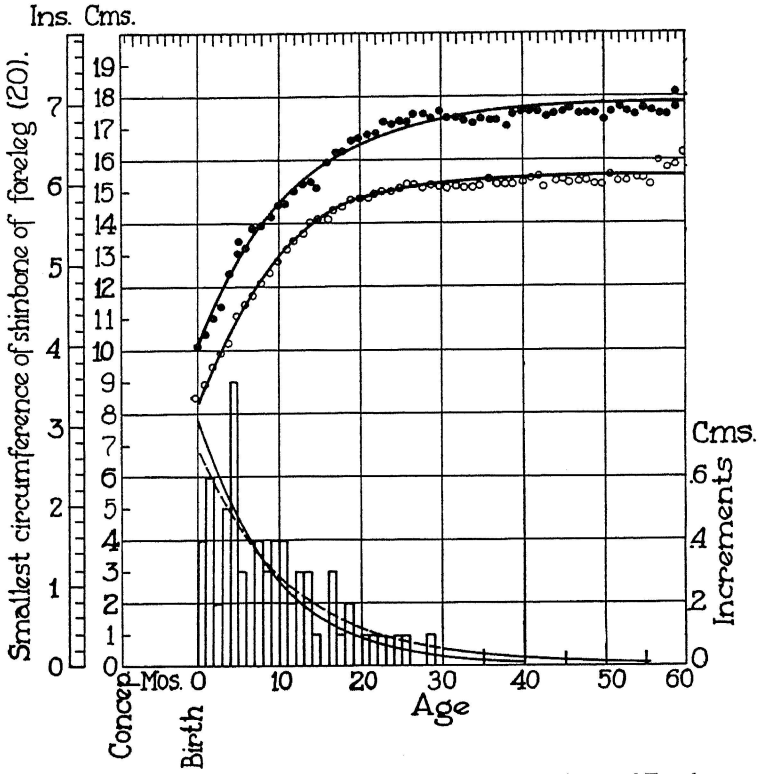


Fig. 20.—Growth in Smallest Circumference of Shinbone of Foreleg.

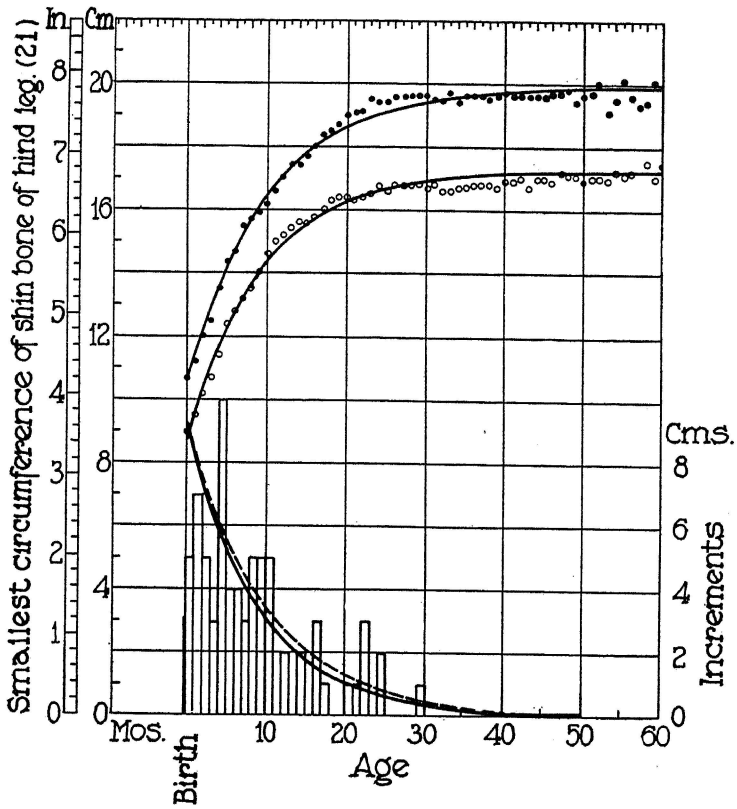


Fig. 21.—Growth in Smallest Circumference of Shinbone of Hindleg.

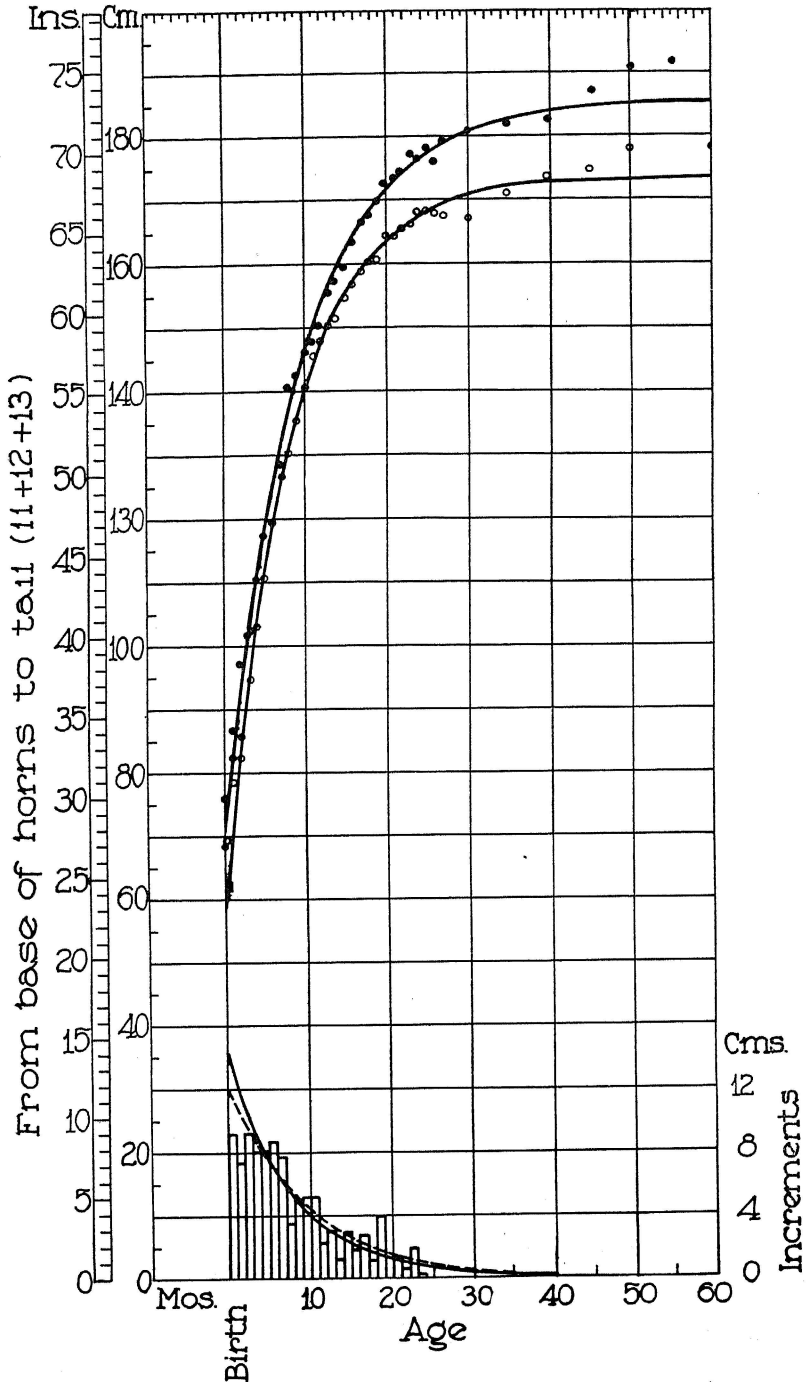


Fig. 22.—Growth in Length from to Horns Tail (11+12+13).

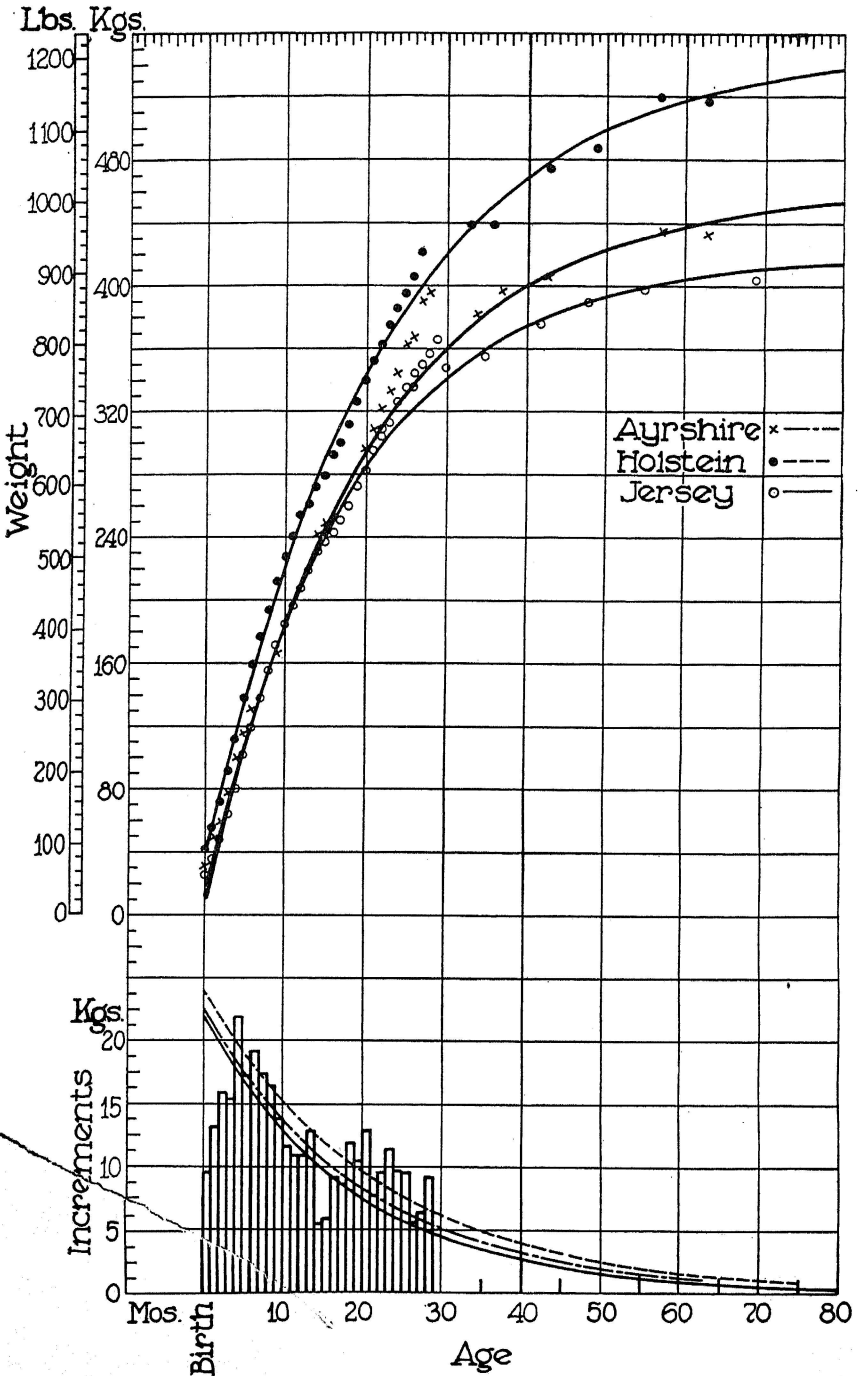


Fig. 23.—Growth in Weight.