GROWTH AND STRUCTURE OF THE THYROID GLAND IN THE COMMON SEAL (*PHOCA VITULINA*)

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INTRODUCTION

Our knowledge of the thyroid gland in Pinnipedia and other aquatic mammals is very scanty. As far as we are aware the only known facts about the seal thyroid are those by Crile (1937) in a comparative survey of the relationship between thyroid and adrenal weights in *Phoca richardii geronimensis* and those of Slijper (1958) on the relation of thyroid weight to body weight in *Phoca vitulina*. The structure of the thyroid gland of seals has not been examined. In view of the unusual development of the gonads and reproductive organs of the seal during foetal life (Harrison, Matthews & Roberts, 1952; Harrison, 1960) it seemed that the endrocrine organs of this species in early stages of development would be of great interest and worthy of investigation. Nothing is known about the secretion and excretion of the sex hormones in seals but the possibility that these hormones may influence the development of foetal endocrine organs prompted us to examine by light and electron microscopy the thyroid gland of the common seal.

Studies on the ultrastructure of the thyroid have been described in the rat (Braunsteiner, Fellinger & Pakesch, 1953*a*, *b*; Monroe, 1953; Weber, Zampi & Ignesti, 1954; Dempsey & Peterson, 1955; Walthard, 1955; Lever, 1960; Walthard & Roos, 1959; Roos, 1960; Wissig, 1960; Waller, 1960); the mouse (Ekholm & Sjöstrand, 1957 *a*, *b*; Ekholm, 1957, 1960); the guinea-pig (Braunsteiner *et al.*, 1953 *a*, *b*); the monkey (Monroe, 1953) and man (Noseda, 1954, Garnier, 1956). Non-mammalian species examined include the chick embryo (Stoll *et al.*, 1957, 1958) and salamander (Herman, 1960). The relation between ultrastructure and secretion in the thyroid has been discussed by Palay (1958) in a general review on secretion.

MATERIALS AND METHODS

Thyroid glands were removed from eighty-two common seals (*Phoca vitulina*) obtained from the area of The Wash, East Anglia, through the co-operation of the Eastern Sea Fisheries Joint Committee. The reproductive organs of many of these seals have been the subject of earlier reports (Harrison *et al.*, 1952; Harrison, 1960). Seventy of the specimens were divided into four age-groups: (*a*) seven foetuses (42 cm. to full term); (*b*) fifteen pups (eight male) obtained during the first post-natal week and fifteen between 2 weeks to 8 months old; (*c*) twenty immature animals, and (*d*) thirteen adults showing evidence of sexual activity.* Another five

* Laws (1956) has suggested that *P. vitulina* reaches sexual maturity at 5–6 years of age, 2–3 years later than usually stated (Asdell, 1946). Observations made on the seals in this series confirm that sexual maturity is reached later than three years and probably at 5 years.

pups were captured immediately after birth and given daily intramuscular injections of oestradiol benzoate and progesterone: the thyroids were removed 8–15 days later. Small pieces of thyroid from a further seven seals of varying age were fixed in Palade's or Dalton's fluid, embedded in methacrylate and ultra-thin sections were examined in a Siemens Elmiskop I electron microscope.

The thyroid glands were removed from all seals immediately after death for light microscopy, fixed whole or in part in a variety of fixatives, including formaldehyde, Bouin's fluid, Zenker-formol and Rossman's fluid (chilled). Each lobe from sixty-two animals in the four age-groups and from the five injected with hormones was then weighed separately. Blocks of tissue were subsequently embedded in paraffin wax and sections prepared at 5–10 μ.

Growth of the follicles was assessed from measurement of the diameter of not less than twenty follicles. Direct measurements were made of the height of the thyroid epithelium according to the method of Rawson & Starr (1938). These authors advocated averaging the measurements from 200 cells selected at random: this was done for two to three animals from each of the four groups. The average cell heights in the remainder were estimated from measurements of 50–100 cells as testing showed the results to be similar to those obtained when 200 cells were measured. Measurements were later checked by microprojection of each section at a known magnification and cell height was determined from a calibrated scale.

RESULTS

Quantitative observations on growth of the thyroid gland

Weight

The two lobes of the thyroid gland of sixty-two seals from age-groups *a–d* (see above) were weighed separately after fixation. Variation in weight of the two lobes was within reasonable limits in all but one animal in which the right and left lobes weighed 4·85 and 0·90 g respectively. On the assumption that the two lobes should be equal in weight it was expected that the regression of the right lobe (x) on the left lobe (y) would fit satisfactorily the theoretical line $x = y$. Two regression analyses were made, the first including and the second excluding the exceptional animal cited above, but quite unexpectedly neither analysis fitted the theoretical line. Elsewhere in this account weight of the thyroid gland refers to the combined weight of the two lobes.

Table 1. *Mean values with standard errors of measurements made of the thyroid gland of common seals grouped according to age*

Stage	Thyroid weight (g.)		Diameter of follicle (mm.)		Epithelial cell height (μ)	
	No. of animals	Mean wt.	No. of animals	Mean diameter	No. of animals	Mean height
Mid-term to parturition	7	1·77 ± 0·43	7	0·052 ± 0·102	7	6·27 ± 0·28
At birth	15	1·83 ± 0·13	17	0·070 ± 0·003	17	7·17 ± 0·35
During 1st year	18	2·39 ± 0·15	18	0·077 ± 0·004	18	6·00 ± 0·22
During 2nd year	13	2·39 ± 0·24	12	0·098 ± 0·004	12	6·05 ± 0·48
Adult	11	5·56 ± 0·30	16	0·129 ± 0·005	16	6·36 ± 0·39

The thyroid gland increased in weight very rapidly during late foetal life and, as shown in Table 1, its mean weight at birth in fifteen specimens was 1·83 g. After birth and throughout the period of immaturity, the rate of thyroid growth was much less but accelerated during or immediately after the attainment of sexual maturity. The weight of the thyroid in adult seals is, on the average, about double that in immature animals. There is no significant difference between the weight of the thyroid in male and female seals.

The relation between thyroid and body weight was examined in nineteen seals weighing from 4 to 16 kg.; these animals included five foetuses in the latter half of gestation and fourteen pups during the first 8 months after birth. Throughout this period the relation was a linear one and could be expressed by the formula:

$$Y = 0{\cdot}083X + 1{\cdot}005,$$

where Y = weight of thyroid (g.) and X = body weight (kg.). The correlation coefficient (r) was 0·475, and with $t = 2{\cdot}706$, was significant ($P = 0{\cdot}02$–$0{\cdot}01$).

The follicles

Mean diameter of the follicles in relation to age is given in Table 1, which shows that it increases from about 0·050 mm. in late foetal stages to 0·130 mm. in adult seals. Individual variation in mean diameter is much greater in foetal than in adult seals and is probably associated with the very active growth of the thyroid during this period of life.

Since the follicles comprise the greater part of the weight of the thyroid gland it would be expected that the volume or weight of the follicles would be related linearly to the weight of the whole gland. To demonstrate this the cube of the mean diameter of the follicles has been calculated for sixty-one foetal, immature and adult seals for which the weight of the thyroid is known and a regression analysis made. The relationship was approximately linear and can be expressed by the formula $Y = 412{\cdot}7X - 221{\cdot}9$, where $Y = (\text{diameter in mm.} \times 100)^3$ and X = weight of thyroid in g. The correlation coefficient $r = 0{\cdot}70$, and with $t = 7{\cdot}53$ the relationship is highly significant ($P = 0{\cdot}001$).

Table 2. *Regression coefficients of cube of follicle-diameter on thyroid weight in seals before and after birth*

Stage	No. of specimens	Regression coefficient	Standard error
Foetal	7	0·000236	±0·000279
Post-natal	54	0·000392	±0·000062

The regression coefficients of the above data for seals before and after birth are not significantly different (Table 2). Unfortunately the number (7) of foetal specimens is small and the estimate of the regression coefficient is consequently imprecise, but it may be concluded tentatively that the changes in the volume of the follicles proceed at a uniform rate throughout life. The regression coefficients do not differ significantly for male and female seals.

The height of the follicular epithelium

The mean height of the cells surrounding the follicles in seals of differing age-groups is given in Table 1. Cell height increases rapidly during late foetal life and reaches a maximum at birth. A small but significant decrease ($P = 0{\cdot}05$) then occurs which seems to persist throughout immaturity. The sixteen adult seals for which a mean cell height of $6{\cdot}36\,\mu$ is recorded in Table 1 have been subdivided according to sex and reproductive state of the females. No statistically significant difference is observed between mean cell height of the thyroid epithelium of males and sexually quiescent females but a highly significant difference ($P = 0{\cdot}001$) occurs between pregnant and lactating seals. The means with standard errors for these groups compared with that given for foetal seals are:

Foetuses (7 seals)	Pregnancy (3 seals)	Lactation (4 seals)
$6{\cdot}57 \pm 0{\cdot}28\,\mu$	$4{\cdot}03 \pm 0{\cdot}42\,\mu$	$7{\cdot}32 \pm 0{\cdot}37\,\mu$

Mean cell height of the follicular epithelium is significantly lower in the pregnant seal than it is in the foetus but there is no difference between the height of these cells in the latter and in lactating seals. The height of the epithelial cells varies independently of thyroid weight or follicle diameter and volume.

The action of sex hormones on the thyroid gland of new-born seals

The thyroid glands of five new-born seals injected by Harrison (1960) to observe the effect of sex hormones on the rate of gonadal involution in the early post-natal period are available for examination. Details of the treatment given and the quantitative results obtained are given in Table 3.

Table 3. *The effect of oestrogen and progesterone on the thyroid gland of newborn seals.*

ODB = oestradiol benzoate in arachis oil. P = progesterone in arachis oil.

No. of seal (SW)	Substances given	Daily dose (mg.)	Period injected (days)	Age when killed (days)	Body wt. (kg.)	Weight (g.)	Mean follicular diam. (mm.)	Mean height of cells (μ)
48♀	ODB	1	8	8	8·75	1·58	0·070	6·3
49♀	ODB	1	15	15	—	1·58	0·076	7·4
117♀	ODB	10	9	10	—	1·35	0·049	7·9
50♀	ODB	1	5	10	7·1	1·35	0·054	8·1
	ODB+P	1+5	9					
51♀	ODB	1	5	10	5·5	0·95	0·080	6·3
	ODB+P	1+5	9					
						1·36 ± 0·11	0·066	7·2

The mean values obtained (irrespective of the nature and duration of treatment) have been compared with those given for normal seals (4) of comparable age. The weight of the thyroids is significantly decreased ($P = 0{\cdot}05$) by treatment; but mean diameter of the follicles and mean height of the epithelial cells are unchanged.

No microscopic changes other than the appearance in SW 49 of a well-marked intervesicular network of capillary vessels engorged with blood have been observed in the three animals treated with oestradiol benzoate alone. In both seals in which progesterone was injected daily, beginning on the 6th day of treatment with oestradiol, the thyroids are highly active and are extremely well vascularized.

Observations with the light microscope

Changes during foetal life

The histological appearances strongly suggest that the thyroid is functional in the near term foetuses and that it may well be starting to function some 2–3 months before term. In the youngest (42 cm.), estimated to be half-way through gestation, formation of follicles is proceeding rapidly and in many the lumen contains a thin, lightly stained colloid. The follicles are regular in size, and lined with cubical cells: some of the cells have a uniformly dark-stained nucleus, others have a clear nucleoplasm containing chromatin particles. The gland is well supplied by capillary blood vessels.

Follicle formation is more advanced in the thyroids of three older foetuses (51, 59 and 65 cm.) in the peripheral zone. Those follicles in the centre are small and lined by a uniform cubical epithelium. A few of the larger peripheral follicles have a lining of flattened cells. The majority of the follicles contain densely stained colloid; in some the outer part of the colloid contains vacuoles.

The follicular epithelium of three near or full term foetuses is uniformly cubical in shape and the majority of its cells have a clear nucleoplasm containing chromatin and a cytoplasm which is conspicuously eosinophil. A few are swollen and have cytoplasm containing pigment. All follicles contain lightly stained colloid. The vascular network is particularly well developed in the peripheral parts in which lie the largest follicles.

Pups: birth to 8 months

The thyroid is strikingly active immediately after birth (see Table 1 and p. 5). Numerous small follicles in evenly distributed patches are a constant feature of the thyroids of pups during the first post-natal week. The largest follicles contain moderately dense colloid which is vacuolated to a very variable degree in different animals. In five animals killed within 24 hr. after birth the epithelial cells were regularly cuboidal but in others obtained between the 2nd and 7th days the follicular cells were frequently columnar. All had a well-developed interfollicular capillary network.

Seals obtained in the period 2 weeks to 8 months after birth consist of three aged 2–3 weeks, one a month old, and eleven aged 3–8 months old. The thyroids of the youngest are similar in appearance to those examined up to 1 week of age. The 1-month-old pup had been suckled by its mother in captivity for the normal 3-week period (Harrison, 1960) and killed 7 days later. The thyroid follicles are fully formed and distended with a lightly stained colloid, showing little vacuolation. The distended follicles are more pronounced in the peripheral region, where the cells of the epithelium are flattened and their nuclei darkly stained and elliptical in shape. Towards the centre the follicles are small, the cells are cubical and their nuclei small and spherical. The gland, particularly in the central region, has an extensive capillary network.

The appearances of the follicles from seals 3–8 months old suggest that colloid is being accumulated in significant quantities. The decline in mean cell height also suggests that the epithelial cells are less active. The epithelium of all but one animal is lower than in almost all other pups: the average cell height in one is as low as $4{\cdot}5\,\mu$. The colloid in all follicles is densely stained and shows little vacuolation.

Immature seals

Specimens from eight seals just over 1 year old, three aged about 17 months and nine estimated as 2–3 years old have been examined. The average weight of the thyroid does not increase significantly during this pre-pubertal period. A few large follicles of the yearlings contain colloid that is generally more deeply stained than that of the smaller follicles. The colloid occasionally shows slight vacuolation. The epithelium consists of columnar or cubical cells and their abundant cytoplasm is brightly eosinophil. The thyroid of seals aged between 2 and 3 years is similar to those of the yearlings except that the follicular epithelium is often considerably flattened. The density of the colloid and degree of vacuolation varies markedly.

Adult seals

The thyroids of two mature *male* seals are among the largest of the series, but in neither is the increase in weight caused by an increase in the size of the follicles. The medium and large sized vesicles contain a densely stained slightly vacuolated colloid, but many are devoid of colloid and some contain small quantities of a finely granular material. An appreciable quantity of inter-follicular hyaline material is present in one specimen so that the number of follicles seen in a given area of section is reduced. The follicles are irregular in outline, in some large clumps of desquamated epithelial cells occur in the colloid. The epithelium is composed of small cubical cells with small nuclei. The other adult male thyroid has swollen, irregularly shaped epithelial cells with small nuclei many of which are pyknotic. Small rod-like, birefringent particles are present in the apical cytoplasm of epithelial cells of both thyroids. The capillary network is extensive, full of blood, and surrounds each follicle.

Thyroid glands from two *females* that had recently ovulated have been examined. One, killed on 15 May contained a recently formed corpus luteum in the right ovary. This is several months earlier than the usual time for ovulation (Harrison, 1960). The thyroid is conspicuous for the amount of collagenous connective tissue lying between the follicles. The colloid is palely stained and vacuolated. The epithelial cells are relatively tall and the apical cytoplasm contains marked aggregations of pale brown granules of varying size (see p. 12). Some follicles show evidence of degeneration. Another adult female, killed on 30 August, has a well developed corpus luteum. The thyroid follicles contain colloid stained to a variable degree and occasionally heavily vacuolated.

Glands from three *pregnant* seals have been examined, one 2 months from term, the others near term. The colloid is dense and unvacuolated in the specimens near term. The average cell height of the follicular epithelium is lower than in any other thyroid in the series (p. 6). (It should be recalled that the foetal thyroid is active in late pregnancy.) The nuclei are heavily basiphilic and the cytoplasm contains a few pale brown granules in its distal portion (see p. 10). Thyroids are available from four *lactating* cows and from one killed 2 weeks after lactation had ceased. The epithelial cells are uniformly columnar and higher than in any other group (p. 6). The outline of individual cells is often indistinct and in section the epithelium thus appears more than one cell deep. Some nuclei are small and intensely basiphilic, but the majority have a clear nucleoplasm. The apical cytoplasm contains numerous pale brown granules or droplets (see p. 8). The colloid is scanty, heavily vacuolated and often contains eosinophil globules of varying size seen most frequently near the free border of the cells. All the glands show varying degrees of accumulation of connective tissue and amorphous hyaline material between the follicles: groups of leucocytes are also present. The capillary blood supply is well developed; every follicle in the central parts of each gland is closely related to congested capillaries. There is evidence that the glands are either in a state of intense activity or have recently been active.

The thyroid from a cow kept in captivity and known to be ten years old had large and palely stained follicular cells. They lack any intracellular inclusions. Colloid is scanty or absent. There is some interfollicular connective tissue but it is not as abundant as in some of the lactating animals.

Observations with the electron microscope

Thyroid cells from seven seals, forming a fairly representative sample from the four main age-groups studied under light microscopy, have been examined with an electron microscope. The functional states of the cells have been assessed by the appearance of the microvilli, Golgi zone, secretion droplets and endoplasmic reticulum (Palay, 1958; Wissig, 1960).

In two pups of 2–3 days microvilli can be seen to protrude from the apex of the follicular cells into the colloid (Pl. 1, figs. 1 and 2). They vary considerably in size, number and orientation. Their length is about 0·15–0·5 μ and width 0·08 μ. They are covered by the plasma membrane which in some views can be seen to consist of a unit membrane. The microvilli have a cytoplasmic core which is continued into the apical cytoplasm for a short distance. No terminal web is seen (Pl. 1, fig. 2).

The plasma membranes between two follicular cells are separated by a space of 150 Å. width. Desmosomes are seen and there is a well marked terminal bar towards the apex of the cell. The plasma membrane is continued around the base of the cell with occasional infolding. Basal processes are often seen which are continued under the adjacent follicular cell. A well marked basement membrane 500 Å. thick is present (Pl. 3, fig. 5). At the base of each follicular cell is the endothelial cell of the perifollicular capillary with its own basement membrane. These basement membranes are separated by a space of 250 Å. width which is sometimes dilated with a pale staining substance but this space may be artifact. The endothelial cell is sometimes very thin, and pores are present (Pl. 3, fig. 6).

The endoplasmic reticulum consists of the usual membrane-bounded cisternae with granules on the outer surface. The cisternae are widely dilated, especially towards the base of the cell, by a pale staining substance similar in appearance to colloid (Pl. 3, figs. 5 and 7). The dilatations give the appearance of vesicles towards the apex of the cell and increase in size towards the base where they are sometimes in contact with the plasma membrane. They often result in mitochondria being surrounded by the granules on the outside of the cisternae. This dilatation of the endoplasmic reticulum is taken as evidence of large-scale resorption of colloid by the follicular cell (Palay, 1958).

There is a well marked Golgi apparatus in the supranuclear region consisting of the typical small vesicles and flattened cisternae (Pl. 2, fig. 4). Secretion droplets of different size and density can be seen extending from the Golgi region towards the apex of the cell. They are surrounded by a smooth membrane, and vary from 0·07 μ to about 0·4 μ in diameter. The larger secretion droplets are electron dense. They appear to be formed in the Golgi apparatus but their fate in the subapical cytoplasm cannot be followed. The presence of a large Golgi apparatus and secretion droplets is taken as evidence of active secretion in the thyroid gland of the seal pup.

The nuclear envelope consists of an inner and outer membrane of similar thickness separated by a perinuclear space of about 250 Å. Some nuclear pores are seen (Pl. 4, fig. 8). The outer membrane sometimes projects from the inner membrane into the cytoplasm and has a few scattered Palade granules on its cytoplasmic surface. On the inner side of the inner membrane is an aggregation of nuclear granules.

Pups aged 14 and 18 days have cells in a markedly active secretory phase. The endoplasmic reticulum is present in increased amounts and sometimes is arranged in orderly arrays. The Golgi zone is prominent and may be either double or horse-shoe shaped as it can sometimes be seen in two places in a cell section. Secretory granules form in the Golgi zone and extend towards the apex of the cell.

In all specimens, but especially marked in two male yearlings, many cells contain large pale staining droplets up to 1·5 μ in diameter surrounded by smooth membranes. These large droplets can sometimes be seen in the colloid near the apex of the cell as though they have been extruded through the plasma membrane. They are numerous in the follicular cells of a pregnant seal where they often appear to have been broken down into smaller vesicles contained in an electron dense layer (Pl. 4, fig. 10). Large, electron dense granules, corresponding to those seen by the light microscope (p. 9), are present. These granules often contain vesicles of density similar to that of the large pale droplets (Pl. 4, fig. 8).

DISCUSSION

Thyroid weight has been shown to bear a linear relation to body weight in seals from mid-foetal life to 8 months after birth. Slijper (1958), who has examined the relative weight of this organ in a small series of common seals in Dutch waters, finds a decrease in thyroid weight with increasing body weight ranging from 0·70 g./kg. in very young pups to 0·1 g./kg. in one mature female. Comparable rates given for the nineteen seals of the present series are as follows: five foetuses 0·266 ± 0·051 g./kg.; six male pups, 0·178 ± 0·020 g./kg. and eight female pups, 0·172 ± 0·015 g./kg. These mean figures do not differ significantly ($P = 0{\cdot}1 - 0{\cdot}05$) and for the period of life mentioned above the results do not, therefore, support Slijper's conclusion. His statement 'that aquatic mammals have a significantly larger thyroid than their terrestrial relatives' is also open to criticism. For example, the relative size of the thyroids in the dog foetus has been shown by Latimer (1954) to be 0·27 g./kg. and is closely similar to that of the foetal seals given above. Gutierrez (1959) has reported that the relative weight of the thyroid rises throughout the vertebrate series from

0·098 g./kg. in fishes to a maximum of 0·68 g./kg. in man, but Marine (1922) states that in a healthy man this ratio does not exceed 0·35 g./kg.

Our observations on the height of the follicular epithelium indicate the existence of two maxima of thyroidal activity, the first during late foetal life culminating at birth or shortly afterwards and the second in the adult during lactation. The former coincides with the period of intense stimulation of gonadal interstitial tissue (Harrison, 1960) in this species and some other mammals, e.g. the horse (Amoroso & Rowlands, 1951). The stimulation of the foetal gonads has been attributed to an action of placental oestrogens and progestogens, and some consideration must be given to the possibility that these substances have also a thyroid stimulating action. This may be direct on the thyroid itself or may be mediated through the anterior pituitary gland. The only significant effect of the injection of oestrogen and progesterone on the thyroid of five newborn seals is a decrease in thyroid weight. A reduction in weight would most likely occur as the result of the withdrawal of colloid from the follicles. Our histological observations on the thyroids of these five seals only partly confirm this suggestion for in only one is colloid absent from the follicles, but that it is being actively withdrawn is suggested by increased vascularity of the gland in another three animals. The action of oestrogens on thyroid function has been studied very extensively in experimental animals, especially the rat. In general these substances have been found to stimulate thyroidal activity, although the records of weight changes in the gland are inconsistent. Several workers, including Noach (1955), Soliman & Reineke (1958) and Grosvenor & Turner (1959) have observed an increase in weight, whereas Feldman (1956) and Bogdanove & Horn (1958) have failed to observe this effect. An increase in thyroid weight largely due to the accumulation of colloid occurs in mice after treatment with oestrogen (Isler *et al.* 1960). It must be emphasized that all of these experiments have been performed in adult animals and often after spaying, hypophysectomy or adrenalectomy so that any correlation of their results in the light of our own observations is extremely difficult.

The condition of the thyroid gland of the foetus should be contrasted with that of the pregnant female: in all three of the adults obtained in late pregnancy the condition of the follicular epithelium suggests a low level of thyroid activity. Whether or not this small sample is representative of the species is a matter of conjecture. If so, the seal differs greatly in this respect from at least two other species which have been examined. In the pregnant cat Racadot (1957) has observed a moderate degree of thyroid activity and in the pregnant ground squirrel Zalesky (1935) has found the thyroids in an extremely active condition. The difference between the high level of thyroid activity in the foetus and the low level of activity in the pregnant seal is difficult to explain on the basis of placental oestrogens. Nevertheless, it is noteworthy that in these species in which massive gonadal stimulation occurs in the foetus the ovaries of the mother are not subjected to stimulation coincidentally.

The thyroid glands of lactating seals are all found to be in a highly active condition similar to that found in the cat and the ground squirrel during lactation (*loc. cit.*). An intimate association between the functional activity of the thyroid gland and lactation has been realized for many years. This correlation has been demonstrated in two ways. On the one hand, thyroidectomy leads to a reduction, if not a cessation, of lactation and thyroid extracts or thyroxine have a galactopoietic action on established lactation in several species, notably the cow (Folley, 1952). These substances have been shown to increase the fat content of milk and the very high fat content of seal milk (Linzell, 1959, p. 546) may well be dependent on a high rate of thyroidal activity during the suckling period.

Although light microscopy suggests considerable variability in both the characteristics of regions of a particular gland and those of a group of glands of similar age and condition, electron microscopy confirms activity in particular cells. As thyroid cells have both secretory and absorptive functions certain ultrastructural features are of particular interest. The microvilli vary considerably in size, number and orientation depending upon the functional state of the thyroid (Braunsteiner *et al.*, 1953*b*; Wissig, 1960). Microvilli are present on the free surfaces of a large number of different cell types and are often characteristic of the particular epithelial surface. Various theories have been put forward as to the function of the microvilli on absorptive cells. They may provide an increase in absorptive area (Granger & Baker, 1950; Zetterqvist, 1956), or be concerned in pinocytosis of lipids (Palay & Karlin, 1959), or in ingestion of whole protein in some newborn mammals (Clark, 1959). The observations of Sjöstrand & Zetterqvist (1957), which are discussed by Robertson (1959), that changes in the membrane of the microvillus in columnar intestinal cells are seen in protein absorption, are of great importance in understanding the mechanism of absorption.

The thyroid follicular cells have both secretory and absorptive function, and experimental stimulation of rat thyroids suggests that the microvilli are concerned with absorption rather than secretion (Wissig, 1960). In seal pup thyroids with very active secretion but little evidence of absorption the microvilli are well marked, suggesting that their function is at least partly concerned with secretion. Herman (1960) states that the possibility that some secretory function might be attached to the microvilli still exists.

The Golgi zone is well marked in the seal thyroid, in particular in newborn pups. In the rat the Golgi zone is normally inconspicuous (Wissig, 1960). The observation of secretory granules in the Golgi zone and between the zone and the cell apex would add support to the theory of the importance of this region in the elaboration of the secretory products (Palay, 1958).

The significance of the pigmented granules seen by light and electron microscopy in the follicular cells of pregnant and lactating cows is obscure. The granules consist of at least two components, one lipid and the other containing traces of iron. The material is not present in young seal thyroids. The occurrence of lipid droplets in the thyroid that increase in number and size and become pigmented in old age has been reported by Dempsey (1949). Payne (1952) has shown that in the thyroids of old fowls the mitochondria are replaced by 'spheres which change into spherical bodies'. There is a similarity between the granules in adult seal thyroid cells and these spherical bodies, suggesting that they may be related to ageing.

SUMMARY

Observations were made on thyroid glands from eighty-two common seals (*Phoca vitulina*) obtained from The Wash, East Anglia.

1. Thyroid weight was related linearly to body weight in seals weighing 4–16 kg. (mid-pregnancy to 8 months after birth).

2. The growth of the follicles and epithelial cell height was studied in seventy specimens. Follicular growth bore a linear relation to thyroid weight. Two maxima of thyroid activity were observed from the measurement of cell height; the first occurred in late pre-natal life and the second in the adult during lactation.

3. The significance of these maxima was discussed in relation to the endocrine environment of the foetus and to the high fat-content of seal milk, respectively.

4. A slight depression of thyroid weight occurred in five newborn seals injected with sex hormones. This could not be related unequivocally to the withdrawal of colloid from the follicles.

5. The ultrastructural characteristics of thyroid cells from seven seals of various ages are described. The significance of microvilli and the Golgi zone in thyroid cell activity is discussed.

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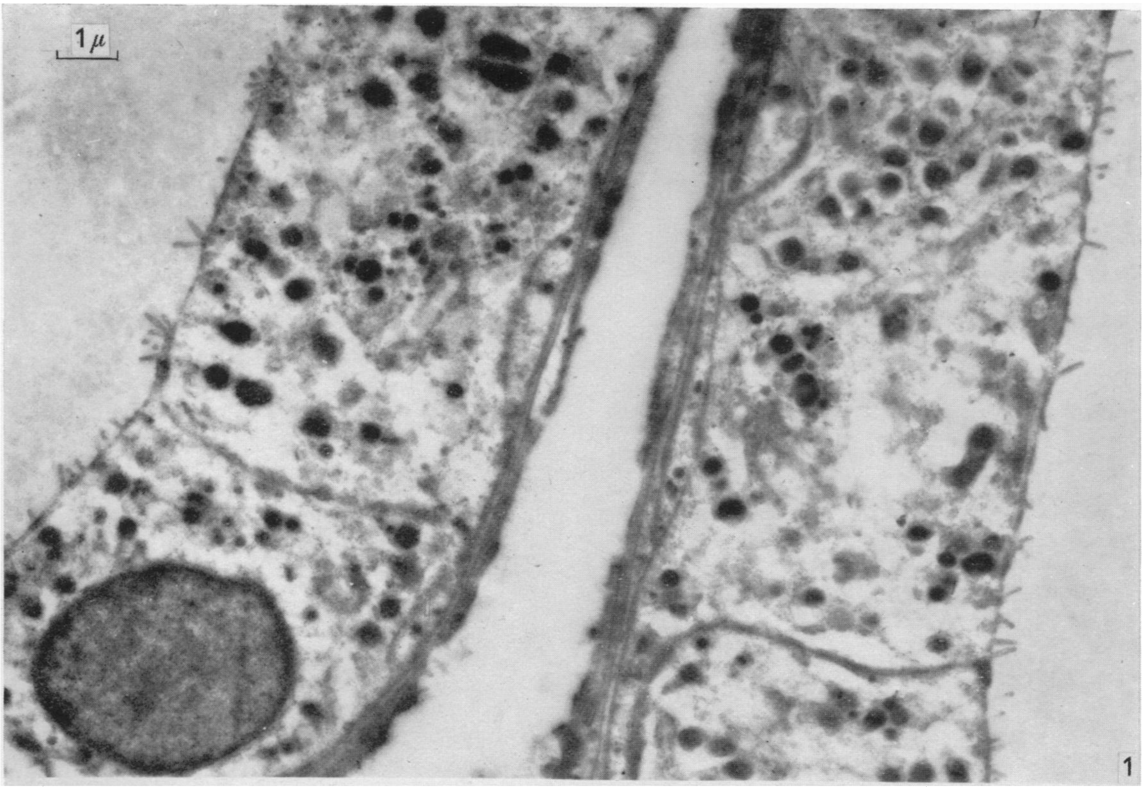

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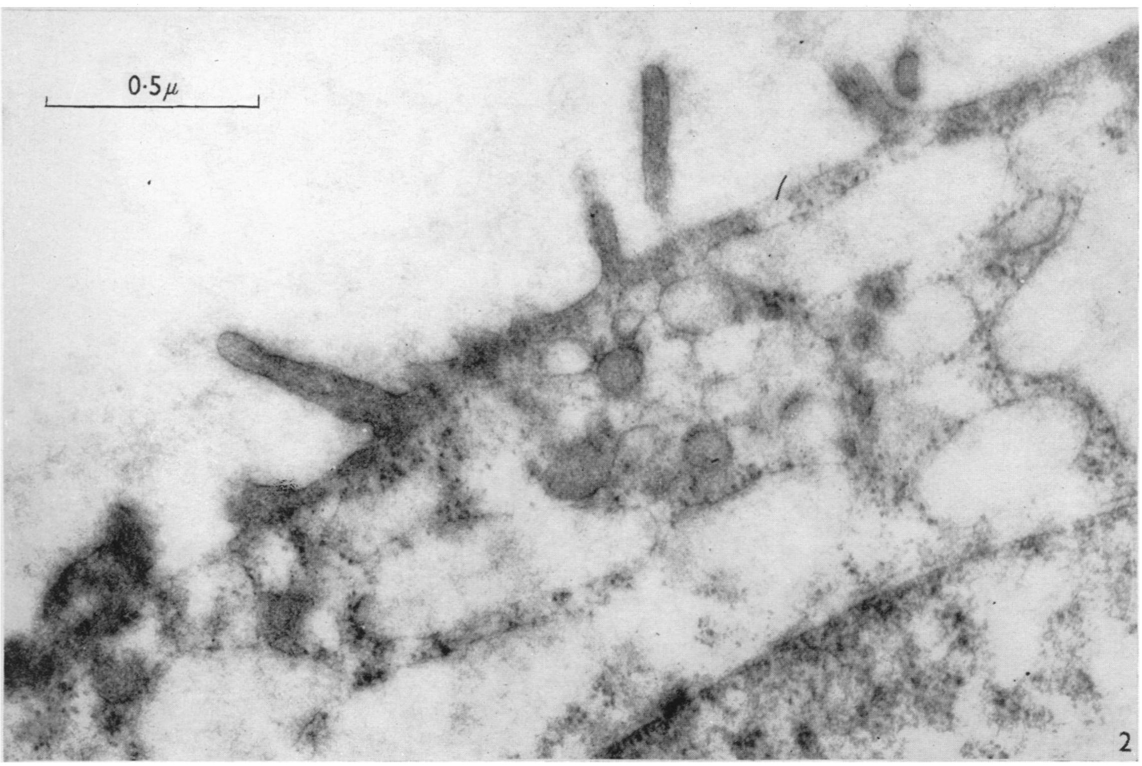
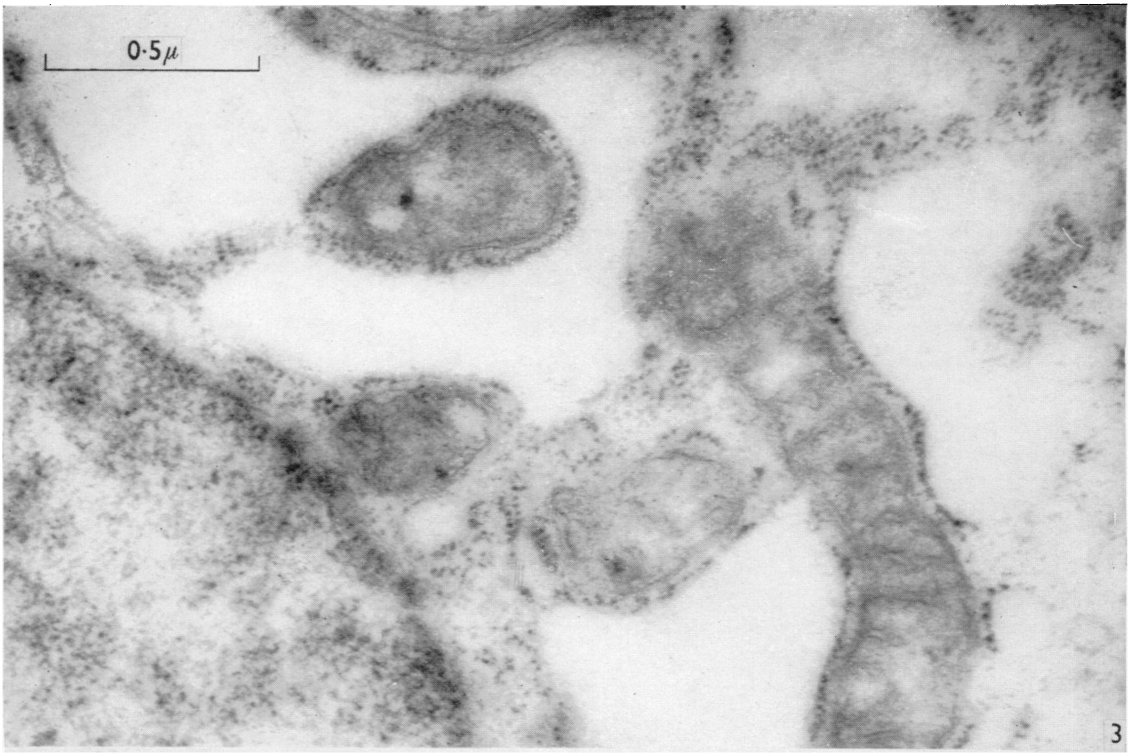


2

HARRISON AND OTHERS—THYROID GLAND IN THE COMMON SEAL

(*Facing p.* 14)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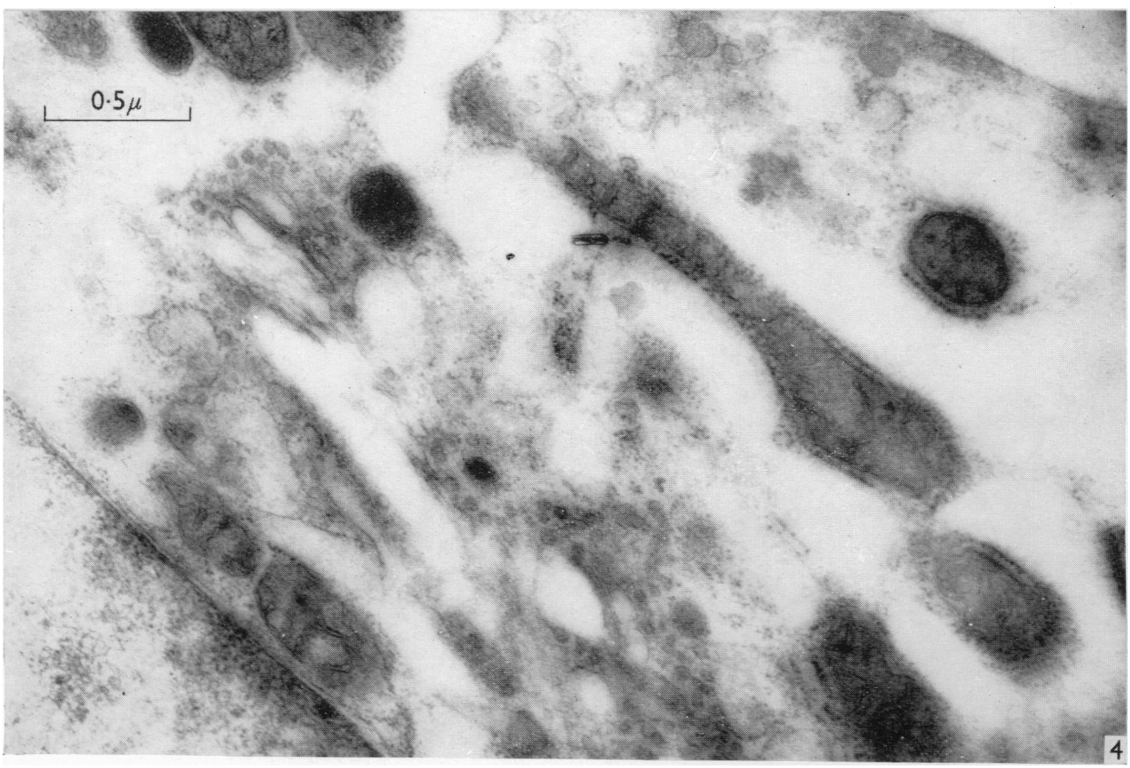
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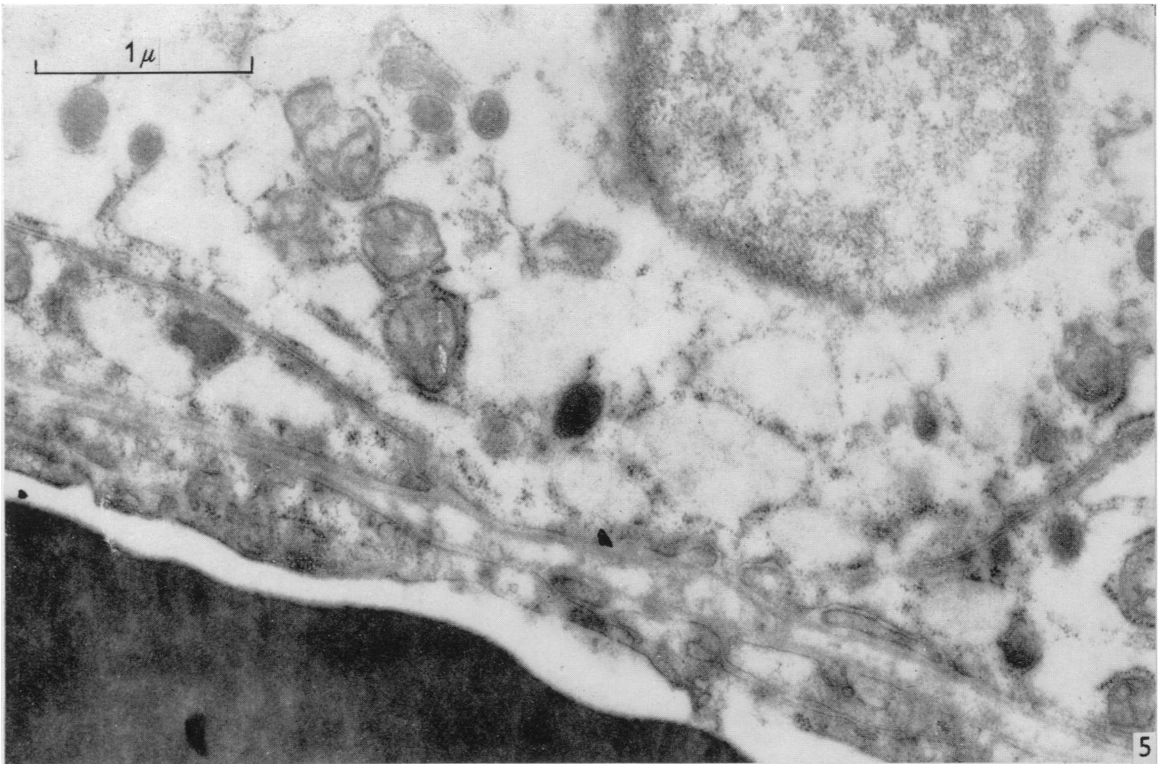
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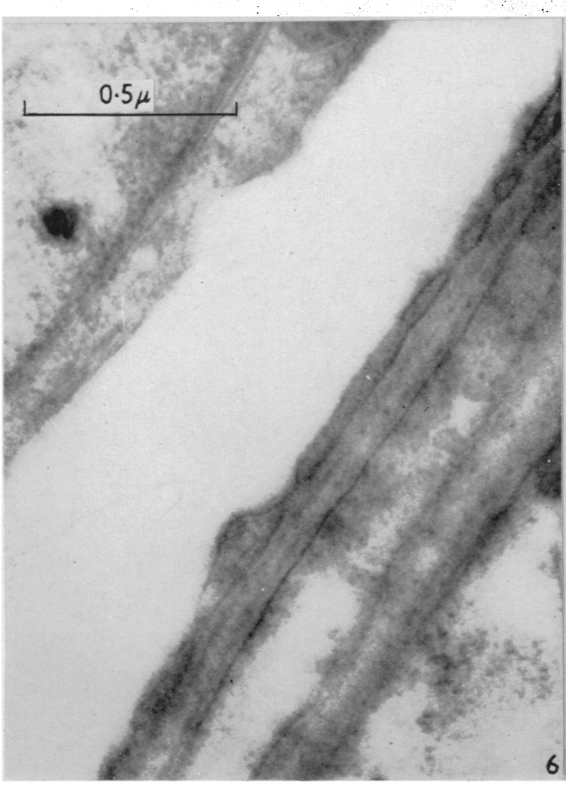
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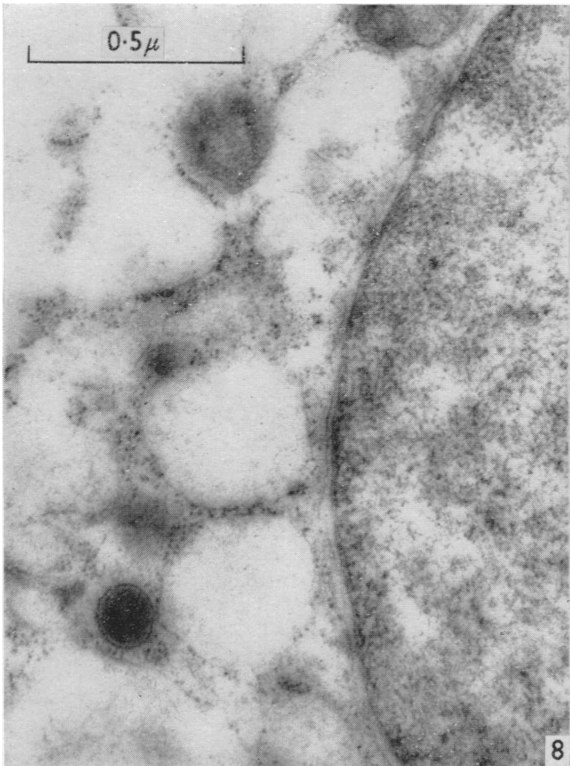
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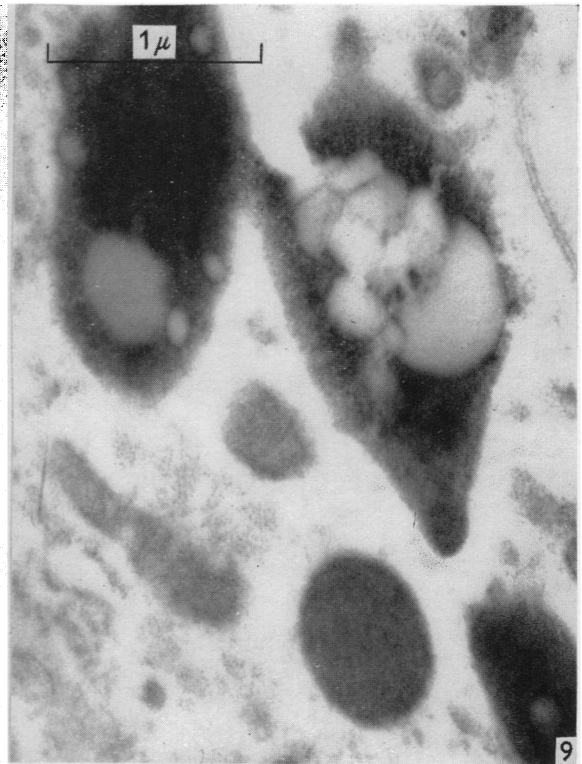
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EXPLANATION OF PLATES

PLATE 1

Fig. 1. Electron micrograph of the thyroid gland from a 2- to 3-day-old seal pup, showing cells from adjacent follicles separated by the perifollicular capillary. The apices of the cells show microvilli protruding into the colloid. × 7800.

Fig. 2. As above, showing the apex of a follicular cell with the edge of the nucleus below and the microvilli above. × 59,100.

PLATE 2

Fig. 3. Electron micrograph of the thyroid gland from a 2- to 3-day-old seal pup, showing edge of nucleus on the left and mitochondria surrounded by the widely dilated endoplasmic reticulum. × 59,100.

Fig. 4. As above, showing the Golgi apparatus in the supranuclear region of a follicular cell. The nucleus is at the bottom left and the colloid at the top right. Secretion granules can be seen in the Golgi apparatus. × 39,400.

PLATE 3

Fig. 5. Electron micrograph of the thyroid gland from a 2- to 3-day-old seal pup, showing the basal region of a follicular cell. Below is a red blood corpuscle in the perifollicular capillary and above the follicular cell with the dilated endoplasmic reticulum coming into contact with the plasma membrane. × 29,400.

Fig. 6. As above, showing the endothelium of the perifollicular capillary with pores and attenuated basement membranes. × 59,100.

Fig. 7. As above, showing the widely dilated endoplasmic reticulum with the attached granules. × 59,100.

PLATE 4

Fig. 8. Electron micrograph of the thyroid gland from a 2- to 3-day-old seal pup, showing the edge of the nucleus on the right. Nuclear pores can be seen and also the relationship of the outer nuclear membrane to the endoplasmic reticulum. × 59,100.

Fig. 9. Electron micrograph of the thyroid gland from a pregnant seal, showing the large, very electron dense granules that can also be seen with the light microscope. × 29,400.

Fig. 10. As above, showing part of a follicular cell containing a large droplet contained in an electron dense layer. × 29,400.