Histological Study on the Innervation of Rectum and Anus of Bat.

In 1940, SETO made a study on the innervation, especially, the sensoy innervation of the anus of human adults and embryos and published a very detailed report on the intraepithelial fibres he had found in its zonae columnalis and intermedia. More recently, IZUMI also studied the innervation of the anus in human adults from the histological angle, and succeeded not only in verifying the results obtained by SETO, but also in arriving at making minute observations on non-intraepithelial sensory terminations in the zonae columnaris and intermedia, as well as on those in the zona cutanea. Such studies have contributed much in shedding light on the sensory innervation of human anus. SHIMODA (1954) has studied the innervation, in particular, the sensory innervation of the caudal part of the rectum and the mucous parts of the anus of dog histologically, and obtained many an interesting finding.

I also felt my interest drawn to the subject, and approaching the matter from the stand-point of comparative anatomy, selected my materials from the sole order of flying mammals, the bats. The specimens including the rectum and the anus, were fixed in 10% neutral formol for a long period and cut into 40 µ transverse frozen sections. Staining these with the ideal SETO's impregnation, I obtained large series of tissue preparations which I subjected to minute microscopic examination. The findings obtained were compared with those observed in man (SETO and IZUMI) and in dog (SHIMODA) and the following results of interest were arrived at.

Individual Findings.

Nearly nothing has been written on the histological figure of bat rectum and anus. So, I will preface my detailed description of the innervation of these parts with a histological picture of them hereunder.

The rectal wall of bat is of course smaller than that of man or dog in size, but in structure, there is no essential difference between them. In the caudal part of the rectum, however, points of considerable difference from that in man in particular are noted, due to the appearance of a well-developed m. sphincter ani ext. and anal glands in the former.
The intestinal crypts in the mucous membrane of the rectum contain numerous goblet cells, its propria is full of free cells and many solitary lymph follicles are found in it here and there. These follicles often contain germ centers in them. The muscularis mucosae is divided into an inner circular and an outer longitudinal layers. The submucosa around them is composed of a loose connective tissue containing much fat tissue. The tunica muscularis also consists of an inner circular and an outer longitudinal layers, as in man and dog, but much thinner. The muscularis is lined by the adventitia of the connective tissue on all sides.

In the caudal part of the rectum, beside the above picture, we see the appearance of a muscle layer of striated fibres running circularly lining the outside of the adventitia. This muscle layer extends to the zona columnaris and thence to the caudal part of the zona intermedia, to form a strongly developed sphincter ani ext.

In the caudal part of the rectum near the anus, the mucous membrane shows no apparent change but the submucosa becomes thinner and poorer in fat tissue. The tunica muscularis becomes rather better developed than in the proximal part, and proctal or anal glands begin to be seen in the connective tissue of the adventitia, i.e., between the tunica muscularis and the sphincter ani ext. Very well-developed nerve plexus come also into appearance between these two muscle layers, especially, on the ventral and the lateral sides.

When the anus is reached, the single rowed columnar epithelium of the mucous membrane of the rectum suddenly changes into a stratified epithelium. The mucous membrane of the anus is composed of the two zones of columnaris and intermedia, as in man and dog, of which the former may be subdivided into the columnae rectales and the sinus rectales, the former covered by a non-cornified stratified flat and the latter by a stratified cylindrical epithelium. The zona intermedia is more extensive than in dog and is covered by a stratified flat epithelium with a horn-plate much thicker than that of the columnae.

The propria of the mucous membrane lining the anus is very narrow and contains lymphocyte gatherings here and there in its connective tissue. In the zona columnaris, nearly no papilla is formed from the propria into the epithelium, but in the zona intermedia, the papillar formation is rather notable. In this respect, a bat is more similar to man and unlike a dog. A muscularis mucosae, which is found in human but not in canine anus, is present in bat anus, formed by longitudinal smooth muscle fibres extending down from the rectum and reaching the mid-part of the zona intermedia.

The submucosa becomes in the anus even narrower than in the caudal part of the rectum and loses nearly all fat tissue contained. The blood
vessels and especially the veins, however, gain heavily in development, penetrating further into the propria and forming venous plexus there. The tunica muscularis extends from the rectum into this part and surrounds the submucosa here. Its inner circular layer extends as far as to the middle of the zona intermedia, but comes to a natural termination there, without forming a well-developed sphincter ani int. surrounding the zona intermedia, as in dog and man. The outer longitudinal layer of the muscularis is poorer in development than the inner. Owing to the formation of anal glands in it, it is seen loosely scattered in the cranial part of the anus, but more caudally, it becomes more and more ill-developed and almost completely disappears by the time we reach the middle of the zona intermedia.

As I have already touched on above, anal glands make their appearance in the caudal part of the rectum and rapidly gain in development anuswards. Due to their presence, the adventitia extends from the zona columnaris to the distal end of the zona intermedia in one broad gland layer. Some glands are formed further in the sphincter ani ext. and even in the surrounding area thereof. So, the development of anal glands in bat is very strong, as in dog (SHIMODA), but in human anus (SETO), such a good development of anal glands is not to be ever anticipated.

The gland bodies of anal glands in bat, as in dog, are seemingly of mucous nature, and in function, they probably serve in facilitating defecation. Their ducts often show ampullar dilatations in their courses and mostly open out into the sinus rectales, but sometimes also into the columnae rectales. Their epithelium is somewhat different from that in dog and man in that it is mostly double rowed cubic in nature. In some places, however, the epithelium is uneven-surfaced and shows a star formed cross-section, due to the alternating arrangement of tall strips of multiple columnar and low strips of single columnar epithelium, as was the case in man and dog.

In man and dog, MORGAGNI's canals and SETO's so called anal canals are conspicuously developed in the anal mucosa, but to my deep interest, I found such canals formed only very rarely in bat anus.

The histological picture of the zona cutanea ani of bat is conspicuous in its difference from that of the mucous membrane detailed in the above and presents many points of deep interest, but since a report on the innervation of this part will be deferred to a future occasion, a description of its histological picture will be also omitted here.

Most of the nerve fibres coming into the adventitia of the bat rectum consist in thin vegetative fibres, but thick myelinated sensory fibres are not rarely seen accompanying them. In the caudal part of rectum where m. sphincter ani ext. begins to appear, as stated above, nerve plexus
consisting of small nerve bundles containing numerous sensory fibres are found formed in adventitia lining the tunica muscularis (Fig. 1).

Fig. 1. Nerve plexus containing many thick sensory fibres formed in the adventitia around the tunica muscularis (m) in the boundary area between the rectum and the anus of a bat. g proctal gland; s m. sphincter ani ext. SETO’s impregnation. Photo ×150.

The vegetative fibres coming into the rectum first come into close contact with the AUERBACH’s plexus in the muscularis and then with the MEISSNER’s plexus in the submucosa. There are a number of ganglia in the AUERBACH’s plexus and numerous typical sympathetic nerve cells showing multipolarity are found therein, but these are hard to classify into the DOGIEL’s Types I and II. Many so-called apolar cells with very indistinct nerve processes are also present, especially, in MEISSNER’s plexus.

Plexuses of both these types are formed also in the rectal mucous membrane near the anus, but the nerve cells therein are very small in number and very poor in development. Plexuses are formed indeed in the mucous membrane of the anus itself too, but they are only extremely poor in development, and nearly no nerve cells are observable in them.

Beside those coming into contact with these plexuses, vegetative fibres in the mucous membrane of the rectum and the anus are also found running along the blood vessels, especially, arteries, forming perivascular plexus. The terminations of all the vegetative fibres are formed into STÖHR’s terminal reticula here as in other organs, and are particularly
well developed in the smooth muscle tissue and the gland tissue.

That there are myelinated fibres running into the caudal part of the rectum has been admitted by OTTAVIANI already (1940), though from unknown reason he called them parasympathetic sensory fibres. He gave also a description of their terminations, but there is some doubt about its accuracy, considering what I have observed, as stated below. SETO (1940) has remarked on the abundant existence of intraepithelial sensory fibres in the anus of man, but failed to detect the sensory fibres to be found in the inferior rectum. In his recent reinvestigation, however, he has discovered a small number of myelinated sensory fibres and their terminations in the mucous membrane of the lower part of the human rectum and he is expected to make a report on the matter in near future. SHIMODA (1954) has detected a comparatively large number of unbranched and branched sensory terminations in the mucous membrane of the lower rectum of dog and has reported on them in detail.

Thus, it has been established that sensory terminations are in formation in the caudal part of the rectum too. In my sections of bat rectum, I found sensory fibres running into the caudal part of it, certainly not in a large number at all, and to end in unbranched or simple branched terminations much simpler than those in man and even somewhat simpler than those in dog, in the propria of the mucous membrane there. These sensory fibres run through the tunica muscularis, then further through the submucosa and the muscularis mucosae into the propria, and losing their myelin sheaths, form their terminations in the circumference of the intestinal crypts. These terminations are rather widely diffused, so that they sometimes reach as far as the orifices of the crypts. The fibres are smooth-surfaced, show little change in size during their courses, which are generally wavy, and end sharply beneath the epithelium. None of them penetrates into the epithelial cells.

As an example of such terminations, an unbranched termination found in the propria between two crypts in the caudal area of the rectum is shown in Fig. 2. It shows that a thin fibre of unchanging size runs a wavy

![Fig. 2. An unbranched sensory termination ending sharply subepithelially around an intestinal crypt of rectum of a bat. Same staining. ×500, reduced to 1/2.](image)
course to end subepithelially in a sharp point. Fig. 3 shows unbranched terminations found in the propria mucosae in the caudal part of the rectum. Most of them are seen to run up to the openings of the crypts. The fibres are thin, smooth-surfaced and invariable in diameter, run wavy courses to diffuse over wide areas and end sharply. In short, my study has revealed the existence of sensory fibres and their terminations in the caudal part of the rectum of bat too.

As stated above, nerve plexus containing numerous sensory fibres is found in the adventitia between the m. sphincter ani ext. and the tunica muscularis in the caudal part of the rectum where this sphincter muscle comes into view. These sensory fibres reach this part penetrating through the m. sphincter ani ext. at its periphery. They extend from the caudal part of the rectum widely into the anus, suggesting the powerful sensory supply of these parts. Now, it is of high interest that in the connective tissue lining the m. sphincter ani ext. and in the adventitia around the tunica muscularis from the caudal part of the rectum to the cranial part of the anus are found a rather large number of PACINian bodies. Such bodies have not been found in dog anus (SHIMODA), but in man they were found in the connective tissue septa between the mm. sphincter ani int. and ext. and in the subcutis of the zona cutanea ani adjacent to them.

The PACINian bodies found in the caudal part of bat rectum, shown in Figs. 4 and 5, were found in formation in the adventitia lining the muscularis. They have only 8—15 each of connective tissue lamellae, which are arranged rather loosely. Their inner bulbs are narrow but usually contain large number of special nuclei. Generally, a single thick sensory fibre runs into the inner bulb at one of its poles, and usually without branching out, but in some cases sending out 2—3 rami, ends bluntly. Fig. 6 shows a small-sized PACINian body found among the
Histological Study on the Innervation of Rectum and Anus of Bat. 289

Fig. 4. Two PACINIan bodies found in the adventitia around the tunica muscularis of the caudal part of rectum of a bat. Details in the text. Same staining. ×400, reduced to 3/5.

Fig. 5. Ditto. Details in the text. Same staining. ×200, reduced to 3/5.

Fig. 6. PACINIan body found in the circumference of m. sphincter ani ext. around the zona intermedia ani of a bat. Details in the text. Same staining. ×200, reduced to 2/3.
plexus around the m. sphincter ani ext. In this, the comparatively few connective tissue lamellae are arranged disjointedly, so that the interlamellar spaces are very wide. The single thick sensory fibre running into the inner bulb containing many special nuclei ends in simple branched termination, which the ramus that runs straightly to the central portion grows gradually in size, to end in a club-form.

What particularly interested me in my study on the sensory supply of bat anus was that pseudo-gglomerular terminations were found here and there in the intermuscular connective tissue of the striated m. sphincter ani ext. As illustrated in Figs. 7 and 8, such a terminatin

![Fig. 7. An uncapsulated pseudo-gglomerular body found in the intermuscular connective tissue of m. sphincter ani ext. around the zona intermedia ani of a bat. Details in the text. Same staining. ×320, reduced to 5/6.](image)

![Fig. 8. A capsulated pseudo-gglomerular termination found in the same place as in Fig. 7. Details in the text. Same staining. ×200.](image)

mostly originates in 2—3 sensory stem fibres, which after branching out into many rami run looped courses, so that the termination as a whole
Histological Study on the Innervation of Rectum and Anus of Bat. 291

presents the appearance of forming a glomerulus. Upon closer microscopic examination, however, it is found that each stem fibre ends in forming a complex branched termination individually, the rami being never interconnected by anastomosis. That is to say, they do not form true glomerular formation in reality. Some of the terminations of this type have a very poorly formed connective tissue capsule around them but some are devoid of any capsule. Internally, they are filled with syncytial tissue containing many special nuclei. The morphological resemblance of these terminations to the genital nerve bodies Type II seems to suggest a similarity of functions between these two types of end bodies. Thus, very peculiar corpuscular terminations are found in the m. sphincter ani ext. of bat, and since no such formations have ever been found in the counterpart of either man or dog, so much so we may point out this finding as extremely noteworthy.

The sensory fibres coming into the mucous membrane of the anus of bat usually run through the muscularis and the submucosa accompanying vegetative fibres, and further penetrating through the muscularis mucosae, diffuse out into the propria. Such sensory fibres are supplied to the zona columnaris in a small quantity, but a very large number go into the zona intermedia. This is due to the fact that, whereas in the zona columnaris no papillar formation is observed, powerful papillae are found in formation in the zona intermedia.

In the zona columnaris, the terminations of the sensory fibres are formed subepithelially or around the ducts of the anal glands, take the form of unbranched or simple branched terminations. In the zona intermedia, the terminations are also of the unbranched and the simple branched types, but in quantity they widely surpass those in the zona columnaris, and the branched terminations are often rather more complex. Besides, in the zona intermedia, we find small-sized genital nerve bodies Type I, i.e., simple glomerular terminations in the propria, especially, in the papillae, and their number is not at all small.

Another fact for special mentioning is that intraepithelial fibres, so abundant in human and rather numerous in canine anus, are found only on very rare occasions in the mucous membrane of the anus of bat.

Upon studying the above findings obtained with specimens of bats on the innervation of the anus in comparison with those of man and dog, we may say that the branched terminations are simpler in structure and only few intraepithelial fibres are found in bat, and in these respects, the sensory innervation may be called to be poorer in development in bat, but on the other hand, in the number of types of sensory terminations and their distribution, the bat anus may be deemed to show greater similitude to that of man rather than to that of dog, for, though intru-
epithelial fibres are rather well developed, no genital nerve bodies or PACINian bodies have ever been found in dog anus.

A more concrete description of the sensory terminations found in the anal mucous membrane of bat follows.

The terminations formed beneath the epithelium or around the ducts of the anal glands in the zona columnaris, as shown in Figs. 9 and 10.

Fig. 9. A bifurcated termination (left) and an unbranched termination passing over into the epithelium as an intraepithelial fibre formed around a gland duct in the mucous membrane of zona columnalis ani of a bat. Details in the text. Same staining. ×400, reduced to 1/2.

Fig. 10. An unbranched and a bifurcated sensory terminations found around a gland duct in the mucous membrane of zona columnalis ani of a bat. Same staining. ×320, reduced to 2/3.

are very simple in structure and are represented by the unbranched and the simple branched types. Their terminal fibres are commonly thin and of unchanging size, and end in sharp points. From some of these, as shown in the upper half of Fig. 9, fibres very slightly penetrating into the epithelium and ending as intraepithelial fibres are derived. Thus, the sensory terminations found in the zona columnaris are few in number and very simple in structure.

We find unbranched and branched terminations formed also beneath the epithelium and around the gland ducts in the zona intermedia, as stated above, and most of the branched terminations here are formed
more complex than those in the zona columnaris, as shown in Figs. 11 and 12. Intraepithelial fibres, however, are very rare. In Fig. 12 are seen intraepithelial fibres consisting of extremely fine fibres found in the gland ducts.

According to the study of SHIMODA, simple branched sensory terminations are found in the parenchyma of the proctal glands and the muscularis in the anus of dog. Since no such existence of branched terminations has been demonstrated in the counterpart of man, it is well worthy of special mention. Now, in bat anus, I could find nothing in the tunica muscularis, but in the proctal glands, quite as SHIMODA has found in dog, sensory fibres and their terminations were found in conspicuous existence. These were in the form of branched terminations, as in the case of dog, but in structure, they were more complex than in dog, and their terminal rami were often found to run simple looped courses (Fig. 13).

A rather large number of small-sized genital nerve bodies are found in the mucous and the cutaneous zones of human anus (SETO and IZUMI), but none in dog anus (SHIMODA). Thus most researchers were led to predict that no genital nerve bodies would be found in the anus of any non-human animal, but my study surprisingly betrayed this prediction,
revealing the existence of genital nerve bodies, rather large in number though exceedingly small in individual size, in the anus of bat. From such findings, we may deduce that the sensory supply in anus is more similar in bat and man than in bat and dog.

In human anus, such genital nerve bodies are found chiefly in the zona intermedia and the zona cutanea and more rarely in the zona columnaris. In form, they belong to the bodies Type I in majority, only a very small number of Type II bodies being found.

The genital nerve bodies found in the anus of bat exist only in the zona intermedia and not in the zona columnaris. They are always of Type I of extremely small size, but in number, they are comparatively abundant, as, for example, you see in Fig. 14, 3 such bodies formed in the papillae appearing in one transverse section of zona intermedia. As shown in Fig. 15, such bodies are found not only in the papillae but also in the propria outside them. These bodies, as may be seen from the illustrations, are either only weakly capsulated or entirely uncapsulted, containing considerably

Fig. 13. A complex branched sensory termination formed in an anal gland in zona columnalis ani of a bat. Details in the text. Same staining. ×600, reduced to 1/2.

Fig. 14. 3 genital nerve bodies Type I found in a papilla of zona intermedia ani of a bat. Details in the text. Same staining. ×500, reduced to 2/5.
Numerous special nuclei in their inner bulbs of finely granulated syncytial tissue. 1-2 each sensory fibres run into the inner bulbs to form glomerular terminations there—showing the typical arrangement of genital nerve bodies Type I.

Summary.

In my specimens taken from bats, I found a very powerfully developed m. sphincter ani ext. of striated nature surrounding the adventitia lining the tunica muscularis that extends from the caudal part of the rectum to the zona intermedia ani, while the m. sphincter ani int. of smooth muscle was nearly absent.

The adventitia, in the area extending from the caudal part of the rectum to the distal edge of the zona intermedia ani, is filled by proctal glands, forming a gland layer. Some of these glands are found in the m. sphincter ext. itself and sometimes even in its periphery.

The histological picture of the mucous part of the anus of bat closely resembles that of man except that the anal canals are much worse developed in the former. That is, the zona columnaris is entirely of the same nature as in man and in the zona intermedia a marked papillary formation not to be found in a dog anus is observed. The muscularis mucosae running longitudinally along the outside of the propria is also well formed—a formation not to be seen in dog.

The majority of the incoming nerve fibres supplied to the rectum consist in fine vegetative fibres, but a small number of sensory fibres are found among them. These vegetative fibres come into close relation with the AUERBACH’s and the MEISSNER’s plexus, in which are found ganglia containing many sympathetic nerve cells with conspicuous nerve
processes as well as some apparently apolar cells. These plexuses are found also in formation in the portion stretching from the caudal end of the rectum to the anus, but their development falls off markedly, and those in the anus contain nearly no nerve cells. Besides, some vegetative fibres originate in the perivascular plexus here, and all these vegetative fibres always end in STÖHR's terminal reticula here too.

Plexus containing many sensory fibres are seen formed between the m. sphincter ani ext. and the tunica muscularis. These sensory fibres have come through the sphincter muscle from its outside before reaching these plexus, and thence run partly to the caudal part of the rectum, but mostly to the mucous part of the anus.

The sensory fibres running to the caudal part of the rectum go into the propria to end in unbranched and simple branched terminations around the intestinal crypts. The terminal fibres are thin, run wavy courses and mostly end subepithelially in sharp points.

In the space extending from the caudal part of the rectum to the cranial part of the anus of bat, we find a good number of small-sized PACINian bodies around the m. sphincter ani ext. and in the adventitia lining the tunica muscularis. These bodies are formed of loosely arranged lamellae of a small number and inner bulbs containing numerous special nuclei, into which run single sensory fibres and end bluntly.

Pseudo-glomerular terminations are found in the intermuscular connective tissue of the m. sphincter ani ext. here and there. In such a termination, sometimes thinly capsulated and sometimes not, 2—3 sensory fibres run into the inner bulb containing many special nuclei and on ramification, pass over into seemingly glomerular termination. Between the rami, however, no anastomosis is found. In short, the terminations of this type are morphologically similar to the genital nerve bodies Type II and probably have the same function as these.

The sensory fibres coming into the mucous membrane of the bat anus run through the muscularis mucosae and diffuse into the propria. Such fibres are rather poor in number in the zona columnaris, but are abundantly found in the zona intermedia, where papillae are in rich formation.

In the zona columnaris, the sensory terminations are formed subepithelially and around the gland ducts in the types of unbranched and simple branched endings. In the zona intermedia also the types are the same, but here the number and the individual size and structure of the terminations are far superior to those in the above. Besides, in this part, a rather large number of genital nerve bodies Type I, though small in size, are found, chiefly in the papillae. In either of these zones, however, intraepithelial fibres are found only in a very limited number.
Branched terminations are also found in the proctal glands of bat. Their terminal branches often run simple looped courses.

In short, the above findings concerning the sensory innervation of the rectum and the anus of bat show far greater similarity to that of man than to that of dog.

References.