Haller there is a full discussion of the influence of the diaphragm and of the movements of the thorax upon the circulation of chyle. Colin always found marked impulses in the flow of chyle from a fistula into the thoracic duct, which were synchronous with the movements of respiration. With each act of expiration the fluid was forcibly ejected, and with inspiration the flow was very much diminished or even arrested. These impulses became much more marked when respiration was interfered with and the efforts became violent. The impulses were sometimes so decided, that the pulsations were repeated in a long elastic tube attached to the canula for the purpose of collecting the fluid.

From all these considerations, it is evident that although there are many conditions capable of modifying the currents in the lymphatic system, the regular flow of the lymph and chyle depends chiefly upon the *vis a tergo;* but the vessels themselves sometimes undergo contraction, and they are subject to occasional compression from surrounding parts, which, from the existence of valves in the vessels, must favor the current toward the venous system. The alternate dilatation and compression of the thoracic duct with the acts of respiration likewise aid the circulation, and they are more efficient than any other force, except the *vis a tergo.* The action of the valves is precisely the same in the lymphatic as in the venous system.

CHAPTER XI.

SECRETION.

Classification of the secretions—Mechanism of the production of the true secretions—Mechanism of the production of the excretions—Influence of the composition and pressure of the blood on secretion—Influence of the nervous system on secretion—Anatomical classification of glandular organs—Classification of the secreted fluids—Synovial membranes and synovia—Mucous membranes and mucus—Physiological anatomy of the sebaceous, ceruminous and Meibomian glands—Ordinary sebaceous matter—Smegma of the prepuce and of the labia minora—Vernix caseosa—Cerumen—Meibomian secretion—Mammary secretion—Physiological anatomy of the mammary glands—Mechanism of the secretion of milk—Conditions which modify the lacteal secretion—Quantity of milk—Properties and composition of milk—Microscopical characters of milk—Composition of milk—Variations in the composition of milk—Colostrum—Lacteal secretion in the newly-born—Secretory nerve-centres.

THE processes of secretion are intimately connected with general nutrition. In the sense in which the term secretion is usually received, it embraces most of the processes in which there is a separation of matters from the blood by glandular organs or a formation of a new fluid out of materials furnished by the blood. The blood itself, the lymph and the chyle, are in no sense to be regarded as secretions. These fluids, like the tissues, are permanent parts of the organism, undergoing those changes only that are necessary to their proper regeneration. They are likewise characterized by the presence of certain formed anatomical elements, which themselves undergo processes of molecular destruction and regeneration. These characters are

not possessed by the secretions. As a rule, the latter are homogeneous fluids, without formed anatomical elements, except as accidental constituents, such as the desquamated epithelium in mucus or in sebaceous matter. The secretions are either discharged from the body, when they are called excretions, or after having performed their proper office as secretions, are absorbed in a more or less modified form by the blood.

Physiologists now regard secretion as the act by which fluids, holding certain substances in solution, and sometimes containing peculiar ferments but not necessarily possessing formed anatomical elements, are separated from the blood or are formed by special organs out of materials furnished by the blood. These organs may be membranes, follicles or collections of follicles, or tubes. In the latter instances they are called glands. The liquids thus formed are called secretions; and they may be destined to perform some office connected with nutrition or may be simply discharged from the organism.

It is not strictly correct to speak of formed anatomical elements as products of secretion, except in the instance of the fatty particles in the milk. The leucocytes found in pus, the spermatozoids of the seminal fluid, and the ovum, which are sometimes spoken of as products of secretion, are anatomical elements developed in the way in which such structures are ordinarily formed. For example, leucocytes, or pus-corpuscles, may be developed without the intervention of any special secreting organ; and spermatozoids and ova are generated in the testicles and the ovaries, by a process entirely different from ordinary secretion. It is important to recognize these facts in studying the mechanism by which the secretions are produced.

Classification of the Secretions.—Certain secretions are formed by special organs and have important uses which do not involve their discharge from the body. These may be classed as the true secretions; and the most striking examples of such are the digestive fluids. Each one of these fluids is formed by a special gland or set of glands, which generally has no other office; and they are never produced by any other part. It is the gland which produces the characteristic constituent or constituents of the true secretions, out of materials furnished by the blood; and the matters thus formed never pre-exist in the circulating fluid. The office which these fluids have to perform is generally not continuous; and when this is the case, the flow of the secretion is intermittent, taking place only when its action is required. When the parts which produce one of the true secretions are destroyed, as is sometimes done in experiments upon living animals, the characteristic constituents of this particular secretion never accumulate in the blood nor are they formed vicariously by other organs. The simple effect of such an experiment is absence of the secretion, with the disturbances consequent upon the loss of its physiological action.

Certain other of the fluids are composed of water, holding one or more characteristic constituents in solution, which result from the physiological wear of the tissues. These matters have no office to perform in the animal economy and are simply separated from the blood to be discharged from the

body. These may be classed as excretions, the urine being the type of fluids of this kind. The characteristic constituents of the excrementitious fluids are formed in the tissues, as one of the results of the constant changes going on in all organized, living structures. They always pre-exist in the circulating fluid and may be eliminated, either constantly or occasionally, by a number of organs. As they are produced continually in the substance of the tissues and are taken up by the blood, they are constantly separated from the blood by the proper eliminating organs. When the glands which thus eliminate these substances are destroyed or when their action is seriously impaired, the excrementitious matters may accumulate in the blood and give rise to certain toxic phenomena. These effects, however, are often retarded by the vicarious action of other organs.

There are some fluids, as the bile, which have important uses as secretions, and which nevertheless contain certain excrementitious matters. In these instances, it is only the excrementitious matters that are discharged from the organism.

In the sheaths of some tendons and of muscles, in the substance of muscles and in some other situations, fluids are found which simply moisten the parts and which contain very little organic matter, with but a small proportion of inorganic salts. Although these are frequently spoken of as secretions, they are produced generally by a simple, mechanical transudation of certain of the constituents of the blood through the walls of the vessels. Still, it is difficult to draw a line rigorously between transudation and some of the phenomena of secretion; particularly as experiments upon dialysis have shown that simple, osmotic membranes are capable of separating complex solutions, allowing certain constituents to pass much more freely than others. This fact explains why the transuded fluids do not contain all the soluble constituents of the blood in the proportions in which they exist in the plasma. All the secreted fluids, both the true secretions and the excretions, contain many of the inorganic salts of the blood-plasma.

Mechanism of the Production of the True Secretions.—Although the characteristic constituents of the true secretions are not to be found in the blood or in any other of the animal fluids, they can generally be extracted from the glands, particularly during their intervals of so-called repose. This fact has been repeatedly demonstrated with regard to many of the digestive fluids, as the saliva, the gastric juice and the pancreatic juice; and artificial fluids, possessing certain of the physiological properties of the natural secretions, have been prepared by simply extracting the glandular tissue with water. There can be no doubt, therefore, that during the periods when the secretions are not discharged, the glands are taking from the blood matters which are to be transformed into the characteristic constituents of the individual secretions, and that this process is constant, bearing a close resemblance to the general act of nutrition. There are certain anatomical elements in the glands, which have the power of selecting the proper materials from the blood and causing them to undergo peculiar transformations; in the same way that the muscular tissue takes from the nutritive fluid albuminoid matters and transforms them into its own substance. The exact nature of this property is unexplained.

In all of the secreting organs, epithelium is found which seems to possess the power of forming the peculiar constituents of the different secretions. The epithelial cells lining the tubes or follicles of the glands constitute the only peculiar structures of these parts, the rest being made up of basement-membrane, connective tissue, blood-vessels, nerves, and other structures which are distributed generally in the economy; and these cells alone contain the constituents of the secretions. It has been found, for example, that the liver-cells contain the glycogen formed by the liver; and it has been farther shown that when the cellular structures of the pancreas have been destroyed, the secretion is no longer produced. There can be hardly any doubt with regard to the application of this principle to the glands generally, both secretory and excretory. Indeed, it is well known to pathologists, that when the tubes of the kidney have become denuded of their epithelium, they are no longer capable of separating from the blood the peculiar constituents of the urine.

With regard to the origin of the characteristic constituents to the true secretions, it is impossible to entertain any other view than that they are produced in the epithelial structures of the glands. While the secretions contain inorganic salts in solution transuded from the blood, the organic constituents, such as ptyaline, pepsine, trypsine etc., are readily distinguished from all other albuminoid substances, by their peculiar physiological properties.

It may be stated, then, as a general proposition, that the characteristic constituents of the true secretions, as contradistinguished from the excretions, are formed by the epithelial structures of the glands, out of materials furnished mainly by the blood. Their formation is by no means confined to what is usually termed the period of activity of the glands, or the time when the secretions are poured out, but it takes place more or less constantly when no fluid is discharged. It is more than probable, indeed, that the formation of the peculiar and characteristic constituents of the secretions takes place with as much activity in the intervals of secretion as during the discharge of fluid; and most of the glands connected with the digestive system seem to require certain intervals of repose and are capable of discharging their secretions for a limited time only.

When a secreting organ is called into activity—like the gastric mucous membrane or the pancreas, upon the introduction of food into the alimentary canal—a marked change in its condition takes place. The circulation in the part is then very much increased in activity, thus furnishing water and the inorganic constituents of the secretion. This difference in the quantity of blood in the glands during their activity is very marked when the organs are exposed in a living animal, and is one of the important facts bearing upon the mechanism of secretion.

In all the secretions proper, there are intervals, either of complete repose, as is the case with the gastric juice or the pancreatic juice, or periods

when the activity of the secretion is very greatly diminished, as in the saliva. These periods of repose seem to be necessary to the proper action of the secreting glands; forming a marked contrast with the constant action of organs of excretion. It is well known, for example, that digestion is seriously disturbed when the act is too prolonged on account of the habitual ingestion of an excessive quantity of food.

From the considerations already mentioned, it is evident that the characteristic constituents of the true secretions are formed by the epithelial structures of the glands. While the mechanism of this process is not understood in all its details as regards all of the secretions, in some of the glands the processes have been studied with tolerably definite results. In some of the salivary glands, in the peptic cells and in the cells of the pancreas, it has been shown that the so-called ferments are not formed directly. The secreting cells are apparently divided into two portions, or zones; an outer zone, which is next the tubular membrane, and an inner zone, next the lumen of the tube or follicle. In the inner zone, during the intervals of actual secretion, there appears a substance, which at the time when the secretion is formed and is poured out, is changed into the true ferment, or active principle of the secretion; so that there is probably a zymogenic, or ferment-forming substance, first produced by the cells. The substance, if such a substance exists, out of which ptyaline is formed, has not been described; but in the viscid forms of saliva, there appears to be first formed a substance called mucinogen, afterward changed into mucine, upon which the viscidity of the fluid depends.

In the salivary glands which produce viscid secretions, the submaxillary and sublingual, the parenchyma presents two kinds of acini, serous and mucous. The so-called serous acini are the more abundant and are thought to produce the true saliva, while the mucous acini secrete the viscid constituents of the saliva.

In the production of pepsine, the inner zone of the peptic cells first forms pepsinogen, which is changed into pepsine as it is discharged from the glands. In the pancreas, trypsinogen is formed in the inner zone of the cells, and this is changed into trypsine. The general name zymogen has been given to the substances which are changed into the digestive ferments; although, as is evident, this substance is not identical in the different glands. The formation of the ferments of the true secretions is analogous in its nature to certain of the nutritive processes.

The theory that the discharge of the secretions is due simply to mechanical causes and is attributable solely to the increase in the pressure of blood can not be sustained. Pressure undoubtedly has considerable influence upon the activity of secretion; but the flow will not always take place in obedience to simple pressure, and secretion may be excited for a limited time without any increase in the quantity of blood circulating in the gland.

The glands possess a peculiar excitability, which is manifested by their action in response to proper stimulation. During secretion, they generally receive an increased quantity of blood; but this is not indispensable, and

secretion may be excited without any modification of the circulation. This excitability will disappear when the artery supplying the part with blood is tied for a number of hours; and secretion can not then be excited even when the blood is again allowed to circulate. If the gland be not deprived of blood for too long a period, the excitability is soon restored; but it may be permanently destroyed by depriving the part of blood for a long time. These facts show a certain similarity between glandular and muscular excitability, although these properties are manifested in very different ways.

Mechanism of the Production of the Excretions.—Certain of the glands separate from the blood excrementitious matters which are of no use in the economy and are simply discharged from the body. These matters, which will be fully considered, both in connection with the fluids of which they form a part and under the head of nutrition, are entirely different in their mode of production from the characteristic constituents of the secretions. The formation of excrementitious matters takes place in the tissues and is connected with the general process of nutrition; and in the excreting glands there is simply a separation of products already formed. The action of the excreting organs is constant, and there is not that regular, periodic increase in the activity of the circulation which is observed in secreting organs; but it has been observed that the blood which comes from the kidneys is nearly as red as arterial blood, showing that the quantity of blood which these organs receive is greater than is required for mere nutrition, the excess, as in the secreting organs, furnishing the water and inorganic salts that are found in the urine. It has also been shown that when the secretion of urine is interrupted, the blood of the renal veins becomes dark like the blood in the general venous system.

Excretion is not, under all conditions, confined to the ordinary excretory organs. When their action is disturbed, certain of the secreting glands, as the follicles of the stomach and intestine, may for a time eliminate excrementitious matters; but this is abnormal and is analogous to the elimination of foreign matters from the blood by the glands.

Influence of the Composition and Pressure of the Blood upon Secretion.—Under normal conditions, the composition of the blood has little to do with the action of the secreting organs, as it simply furnishes the materials out of which the characteristic constituents of the secretions are formed; but when certain foreign matters are taken into the system or are injected into the blood-vessels, they are eliminated by the different glandular organs, both secretory and excretory. These organs seem to possess a power of selection in the elimination of different substances. Thus, sugar and potassium ferrocyanide are eliminated in greatest quantity by the kidneys; the salts of iron, by the kidneys and the gastric tubules; and iodine, by the salivary glands.

The discharge of secretions is almost always accompanied with an increase in the pressure of blood in the vessels supplying the glands; and it has been shown, on the other hand, that an exaggeration in the pressure, if the nerves of the glands do not exert an opposing influence, increases the

activity of secretion. The experiments of Bernard on this point show the influence of pressure upon the salivary and renal secretions, particularly the latter. After inserting a tube into one of the ureters of a living animal, so that the activity of the renal secretion could be accurately observed, the pressure in the renal artery was increased by tying the crural and the brachial. It was then found that the flow of urine was markedly increased. The pressure was afterward diminished by the abstraction of blood, which was followed by a corresponding diminution in the quantity of urine. The same phenomena were observed in analogous experiments upon the submaxillary secretion. These facts, however, do not demonstrate that secretion is due simply to an increase in the pressure of blood in the glands, although this undoubtedly exerts an important influence. It is necessary that every condition should be favorable to the act of secretion for this influence to be effective. Experiments have shown that pain may completely arrest the secretion of urine, operating undoubtedly through the nervous system. If the flow of urine be arrested by pain, an increase in the pressure of blood in the part fails to excite the secretion.

Influence of the Nervous System on Secretion.—The fact that the secretions are generally intermittent in their flow, being discharged in obedience to impressions which are made only when there is a demand for their physiological action, would naturally lead to the supposition that they are regulated, to a great extent, through the nervous system; particularly as it is now well established that the nerves are capable of modifying and regulating local circulations. The same facts apply, to a certain extent, to the excretions, which are also subject to considerable modifications.

It is evident that the nervous system has an important influence in the production of the secretions; and this is exerted largely through modifications in the activity of the circulation in the glands. This takes place in greatest part through vaso-motor nerves distributed to the muscular coats of the arteries of supply. When these nerves are divided, the circulation is increased here, as in other situations, and secretion is the result; and if the extremity of the nerve connected with the gland be stimulated, contraction of the vessels follows, and the secretion is arrested.

With regard to many of the glands, it has been shown that the influence of the vaso-motor nerves is antagonized by certain other nerves, which latter are called the motor nerves of the glands. The motor nerve of the submaxillary is the chorda tympani; and as both this nerve and the sympathetic, which latter contains the vaso-motor filaments, together with the excretory duct of the gland, can be easily exposed and operated upon in a living animal, many experiments have been performed upon this gland. When all these parts are exposed and a tube is introduced into the salivary duct, division of the sympathetic induces secretion, with an increase in the circulation in the gland, the blood in the vein becoming red. On the other hand, division of the chorda tympani, the sympathetic being intact, arrests secretion, and the venous blood coming from the gland becomes dark. If the nerves be now stimulated alternately, it will be found that stimulation of the sympathetic

produces contraction of the vessels of the gland and arrests secretion, while a stimulus applied to the chorda tympani increases the circulation and excites secretion (Bernard). Enough is known of the nervous influences which modify secretion, to admit of the inference that all the glands are supplied with nerves through which certain reflex phenomena, affecting their secretions, take place.

As reflex phenomena involve the action of nerve-centres, it becomes a question to determine whether any particular parts of the central nervous system preside over the various secretions. Experiments showing the existence of such centres are not wanting, but it will be more convenient to treat of these in connection with the physiology of the individual secretions.

Mental emotions, pain, and various conditions, the influence of which upon secretion has long been observed, operate through the nervous system. Many familiar instances of this kind are mentioned in works on physiology: such as the secretion of tears; arrest or production of the salivary secretions; sudden arrest of the secretion of the mammary glands, from violent emotion; increase in the secretion of the kidneys or of the intestinal tract, from fear or anxiety; with other examples which it is unnecessary to enumerate.

Paralytic Secretion by Glands.—The effects of destruction of the nerves distributed to the parenchyma of some of the glandular organs are very remarkable. Müller and Peipers destroyed the nerves distributed to the kidney and found that not only was the secretion arrested in the great majority of instances, but the renal tissue became softened and broken down. Bernard found that animals operated upon in this way died, and that the tissue of the kidney was broken down into a fetid, semi-fluid mass. After division of the nerves of the salivary glands, the organs became atrophied, but they did not undergo the peculiar putrefactive change which was observed in the kidneys. The same effect was produced when the nerves were paralyzed by introducing a few drops of a solution of curare at the origin of the little artery which is distributed to the submaxillary gland. It is possible that other glands have so-called motor-nerves, stimulation of which excites secretion, but such nerves have been most satisfactorily isolated and studied in connection with the salivary secretions. When the motor-nerves of the salivary glands are divided, in the course of a day or two, the secretion becomes abundant and watery, losing its normal characters. After about eight days, the secretion begins to diminish and the glands undergo atrophy. The increased secretion first observed has been called "paralytic." The watery secretion discharged from a permanent pancreatic fistula is thought to be paralytic; and certainly it does not present the physiological properties of normal pancreatic juice.

Anatomical Classification of Glandular Organs.—The organs which produce the different secretions are susceptible of a classification according to their anatomical peculiarities, which greatly facilitates their study. They may be divided as follows:

1. *Secreting membranes.*—Examples of these are the synovial membranes.

2. *Follicular glands.*—Examples of these are the simple mucous follicles, the follicles of Lieberkühn and the uterine follicles.

3. *Tubular glands.*—Examples of these are the ceruminous glands, the sudoriparous glands and the kidneys.

4. *Racemose glands, simple and compound.*—Examples of the simple racemose glands are the sebaceous and Meibomian glands, the tracheal glands and the glands of Brunner. Examples of the compound racemose glands are the salivary glands, the pancreas, the lachrymal glands and the mammary glands.

5. *Ductless, or blood-glands.*—Examples of these are the thymus, the thyroid, the suprarenal capsules and the spleen.

The liver is a glandular organ which can not be placed in any one of the above divisions. The lymphatic glands and other parts connected with the lymphatic and the lacteal system are not true glandular organs; and these are sometimes called conglobate glands.

The general structure of secreting membranes and of the follicular glands is very simple. The secreting parts consist of a membrane, generally homogeneous, covered on the secreting surface with epithelial cells. Beneath this membrane, ramify the blood-vessels which furnish materials for the secretions. The follicular glands are simply digital inversions of this structure, with rounded, blind extremities, the epithelium lining the follicles.

The tubular glands have essentially the same structure as the follicles, except that the tubes are long and are more or less convoluted. The more complex of these organs contain connective tissue, blood-vessels, nerves and lymphatics.

The compound racemose glands are composed of branching ducts, around the extremities of which are arranged collections of rounded follicles, like bunches of grapes. In addition to the epithelium, basement-membrane and blood-vessels, these organs contain connective tissue, lymphatics, non-striated muscular fibres, and nerves. In the simple racemose glands the excretory duct does not branch.

The ductless glands contain blood-vessels, lymphatics, nerves, sometimes non-striated muscular fibres, and a peculiar structure called pulp, which is composed of fluid with cells and occasionally with closed vesicles. These are sometimes called blood-glands, because they are supposed to modify the blood as it passes through their substance.

The testicles and the ovaries are not simply glandular organs; for in addition to the production of mucous or watery secretions, their principal office is to develop certain anatomical elements, the spermatozoids and the ova. The physiology of these organs will be considered in connection with the physiology of generation.

Classification of the Secreted Fluids.—The products of the various glands may be divided, according to their uses, into secretions proper and excretions. Some of the true secretions have certain mechanical uses, and some, like mucus, are thrown off in small quantity without being actually excrementitious; while others, like most of the digestive fluids, are produced at certain intervals and are taken up again by the blood.

TABULAR VIEW OF THE SECRETED FLUIDS.

Secretions Proper.

Synovia.	Saliva.
Mucus, in many varieties.	Gastric juice.
Sebaceous matter.	Pancreatic juice.
Cerumen, the waxy secretion of the external auditory meatus.	Secretion of the glands of Brunner.
	Secretion of the follicles of Lieberkühn.
Meibomian fluid.	Secretion of the follicles of the large intestine.
Milk and colostrum.	
Tears.	Bile (also an excretion).

Excretions.

Perspiration and the secretion of the axillary glands.	Urine.
	Bile (also a secretion).

Fluids containing Formed Anatomical Elements.

Seminal fluid, containing, in addition to spermatozoids, the secretions of a number of glandular structures.

Fluid of the Graafian follicles.

The serous cavities are now regarded as sacs connected with the lymphatic system, and the liquids of these cavities are not classed with the secretions.

Synovial Membranes and Synovia.—The true synovial membranes are found in the diarthrodial, or movable articulations; but in various parts of the body are found closed sacs, sheaths etc., which resemble synovial membranes both in structure and in their office. Every movable joint is enveloped in a capsule, which is closely adherent to the edges of the articular cartilage and is even reflected upon its surface for a short distance; but it is now the general opinion that the cartilage which incrusts the articulating extremities of the bones, though bathed in synovial fluid, is not itself covered by a distinct membrane.

The fibrous portion of the synovial membranes is dense and resisting. It is composed of ordinary fibrous tissue, with a few elastic fibres, and blood-vessels. The internal surface is lined with small cells of flattened endothelium with rather large, rounded nuclei. These cells exist in one, two, three or sometimes four layers.

In most of the joints, especially those of large size, as the knee and the hip, the synovial membrane is thrown into folds which contain adipose tissue. In nearly all the joints, the membrane presents fringed, vascular processes, called synovial fringes. These are composed of looped vessels of considerable size; and when injected they bear a certain resemblance to the choroid plexus. The edges of these fringes present a number of leaf-like, membranous appendages, of a great variety of curious forms. They are generally situated near the attachment of the membrane to the cartilage.

The arrangement of the synovial bursæ is very simple. Wherever a tendon plays over a bony surface, there is a delicate membrane in the form of