NOVEMBER, 1948 RESEARCH BULLETIN 427

UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE

AGRICULTURAL EXPERIMENT STATION

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Relation of Endocrine Gland Weight to Body Weight in Growing and Mature Female Dairy Goats

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(Publication authorized November 15, 1948)

COLUMBIA, MISSOURI

Relation of Endocrine Gland Weight to Body Weight in Growing and Mature Female Dairy Goats

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In a number of species of animals it has been observed that the increase in the weight of certain glands and organs during growth may not be in direct proportion to the increase in body weight but to some power of body weight. Each gland and organ apparently has its own characteristic relative growth rate under normal conditions.

In as much as certain physiological processes of the animal body are influenced specifically by individual as well as by a combination of the activities of the various glands, it may be possible that the relative change in size of these glands may be roughly indicative of the hormone secretion of the particular gland. It is realized, of course, that gland size as an indicator of functional activity is limited by the fact that size does not necessarily indicate the degree of activity per unit weight of gland nor the extent of hormone storage. Further, glands such as the pancreas are of dual nature being both exocrine and endocrine glands.

In the course of investigations in our laboratory, the weight of certain endocrine glands and organs of various species have been recorded. The relation of body weight to certain endocrine gland weight in the following species has been reported. Guinea pig (Mixner, Bergman and Turner, 1943); New Zealand white rabbit (Kibler, Bergman and Turner, 1942 and Campbell and Turner, 1942); chickens (Schultze and Turner, 1945) and goats (Reineke et al., 1941; Campbell and Turner, 1942; Schultze and Turner, 1945).

Such data are believed to be of value in serving as standards of normal endocrine gland weight during growth and of mature animals of varying body weight. As already indicated, it is possible that the normal rate of hormone secretion may be more closely related to endocrine gland weight than to body weight. Similarly, hormones might be expected to be more effectively administered in proportion to the respective endocrine gland weight rather than to body weight until such time as the normal hormone secretion rate is determined.

The dairy goat has been used as an experimental animal in considerable research at this Station. Various glands and organs have been weighed in normal and experimental animals. Some of these

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TABLE 1.--ORGAN WEIGHTS OF GOATS OF INCREASING BODY WEIGHT

Body Weight		Pituitary weight act. - cal. (1)		Adrenal weight act. - cal. (2)		Ovary weight act. - cal. (3)		Pancreas weight act. - cal. (4)		Liver weight act. - cal. (5)		Kidney weight act. - cal. (6)	
lbs.	kg.	mgm.	mgm.	mgm.	mgm.	mgm.	mgm.	gms.	gms.	gms.	gms.	gms.	gms.
15.0	6.7	174.0	58.34	901	627	1115	331	17.0	9.35	301	206	47.5	40.0
15.5	6.9	119.5	60.39	769	646	891	344	8.4	9.61	207	211	38.5	40.7
16.5	7.4	147.8	65.46	656	692	1088	380	8.8	10.28	275	221	39.9	42.6
18.0	8.1	134.2	72.61	700	757	1200	432	13.0	11.19	148	236	34.0	45.2
19.5	8.7	136.9	79.07	243	813	803	478	16.2	11.97	403	248	80.0	47.3
20.0	9.0	247.2	82.22	920	840	989	500	13.6	12.33	285	254	54.3	48.3
20.5	9.3	202.8	84.33	806	859	850	516	12.4	12.59	213	258	50.3	49.1
21.0	9.5	217.3	86.50	645	877	739	532	7.9	12.85	321	261	42.1	49.8
21.5	9.8	186.8	89:74	648	906	914	556	15.8	13.24	429	267	63.3	50.8
21.5	9.8	213.6	89.74	900	906	975	647	14.0	13.24	297	267	56.3	50.8
24.0	10.9	168.0	101.6	840	1007	1257	885	16.4	14.66	259	288	50.1	54.5
30.0	13.6	169.0	131.8	1630	1259	1046	971	13.5	18.07	222	337	55.0	63.1
32.0	14.5	152.0	142.2	1652	1343			17.9	19.23	293	353	52.5	65.8
33.0	15.0	183.0	147.9	1383	1387	949	1019	17.0	19.82	234	361	52.0	67.3
34.0	15.4	178.0	152.4	802	1426	1025	1047	19.5	20.32	582	368	87.7	68.4
37.5	17.0	232.0	171.4	1748	1574	950	1216	17.9	22.34	293	395	59.2	73.1
38.0	17.3	161.0	175.0	1410	1603	963	1247	18.9	22.70	308	400	70.3	74.0
38.0	17.3	212.0	175.0	1461	1603	1648	1247	24.1	22.70	331	400	59.5	74.0
40.0	18.2	264.0	185.8	1382	1687	900	1340	25.0	23.82	294	414	68.0	76.4
40.0	18.2	180.0	185.8	1562	1687	1150	1340	21.5	23.82	325	414	71.5	76.4
42.5	19.3	222.5	199.1	1575	1786	1836	1455	25.5	25.18	297	433	63.5	79.4
43.0	19.5	214.5	201.4	2142	1807	662	1479	18.5	25.47	314	436	88.2	80.0
43.5	19.8	241.0	203.7	1383	1824	1398	1500	20.0	25.70	363	439	70.8	80.5
44.0	20.0	292.0	207.5	546	1854	1588	1531	23.0	26.06	263	443	69.6	81.3
45.0	20.4	204.0	211.3	1706	1879	2257	1567	25.1	26.42	327	448	72.8	82.2
45.0	20.4	212.0	212.3	1260	1888	1371	1578	37.5	26.55	505	450	71.2	82.4
45.0	20.4	219.0	212.3	1820	1888			30.5	26.55	370	450	67.4	82.4
47.0	21.4	300.0	223.4	1962	1972	2420	1675	20.7	27.67	409	463	87.5	84.7
47.0	21.4	236.0	223.4	1739	1972	2352	1675	24.9	27.67	418	463	61.5	84.7
47.0	21.4	208.0	223.4	1280	1972	1530	1675	29.9	27.67	288	463	74.5	84.7
47.5	21.6	222.0	227.0	1687	2000			29.8	28.05	355	468	69.0	85.5
48.5	22.0	428.0	232.3	3197	2037	2336	1754	35.8	28.51	677	474	105.8	86.7
50.0	22.7	425.0	241.0	5400	2104	2518	1837	30.0	29.38	748	484	116.0	88.5
51.0	23.2	301.0	247.2	3473	2153	1684	1892	28.2	29.99	492	492	78.5	89.7
51.0	23.2	271.0	247.2	1556	2153	2728	1892	31.2	29.99	440	492	64.0	89.7
55.0	25.0	399.0	269.8	3172	2317	2127	2104	26.0	32.21	419	519	98.0	94.2
55.0	25.0	294.0	269.8	2929	2317	1509	2104			681	519	122.0	94.2
55.0	25.0			2234	2317	1504	2104	25.3	32.21	432	519	75.3	94.2
56.0	25.5	338.0	274.8	4599	2355	2771	2153	48.0	32.73	681	525	105.4	95.3
56.0	25.5			2863	2355	2154	2153	36.2	32.73	669	525	132.0	95.3
57.0	25.9	220.0	281.2	2210	2404	2703	2213	28.0	33.34	363	532	70.0	96.4
58.5	26.6	304.0	290.4	1767	2466	1906	2296	21.5	34.20	408	542	130.1	98.2

59.0	26.8	323.0	292.4	4200	2483	2779	2323	28.8	34.43	415	545	114.0	98.6
62.0	28.2	502.0	309.7	3195	2606	4700	2483	51.9	35.97	736	564	142.5	101.9
63.0	28.6	500.0	316.2	3190	2655	4690	2547	49.9	36.64	430	570	140.2	103.0
64.0	29.1	321.0	322.1	3321	2698	2669	2612	49.0	37.24	552	578	118.0	104.2
64.0	29.1	332.0	322.1	2239	2698	2640	2612	35.5	37.24	931	578	152.0	104.2
65.0	29.5	334.0	327.3	3328	2735	3124	2661	50.0	37.67	772	583	120.0	105.2
65.0	29.5			3422	2735	2676	2661	70.0	37.67	931	583	141.0	105.2
66.0	30.0	357.0	334.2	2447	2786	3038	2729	43.0	38.28	730	562	100.6	106.4
67.0	30.5			2952	2818	3248	2780	52.0	38.82	863	596	105.0	107.2
71.0	32.3	497.0	363.1	3100	2992	4500	3013	63.8	40.93	643	621	97.0	111.4
72.0	32.7	540.0	369.8	4254	3034	2165	3083	36.4	41.59	953	628	110.0	112.5
72.0	32.7			3642	3034	3534	3083	49.0	41.59	726	628	129.0	112.5
72.0	32.7			2758	3034	2560	3083	57.0	41.59	728	628	181.0	112.5
73.0	33.2	558.0	375.0	3661	3076	3576	3133	58.5	42.07	616	632	149.4	113.5
75.0	34.1	468.0	388.2	3840	3170	6100	3273	57.0	43.25	1010	647	157.3	115.6
75.0	34.1	925.0	388.2			2860	3273	51.7	43.25	906	647	153.0	115.6
75.5	34.3	411.0	390.8	1868	3184	2361	3296	37.7	43.45	700	649	81.8	116.1
76.0	34.5	283.0	393.6	1980	3206	3048	3327	32.5	43.75	607	652	86.8	116.7
76.0	34.5	320.0	393.6	3801	3206	2641	3327	52.5	43.75	432	652	120.0	116.7
77.5	35.2	453.0	403.6	2479	3266	3500	3420	45.3	44.57	500	661	85.6	118.0
79.0	35.9	256.0	413.0	3162	3334	3800	3516	55.3	45.39	472	670	90.8	119.7
79.0	35.9	280.0	413.0	2902	3334	3300	3516	46.7	45.39	676	670	94.3	119.7
80.0	36.4			2916	3373	2273	3573			1089	676	181.0	120.5
81.0	36.8	516.0	424.6	4681	3420	9238	3648	56.4	46.45	681	682	143.1	121.6
82.0	37.3	624.0	430.5	2738	3451	2557	3698	50.0	46.99	696	687	134.9	122.5
83.0	37.7	378.0	437.5	2233	3499	3600	3776	49.9	47.53	709	693	106.6	123.6
84.0	38.2	399.0	442.6	2074	3540	2292	3826	42.1	48.08	652	700	112.7	124.5
86.0	39.1	485.0	455.0	3635	3622	4500	3963	52.0	49.09	975	711	146.1	126.5
87.0	39.5	268.0	462.4	2699	3673	1597	4027	38.0	49.77	545	718	100.7	127.4
87.0	39.5			2300	3673	2850	4027	33.0	49.77	660	718	98.4	127.4
90.0	40.9	726.0	480.8	4000	3802			77.8	51.40	849	735	169.7	130.3
93.5	42.5	823.0	502.3	4640	3945	5279	4457	61.1	53.21	661	755	124.9	133.7
95.0	43.2	532.0	511.7	2834	3990	4100	4560	53.2	54.08	746	764	119.5	134.9
97.0	44.1			3510	4093	4500	4699	49.3	55.08	498	774	103.8	136.8
97.5	44.3	775.0	528.4	4100	4121	6100	4742	57.3	55.46	742	778	149.8	137.4
100.0	45.5	538.0	544.5	5600	4217	6100	4909	47.0	56.75	751	793	125.2	139.6
103.0	46.8	1040.0	563.6	4800	4355	5500	5129	87.0	58.34	1017	809	192.6	142.6
105.0	47.7	431.0	576.8	4322	4436	4438	5272	64.0	59.43	928	820	147.7	144.5
106.0	48.1	610.0	582.1	4300	4477	5800	5333	54.5	49.98	902	824	139.3	145.2
107.0	48.6	687.0	588.8	3100	4519	5400	5408	59.0	60.53	882	832	127.1	146.2
112.0	50.9	1007.0	620.9	4100	4721	5100	5768	68.7	63.10	745	857	128.7	150.7
118.0	53.6	926.0	660.7	4000	4989	5600	6223	60.0	66.37	1080	891	193.5	156.0
120.0	54.5	883.0	674.5	4000	5070	4300	6368	58.0	67.45	752	902	126.4	157.8
120.5	54.8	1062.0	677.6	5250	5093	8075	6397	52.4	67.76	810	904	156.6	158.1
129.0	58.6	889.0	734.5	4279	5458	7237	7063	88.0	72.28	1037	948	173.5	165.6

(1) Calculated from equation $Y = 6.12X^{1.18}$ X = Kg.
(2) Calculated from equation $Y = 91.62X^{1.00}$ X = Kg.
(3) Calculated from equation $Y = 21.73X^{1.42}$ X = Kg.

(4) Calculated from equation $Y = 1.52X^{0.95}$ X = Kg.
(5) Calculated from equation $Y = 53.16X^{0.71}$ X = Kg.
(6) Calculated from equation $Y = 11.26X^{0.66}$ X = Kg.

data have been published by Reineke, Bergman and Turner, 1941; Campbell and Turner, 1942; and Schultze and Turner, 1945; but much has remained unpublished. It seemed desirable to bring all of our observations together as standards of endocrine gland and organ weight in these animals which are so admirably suited for research work in the endocrinology of milk secretion.

The gland and organ weights were obtained from goats of mixed breeding of dairy type. Except when upon special experiments, the goats were fed a ration of mixed grain and alfalfa hay. Data on the weight of the pituitary, adrenal, ovary, pancreas, liver and kidney of goats of increasing body weight are included in Table 1. The relation between body weight and gland weight was determined by fitting the exponential equation $Y = AX^b$ to the data since when plotted on logarithmic paper a straight line relationship was indicated (Brody & Kibler, 1941). From the equation thus obtained, the calculated gland weight for increasing body weight was obtained (Table 1). The exponent b in this equation is of special significance since it indicates the relation of body weight to gland weight. An exponent b of 1.0 indicates that body growth and gland growth occur at the same rate. If the exponent is less than 1.0, for example, 0.75 it indicates that the gland growth rate at any given time is only ¾ as rapid as the growth in body weight. If the exponent is more than 1.0, for example 1.5, it would indicate that the gland growth rate is 1½ times as rapid as the growth in body weight. (For a further review and discussion see Brody, 1945.)

PITUITARY WEIGHT AND BODY WEIGHT

The pituitary is one of the key glands of the endocrine system. It secretes the hormone which directly controls general body growth as well as those stimulating the growth and secretion of the mammary gland, the thyroid, adrenal, ovary and testes and possibly other gland

TABLE 2.--VALUE OF THE EXPONENT b FOR PITUITARY AND BODY WEIGHT IN VARIOUS SPECIES

Species	Sex	b Exponent	Authority
Rat, albino	male	0.74	Brody & Kibler (1941)
Rat, albino	female	0.93	Brody & Kibler (1941)
Rat (Wistar strain)	male	0.68	Mixner & Turner (1942)
Guinea pig	male	0.71	Mixner, Bergman & Turner (1943)
Guinea pig	female	0.73	Mixner, Bergman & Turner (1943)
Fetal & new-born cats		0.45	Brody & Kibler (1941)
New Zealand white rabbits	male	0.58	Kibler, Bergman & Turner (1942)
New Zealand white rabbits	female	0.68	Kibler, Bergman & Turner (1942)
Mature animals of various species		0.762	Brody & Kibler (1941)
Growing goats	female	1.18	Present data

and organ changes. The relation of the pituitary weight to body weight and to other endocrine gland weight is, therefore, of especial significance.

Of the species studied, the value of the b exponent varies from a low of 0.45 in fetal and new born cats to a high of 0.93 in female albino rates (Table 2). From a study of limited data on mature animals of various species, Brody and Kibler (1941) obtained a value of 0.762. From this relation, the pituitary weight of mature animals of different species for given body weight has been computed.

The equation for the relation of body weight to pituitary weight in the goat was as follows: Y (pituitary weight, mg.) $= 6.12X^{1.18}$ where X equals body weight in kilograms.

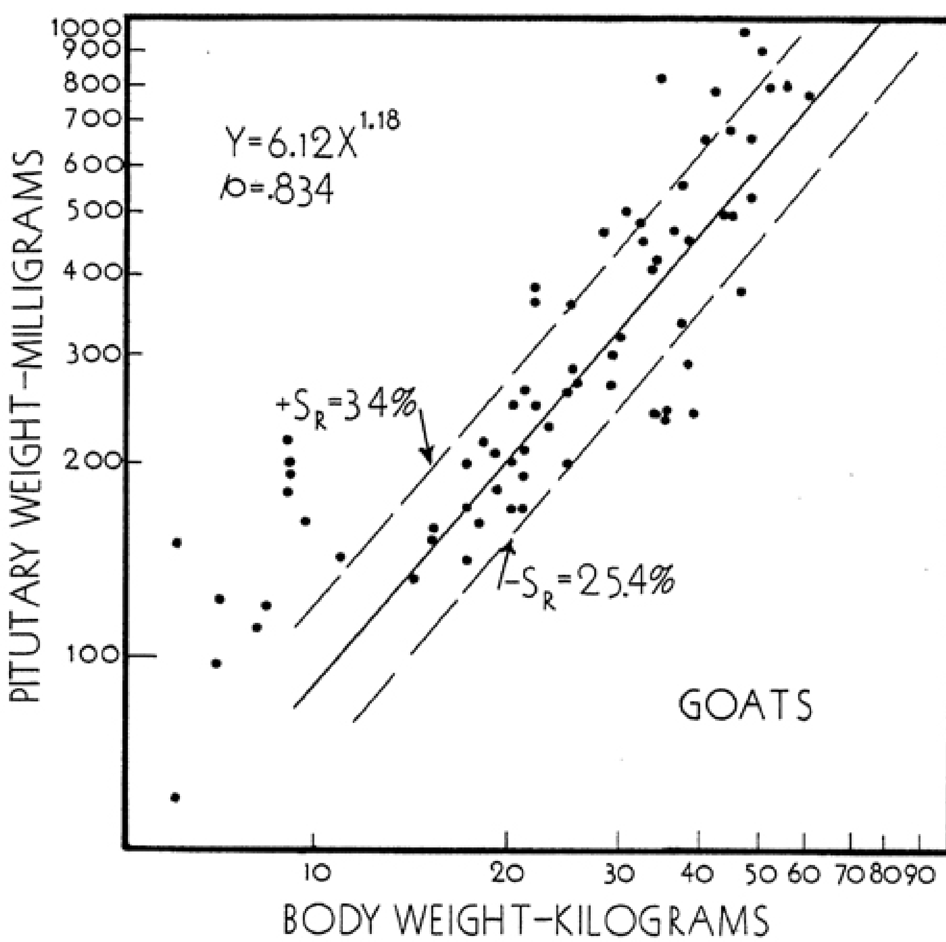

Fig. 1.—The relation of pituitary weight (in mg.) to body weight (kg.) is plotted on a logarithmic grid. The circles present the data for growing and mature female goats. The heavy continuous line represents the equation $Y = AX^b$ fitted by the method of least squares. The broken lines on either side represent the standard error of estimate S^r, including between them 2/3 of the data points. The letter rho (P) represents the index of correlation, corresponding to the coefficient of correlation for linear equations.

The present data on the growing female goat indicates growth of the pituitary at a rate more rapid than body weight since the b exponent is 1.18. Whether this value for the rate of pituitary growth in the goat is unusual for the larger domestic animals can not be determined until further data becomes available. It appears that this value is much higher than that of any of the experimental animals so far investigated. Due to the great difference in the b exponent in the goat and that observed by Brody and Kibler for mature animals, the prediction value of their table is not close for goats.

In Table 1 are presented the calculated pituitary weights of goats of increasing body weight as determined by the above equation. The index of correlation of 0.834 may be considered in conjunction with the standard error of estimate of + 34% and — 25.4% as indicative of the accuracy of these predicted values (Fig. 1).

ADRENAL WEIGHT

The adrenal gland is made up of two distinct parts. The central part, called the medulla, secretes the hormone called epinephrin or adrenaline. This part is not regulated by the adrenotrophic hormone of the pituitary. The outer layer is called the cortex. It is composed of several zones. The cortex of the adrenal has been thought to be under the control of a pituitary hormone. Recent work, however, indicates that the secretory activity of the outer zone called the glomerulosa is independent of the pituitary.

The adrenal cortex secretes many steroid hormones. Those secreted under the influence of the pituitary are believed to influence protein and carbohydrate metabolism through their gluconeogenic action on amino acids. In the guinea pig and rabbit, the weight of the adrenal gland was shown to increase more rapidly than body weight following sexual maturity. The theory was advanced that the increased secretion of the adrenal cortical hormones (suggested by the increased adrenal weight following sexual maturity) might be one mechanism for the gradual inhibition of the growth rate due to the increased diversion of amino acids for energy purposes instead of growth as a result of gluconeogenesis.

In the present data, no clear break in the line is apparent after sexual maturity was reached (Fig. 2). However, in the goats weighing 20 kg. and more there may be observed a tendency for considerable scatter in the weights of the adrenals, especially above the line.

The equation for the relation of body weight to adrenal weight was as follows: Y (adrenal weight, mg.) $= 91.62X^{1.00}$ where X equals body weight in kilograms. It will be noted that the b exponent is 1.00

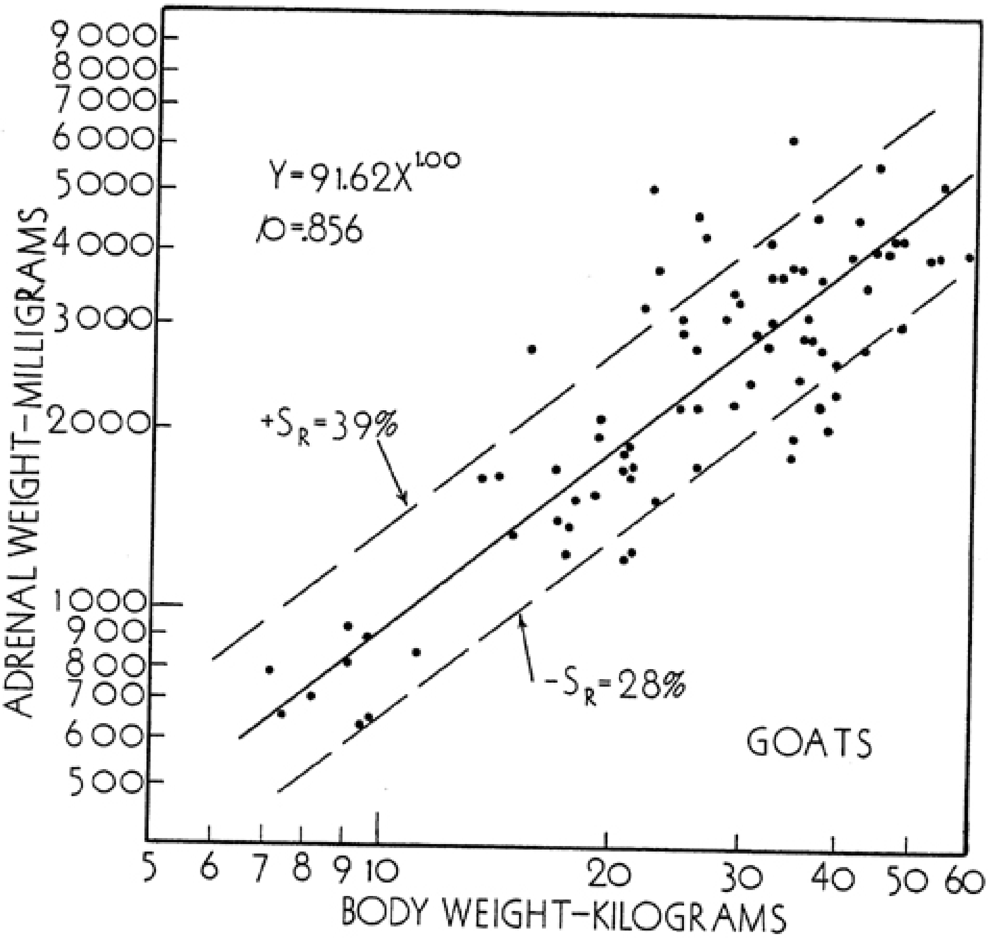

Fig. 2.—The relation of adrenal weight (in mg.) to body weight (kg.) is plotted on a logarithmic grid. The circles present the data for growing and mature female goats. The meaning of the symbols is explained in Fig. 1.

TABLE 3.--VALUE OF THE EXPONENT b FOR ADRENAL AND BODY WEIGHT IN VARIOUS SPECIES

Species	Sex	b Exponent	Authority
Growing rats	male	0.77	Brody & Kibler (1941)
Growing rats	female	0.77	Brody & Kibler (1941)
Guinea pig (under 500 gm.)	male & female	0.95	Mixner, Bergman & Turner (1943)
Guinea pig (over 500 gm.)	male & female	1.79	Mixner, Bergman & Turner (1943)
Fetal & new born cats		0.64	Brody & Kibler (1941)
Immature dogs		0.78	Brody & Kibler (1941)
New Zealand white rabbits (under 2500 gm. weight)	male & female	0.94	Kibler, Bergman & Turner (1943)
New Zealand white rabbits (over 2500 gm. weight)	male & female	1.78	Kibler, Bergman & Turner (1943)
Growing goats	female	1.00	Present data

indicating that in the growing female goat the adrenal weight keeps pace with increasing body weight.

In comparison with other species studied (Table 3) this value is somewhat greater than others before sexual maturity was reached and considerably less later.

In Table 1 are presented the calculated adrenal weights of goats of increasing body weight as determined by the above equation. The accuracy of these predicted values may be judged by the statistical constants presented in Figure 2.

OVARIAN WEIGHT

Variability in ovarian weight with increasing body weight is probably due first to the variation in the time of sexual maturity; second, to the period of ovarian inactivity during the summer; and third to the variation in the weight of the ovaries during various stages of follicle development, ovulation and luteal development.

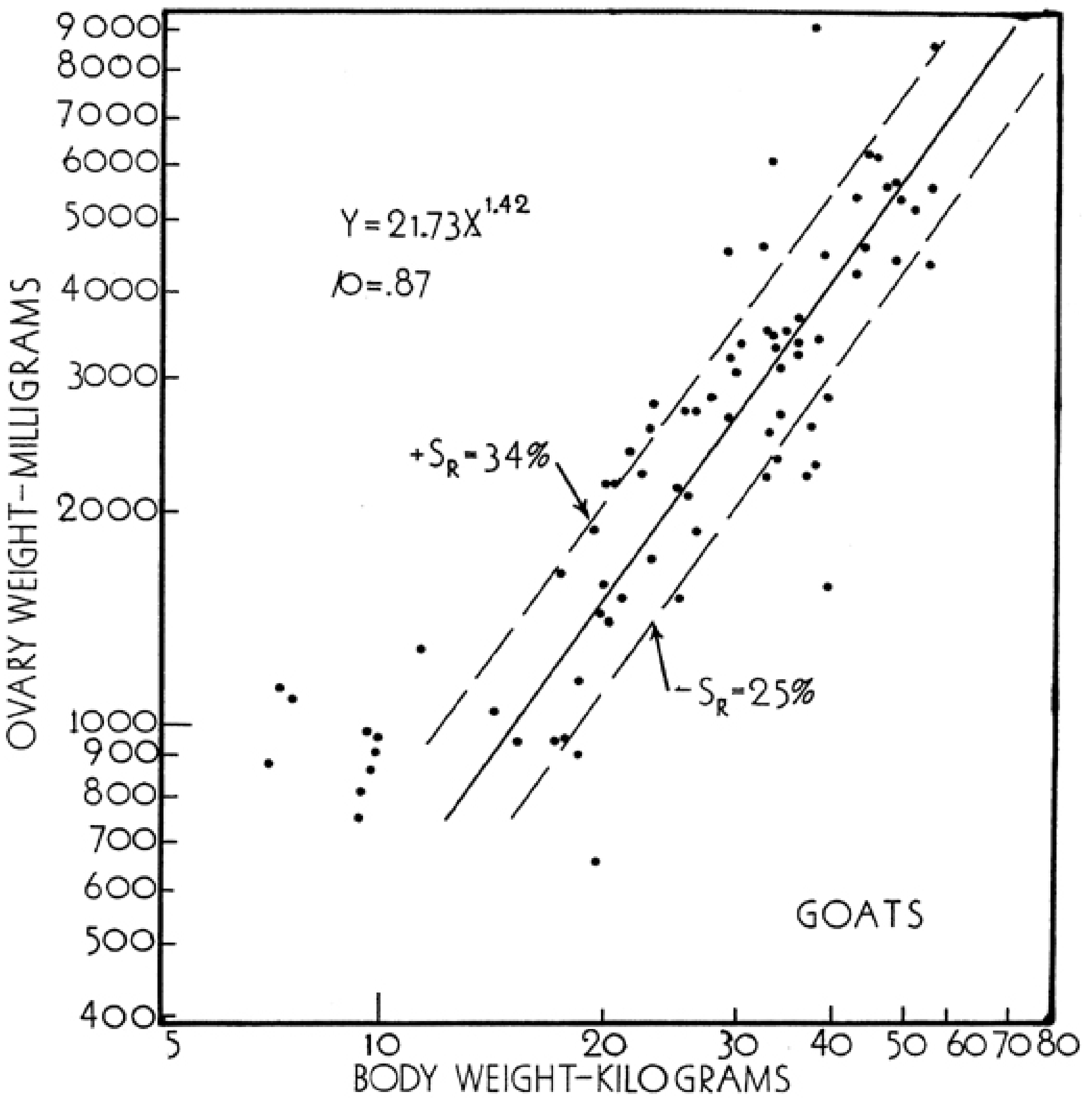

Fig. 3.—The relation of ovarian weight (in·mg.) to body weight (kg.) is plotted on a logarithmic grid. The circles present the data for growing and mature female goats. The meaning of the symbols is explained in Fig. 1.

From the time the kids weigh about 15 kg., the equation for the relation of body weight to ovarian weight was as follows: Y (ovarian weight, mg.) = $21.73X^{1.42}$ where X equals body weight in kilograms (Fig. 3). The exponent b for the ovary of 1.42 indicates that following sexual maturity in the goat, the ovary increases in weight faster than the increase in body weight. In table 4 it will be seen that in this respect the goat is intermediate between the guinea pig and the rabbit.

The calculated ovarian weight of goats of increasing body weight is presented in Table 1.

TABLE 4.--VALUE OF THE EXPONENT b FOR OVARY AND BODY WEIGHT IN VARIOUS SPECIES

Species	b Exponent	Authority
Guinea pig	0.76	Mixner, Bergman & Turner (1943)
Rabbit (above 800 gm. wt.)	2.04	Kibler, Bergman & Turner (1943)
Goat (15-50 kg.)	1.42	Present data

THYROID WEIGHT

The thyroid is a typical endocrine gland with provision for the storage of hormone in the central lumina of the follicles . The weight of the thyroid glands thus includes the accumulated colloid (storage thyroglobulin) as well as the glandular cells. In periods of most active secretion (in cold weather) the storage hormone may be discharged into the blood and the glandular cells elongate under the stimulus of increased secretion of the pituitary thyrotrophic hormone. During periods of thyroid inactivity (in warm weather) the colloid is stored in increasing amounts while the glandular cells shorten and appear less active.

These two opposing processes relating to hormone storage and cell activity in mammals tend to offset each other in so far as thyroid weight in mature animals is concerned thus masking, in part, the possible relation of endocrine gland weight and secretion activity.

The value of the exponent b indicating the relation of the rate of thyroid gland growth to increasing body weight for various experimental animals is remarkably constant varying from 0.73 in the male quinea pig to 0.88 in the New Zealand white rabbit (Table 5). Comparable data on growing female goats is represented by the equation Y (thyroid weight, mg.) = $174.6X^{0.70}$ where X equals body weight in kilograms. The b exponent 0.70 for the goat is thus at the lower limits of the species studied (Fig. 4).

The hormone of the thyroid gland, thyroxine, is concerned in energy metabolism and heat production of the body. It is interesting

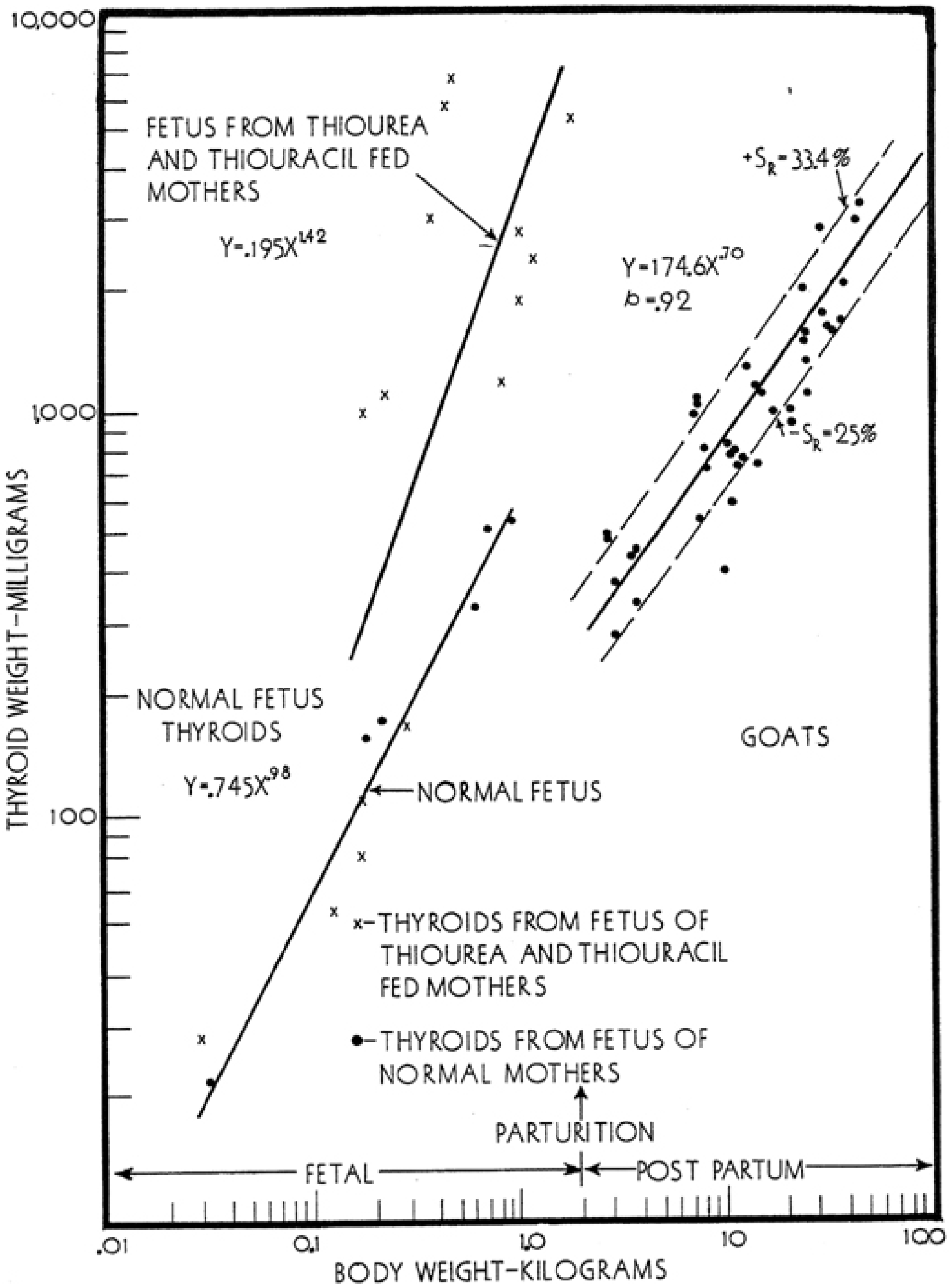

Fig. 4.—The relation of thyroid weight (in mg.) to body weight (kg.) is plotted on a logarithmic grid. Data on the thyroid weight of normal fetuses and those whose mothers were fed thiouracil is presented on the left side of the grid. On the right side is presented the data on the thyroid weight of the growing and mature female goats.

TABLE 5.--VALUE OF THE EXPONENT b FOR THYROID AND BODY WEIGHT IN VARIOUS SPECIES

Species	Sex	b Exponent	Authority
Rats		0.81	Brody & Kibler (1941)
Guinea pig	male	0.73	Mixner, Bergman & Turner (1943)
Guinea pig	female	0.83	Mixner, Bergman & Turner (1943)
Fetal and new born cats		0.77	Brody & Kibler (1941)
New Zealand white rabbits	male & female	0.88	Kibler, Bergman & Turner (1943)
Man	male & female	1.08	Brody (1945)
Premature & new born horses		0.95	Brody & Kibler (1941)
Horses over 1 year		1.17	Brody & Kibler (1941)
Mature mammals		0.924	Brody & Kibler (1941)
Goat fetuses	male & female	0.98	Schultze & Turner (1945)
Goat, fetuses (mothers fed thiouracil)	male & female	1.42	Schultze & Turner (1945)
Goats, dairy	female	0.70	Schultze & Turner (1945)

to note that the heat production of female Toggenburg goats increases with the 0.71 power of body weight (Brody 1938). Thus the average heat production and thyroid gland weight of the goat increases at approximately the same rate with increasing body weight.

Equations for the relation of thyroid weight to body weight in normal fetal goats and fetal goats whose mothers were fed thiouracil are as follows:

$$Y \text{ (thyroid weights, mg.)} = .745X^{0.98} \text{ (normal)}$$
$$Y \text{ (" " ")} = .195X^{1.42} \text{ (thiouracil)}$$

where X equals body weight in kilograms. It thus appears that the fetal thyroid growths at essentially the same rate as the body but under the stimulus of thiouracil the fetal thyroid is stimulated to more rapid growth. In fact many of these fetal thyroids were actually as large as or larger than the thyroids of their dams.

The calculated thyroid weights of goats of increasing body weight according to the equation presented above are presented in Table 2 (page 17) in Missouri Agr. Exper. Station Research Bulletin 392 (Schultze & Turner, 1945) to which the reader is referred.

PARATHYROID WEIGHT

The parathyroid is a solid endocrine gland composed of masses or cords of epithelial cells arranged without definite alveolar structure and surrounded by a connective tissue capsule. It is thus unlike the thyroid gland with definite follicles for the storage of hormone. In the parathyroid gland storage of hormone must be intracellular. This hormone is concerned with calcium and phosphorus metabolism.

A limited amount of data (20 animals) has been collected on the relation of the parathyroid gland weight to body weight in growing and mature goats by Campbell and Turner (1942). The equation for

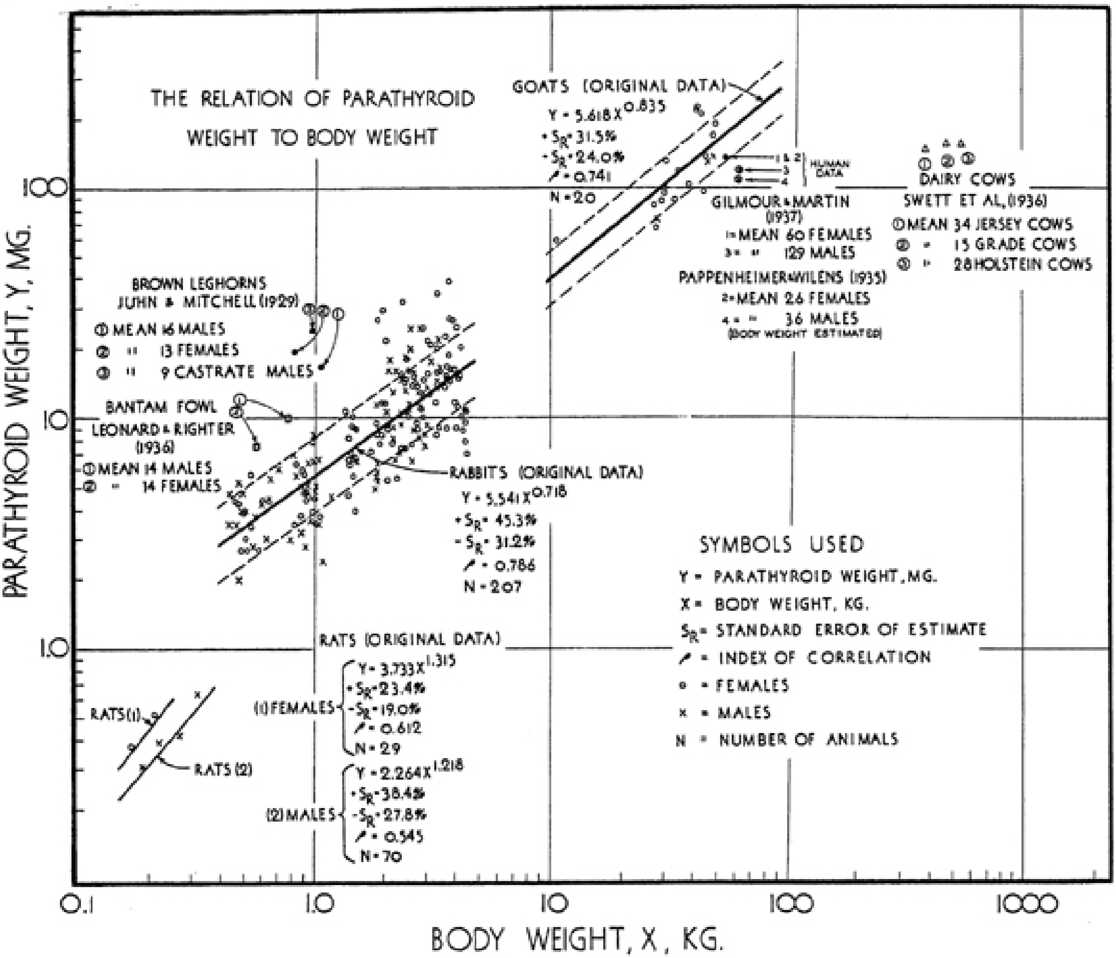

Fig. 5.—The relation of parathyroid weight to body weight is plotted on a logarithmic grid. In addition to the data on growing goats, certain data on other species obtained by Campbell and Turner (1942) and data from the literature is included.

TABLE 6.--VALUE OF THE EXPONENT b FOR PARATHYROID AND BODY WEIGHT IN VARIOUS SPECIES

Species	Sex	No.	b Exponent	Authority
Rat	female	29	1.315	Campbell & Turner (1942)
Rat	male	70	1.218	Campbell & Turner (1942)
Rabbit	male & female	207	0.718	Campbell & Turner (1942)
Goat		20	0.835	Campbell & Turner (1942)

the relation of body weight to parathyroid gland weight was as follows:

Y (parathyroid, mg.) = $5.62X^{0.835}$ where X equals body weight in kilograms. The standard error of estimate (S_R) was + 31.5 and — 24.0 per cent and the index of correlation (P) was 0.741 (Figure 5).

The value of the b exponent for the goat agrees quite well with the comparable value for male and female rabbits but is considerably below that of the rat (Table 6).

PANCREAS WEIGHT

The pancreas is a dual gland secreting pancreatic juice in its capacity as an exocrine gland and secreting insulin in the islets of Langerhans as an endocrine gland. The exocrine gland far outweighs the islets of Langerhans so the endocrine activity is not necessarily closely related to increasing pancreas weight.

In the rat, Overholser (1925) observed that the number of islets in the pancreas increase during the first 20 days of life, then reaches and maintains a maximum value for 30 days. From this point there begins a slight decrease with advancing age reaching a level between 90 and 150 days of age which is maintained until old age.

The relation of pancreas weight to body weight in growing or mature animals has not been studied previously.

The equation for the relation of body weight to pancreas weight of female goats was as follows:

Y (pancreas, gm.) $= 1.52X^{0.95}$ where X equals body weight in kilograms. The exponent b of 0.95 indicates that pancreas weight increases at practically the same rate as body weight (Figure 6).

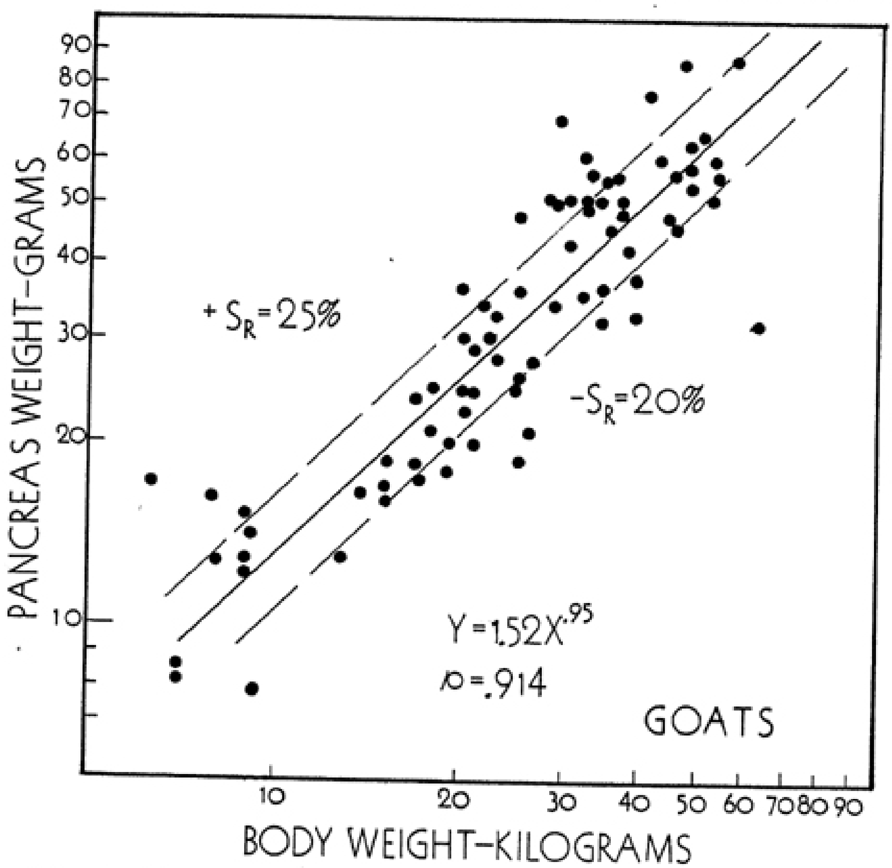

Fig. 6.—The relation of pancreas weight (in gm.) to body weight (kg.) is plotted on a logarithmic grid. The circles present the data for growing and mature female goats. The meaning of the symbols is explained in Fig. 1.

The pancreas weight of goats calculated from the above equation is presented in Table 1.

LIVER WEIGHT

While the liver may not be an endocrine gland, it is an important exocrine gland and probably the most important organ of the body concerned with the metabolism and detoxification of hormones. It is also an important storage depot for glycogen, fat, protein and vitamins.

In its capacity as a storage depot, the liver weight might be expected to vary considerably independent of body weight. Studies by Brody & Kibler (1941) of a number of species of mammals indicate that the exponent b indicating the relation of the rate of liver growth to increasing body weight varies from 0.61 to 0.71 and of mature animals is of the order of 0.87 (Table 7).

Comparable data on growing female goats is represented by the equation Y (liver weight) = $53.16X^{0.71}$ where X equals body weight in kilograms (Figure 7). It will be noted that the b exponent 0.71 for the goat liver is similar to that of the other species studied.

The weight of the liver of goats of increasing body weight calculated from the above equation is presented in Table 1.

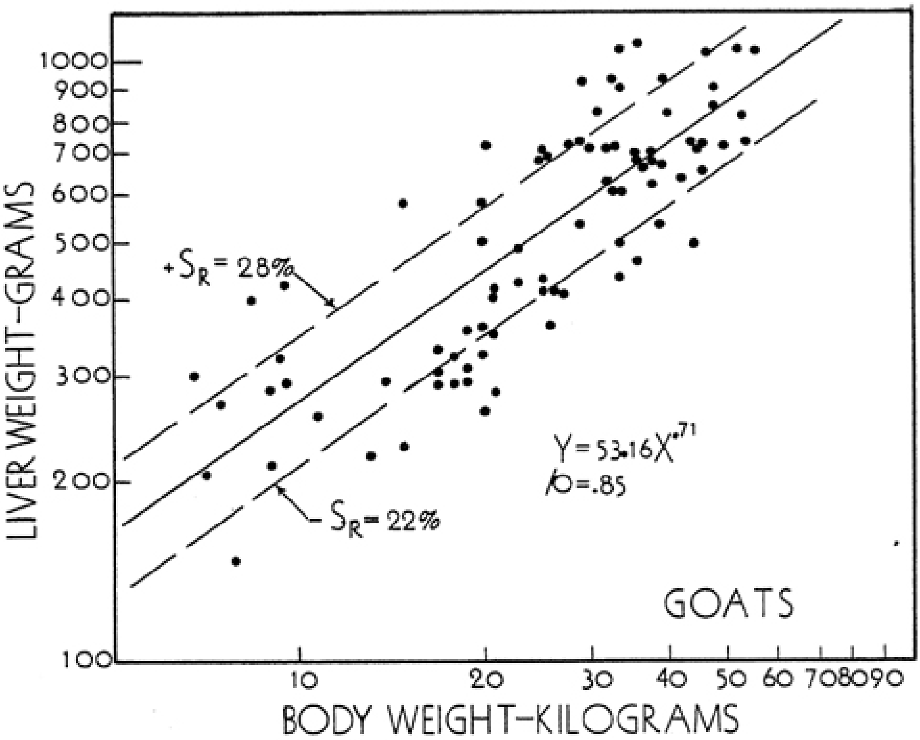

Fig. 7.—The relation of liver weight (in gm.) to body weight (kg.) is plotted on a logarithmic grid. The circles present the data for growing and mature female goats. The meaning of the symbols is explained in Fig. 1.

TABLE 7.--VALUE OF THE EXPONENT b FOR LIVER AND BODY WEIGHT IN VARIOUS SPECIES

Species	Sex	b Exponent	Authority
Rat (up to 60 gm.)		1.14	Brody & Kibler (1941)
Rat (60 gm. and above)		0.68	Brody & Kibler (1941)
Dogs		0.71	Brody & Kibler (1941)
Dairy cattle		0.66	Brody & Kibler (1941)
Steers		0.70	Brody & Kibler (1941)
Horses		0.61	Brody & Kibler (1941)
Man (fetal)		0.92	Brody & Kibler (1941)
Mature mammals		0.867	Brody & Kibler (1941)
Growing goats	female	0.71	Present data

KIDNEY WEIGHT

The kidney is the chief organ of excretion of water and the by-products of metabolism. Through it large quantities of water are filtered and resorbed. It might be thought that the kidney weight would be related to water and feed consumption.

In the study by Brody and Kibler (1941) the exponent b of the

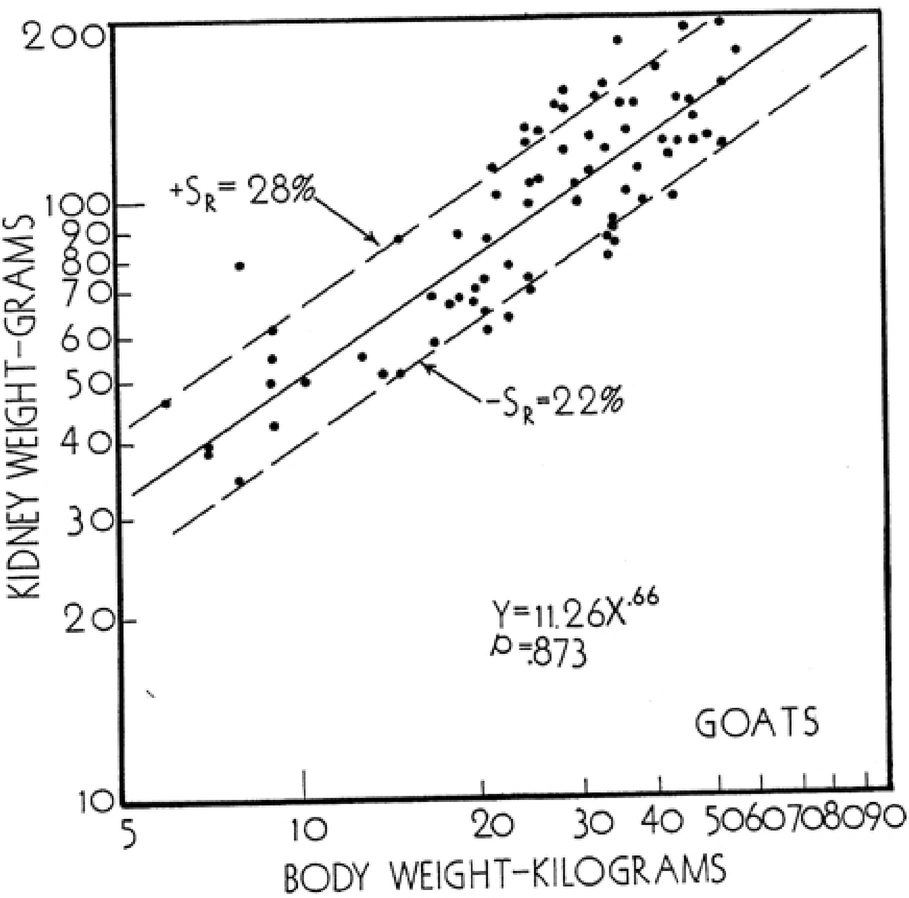

Fig. 8.—The relation of kidney weight (in gm.) to body weight (kg.) is plotted on a logarithmic grid. The circles present the data for growing and mature female goats. The meaning of the symbols is explained in Fig. 1.

TABLE 8.--VALUE OF THE EXPONENT b FOR KIDNEY AND BODY WEIGHT IN VARIOUS SPECIES

Species	Sex	b Exponent	Authority
Rat		0.82	Brody & Kibler (1941)
Cat	male	0.65	Brody & Kibler (1941)
Cat	female	0.61	Brody & Kibler (1941)
Dog		0.70	Brody & Kibler (1941)
Man (fetal)		1.10	Brody & Kibler (1941)
Steers		0.51	Brody & Kibler (1941)
Horses		0.66	Brody & Kibler (1941)
Mature mammals		0.846	Brody & Kibler (1941)
Growing goats	female	0.66	Present data

equations relating kidney and body weight in various species is reported (Table 8.). It will be seen that this value varies from 0.51 for steers to 0.82 for the rat. Mature animals of various species were observed to have a "b" of 0.846.

Comparable data on growing female goats is represented by the equation Y (kidney weight, gm.) = $11.26X^{0.66}$ where X equals body weight in kilograms. The b exponent of 0.66 is comparable to that of the other species studied (Figure 8).

In Table 1 is presented the calculated kidney weight of goats of increasing body weight as determined by the above equation.

ESTIMATING HORMONE DOSAGE IN RELATION TO GLAND WEIGHT*

It has been suggested that these data might be of value in estimating the hormone dosage which would be required in goats of varying body weight. It should be emphasized at this time that neither the relation between the normal hormone secretion rate of these endocrine glands in relation to increasing body weight nor the relation of hormone dosage to increasing body weight is known. However, with the present data relating increasing endocrine gland weight with increasing body weight it is possible to determine if these data may serve as guides in the estimation of hormone dosage.

When the exponent b is less than 1.0, the ratio of gland weight to body weight decreases as body weight increases. On the other hand, when the exponent b is more than 1.0, the ratio of gland weight to body weight increases as body weight increases. The relative change in gland weight for increasing body weight may be computed from the equation:

$$\frac{G_2}{G_1} = \left(\frac{X_2}{X_1}\right)^b$$

*The authors are indebted to H. H. Kibler, Dept. Dairy Husbandry for aid in calculating the equations relating gland weight to body weight and for the above example and computation of Table 9.

where $\frac{X_2}{X_1}$ represents the ratio of body weights and $\frac{G_2}{G_1}$ indicates the unknown ratio of gland weight. The b is the exponent in the growth equation.

For example, the equation relating pituitary weight, Y, with body weight, X in goats is

$$Y = 6.12X^{1.18}$$

The pituitary weight for a 30 kg. goat relative to that of a 15 kg. goat could be computed as follows:

$$\frac{G_2}{G_1} = \left(\frac{30}{15}\right)^{1.18} = 2^{1.18} = 2.27$$

The pituitary weight of the 30 kg. goat would be 2.27 times the pituitary weight of the 15 kg. goat. For convenience, tables may be computed by this method (Kibler, Bergman and Turner, 1942) to give the percentage increase in gland weight for various percentage increases in body weight (Table 9).

TABLE 9.--RELATIVE INCREASE IN GLAND WEIGHT WITH PERCENTAGE INCREASE IN BODY WEIGHT

Live Weight Change	Pituitary Weight Change b=1.18	Adrenal Weight Change b=1.00	Ovary Weight Change b=1.42	Thyroid Weight Change b=0.70	Parathyroid Weight Change b=0.84	Pancreas Weight Change b=0.95
%	%	%	%	%	%	%
1	1.2	1	1.4	0.7	0.8	0.9
5	5.9	5	7.2	3.5	4.2	4.7
25	30	25	37	17	21	24
50	61	50	78	33	41	47
75	94	75	121	48	60	70
100	127	100	168	62	79	93

If the thyroid hormone requirements, for example, were related to the relative increase in gland weight with increasing body weight, the following relation should exist: A goat that is 50 per cent heavier than another would require only 33% more hormone to produce a comparable increase in energy metabolism. As indicated above it is not known that this relation exists but the present data will make possible such comparisons in order to test the validity of this theory.

DISCUSSION

The data presented in this bulletin are believed to be of value as an indication of the normal variation in the gland and organ size of 87 normal female goats of increasing body weight. These data may serve as normal or control values in comparison with the gland and organ weights of goats following experimental conditions.

The problem of the relation of gland size and weight to functional activity or hormone secretion rate is most interesting. Does the presence of a large endocrine gland in an animal indicate greater capacity for hormone secretion? Is the average rate of increase in gland size related to the increase in hormone secretion? It is quite probable that each endocrine gland will present special problems depending upon the type of gland presented. Thus in the case of the pituitary and the parathyroid where there is no provision for hormone storage outside of the gland, as is true of the thyroid follicle, one might expect the closest relation between gland weight and secretory activity.

In dual endocrine glands such as the adrenal, the stimuli of secretory activity of the medulla and cortex and even part of the cortex comes from distinctly varied sources. The problem of pancreas weight is further confused by the intimate intermingling of the exocrine and endocrine glands.

It is interesting to note that the relative rate of growth of such organs as the liver and kidney with functions responsible for the entire bodily welfare have b exponents in the neighborhood of 0.7. This is close to the value of 0.73 relating body weight and heat production in various mature mammals (Brody & Kibler, 1941) or for heat production in the goat (b exponent = 0.71). The explanation which has been advanced for these relative organ growth rates being less than 1.0 is that the supporting tissue of the body such as the bone, cartilage and connective tissue contribute relatively little to the metabolic processes of the body represented by the function of the liver or kidney. Therefore, the functional organs need grow only as fast as the functional tissue, i.e., the total body weight less the supporting tissue.

Of the endocrine glands of the goat, the thyroid glands' relative growth rate most closely compares to the b exponent of the above organs. The reasoning indicated above would apply to the thyroid gland since the hormone secreted acts upon the functional tissue and not the supporting tissue. The b exponent for the equation relating increasing body weight and heat production being of the same order would also fit into the same pattern since the heat would be produced largely by functional not supporting tissue.

The intermediate position for the relative growth rate of the parathyroid glands (b exponent, 0.84) may indicate the importance of the parathyroid hormone in calcium and phosphorus metabolism not only during growth but during lactation as well. It has been shown in experimental animals (Campbell & Turner, 1942) that intense lactation causes parathyroid hypertrophy. Two other factors, namely the vitamin D content and the calcium content of the ration would influence the parathyroid gland size. Insufficiency of this vitamin and or/of calcium would cause parathyroid gland enlargement. That the relative growth rate of the parathyroid glands was increased by lactation in these goats is probable. To what extent the vitamin D or calcium content of the ration influenced the parathyroid is difficult to evaluate. Good alfalfa hay should supply the necessary calcium and possibly the vitamin D.

The relative growth rates of the pancreas and adrenal approaching 1.0 indicate that these dual glands may secrete hormones or secretions required in amounts in excess of the functional tissue. It is well known that the insulin concentration in the pancreas of young animals is greater than that in older animals. If the rate of insulin secretion per unit of islet tissue declined with age the size of the pancreas may enlarge relatively to compensate.

Since the adrenal is the source of large numbers of steroid hormones of diverse function in addition to the secretion of adrenaline in the medulla, a possible explanation for the relative growth rate of 1.0 in relation to body weight is hopeless other than its indication of requirements of these hormones in relation to body weight rather than functional tissue.

The high value for the b exponent of the pituitary in the goat as compared to all other mammals so far studied raises the question whether the pituitaries of our other large domestic animals will be similar to the goat or more in line with the small experimental mammals.

The reason for the high exponent b for the ovary is undoubtedly due to the influence of the cyclic production of ovarian follicles, ovulation and corpora lutea formation under the stimulus of the pituitary gonadotrophic hormones. Thus, a considerable temporary weight increment occurs as a result of the secretion of follicular fluid and corpora lutea. It is probable that if the ovaries were weighed during the spring and summer anestrus period, when cyclic activity is at a minimum, the exponent b would probably be close to 1.0 or even less.

The method of determining whether these data on the relative growth rate of dairy goats may be of value in estimating the hormone dosage has been described. It is hoped that the validity of this theory will be tested.

REFERENCES

Brody, S. 1938 *Growth, milk production, energy metabolism, and energetic efficiency of milk production in goats.* Mo. Agr. Exper. St. Res. Bull. 291.

Brody, S. 1945 *Bioenergetics and growth. With special reference to the efficiency complex in domestic animals.* Pub. Reinhold Pub. Corp., New York, N. Y.

Brody, S., & Kibler, H. H. 1941 *Growth and Development LII. Relation between organ weight and body weight in growing and mature animals.* Mo. Agr. Exper. Sta. Res. Bull. 328.

Campbell, I. L., & Turner, C. W. 1942 *The relation of the endocrine system to the regulation of calcium metabolism.* Mo. Agr. Exper. Sta. Res. Bull. 352.

Kibler, H. H. Bergman, A. J., and Turner, C. W. 1942 *Pituitary weight in growing New Zealand white rabbits in relation to live weight.* Endocrinology *31*: 59-62.

Mixner, J. P., Bergman. A. J., & Turner, C. W. 1943 *Relation of certain endocrine glands to body weight in growing and mature guinea pigs.* Endocrinology *32*: 298-304.

Mixner, J. P., & Turner, C. W. 1942 *Pituitary weight of growing male albino rat related to body weight.* Endocrinology *31*: 261-263.

Overholser, M. D. 1925 *The number of islets of Langerhans in the pancreas of the albino rat.* Endocrinology *9*: 493-504.

Reineke, E. P., Bergman, A. J. and Turner. C. W. 1941 *Effect of thyroidectomy of young male goats upon certain A. P. hormones.* Endocrinology *29*: 306-312.

Schultze, A. B. & Turner, C. W. 1945 *The determination of the rate of thyroxine secretion by certain domestic animals.* Mo. Agr. Exper. Sta. Res. Bull. 392.