OBSERVATIONS ON THE SUCCUS ENTERICUS.*

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The following experiments were performed as controls on tests in nephritis for the increased elimination of nitrogen by the intestines. They are reported because they demonstrate facts concerning the origin of fecal nitrogen, which although already known, are not universally appreciated, and because they emphasize, furthermore, the possible importance of intermediate cycles of metabolism.

Animals.—In these experiments, dogs which were kept in metabolism cages and fed on the required diet were used. Only those dogs were retained which took kindly to the cage life and food, and which showed no pathological amounts of albumin in the urine.

Operation.—A resection of a portion (ten to twenty inches) of the lower ileum was made. The severed gut was reunited. The resected gut, with its mesentery and blood and nerve supply intact, was closed by suture at both ends. The distal end was sewed to the abdominal wall. A few days later, after adhesions had formed, an opening was made into the isolated loop, a bronze canula was inserted and held in place by a silver wire purse string suture, forming in this way a Thiry fistula.[1] The fistula was dressed once or twice a day with absorbent cotton and vaseline, the cotton being held in place by a specially devised canvas jacket. To prevent contamination of the abdominal wound with urine, bitches were selected. These operations were performed by Dr. Henry Janeway, of the Research Laboratory of the Department of Surgery, College of Physicians and Surgeons.

As soon as possible the dogs were put on a constant, weighed

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[1] Thiry, *Sitzungsber. d k Akad d. Wissensch., Math.-Wissensch Kl.*, Vienna, 1864, Abt iii, l, 77.

TABLE I.

Complete Protocols.

	Date	Volume of urine in 24 hrs. in c.c.	Weight of dog, in kilos.	Secretion from Thiry fistula.					Nitrogen for 24 hours in gms.						Ammonia N of succus entericus in per cent. of total N of succus entericus.	Total succus entericus for 24 hours in c.c.
				Hours after feeding before collection was begun.	Period of collection, in hours.	Secretion in c.c. for period.	Calculated for 24 hrs.		Intake.	Urine.	Feces.	Succus entericus.		Excess of N of retained succus entericus over fecal N.		
							Secretion in c.c.	Amount N in gms.				Total.	Total minus loss through fistula.			
Dog 1.	1909															
	Dec. 22	435	13.93	Right after	6	86.00	344.0		8.81		.80*					2511
	24				6	90.00	360.0	.50	"		.80	3.68	3.18	+2.38		2628
	28				6	115.00	460.0	.49	"		.80	3.56	3.07	+2.27		3358
	29				6	42.00	168.0	.30	"		.80	2.19	1.89	+1.09		1226
Dog 2.	1909															
	Sept. 21		11.62	Right after	5	11.75	56.4	.30	6.96		.60*	2.57	2.27	+1.67		482
	29				2.75	8.00	65.2	.24	"		.60	2.05	1,81	+1.21	1.55	557
	Oct. 6	230			6	13.00	52.0	35	"		.60	2.99	2.64	+2.04	3.28	445
	26	285			6	7.50	30.0	.22	"	5.02	.60	1.98	1.76	+1.16		257
	28	225	11.63		6	7.00	28.0	.26	"	5 02	.60	2.22	1.96	+1.36	1.82	239
Dog 3.	1910															
	Feb. 9		7.00	0	6	15.00	60.0	.22	7.35	5.28	.63	1.08	.86	+ .23		300
	10	131		0	6	14.50	58.0	.34	"	5.28	.63	1.69	1.35	+ .72		290
	12	131		23	6	16.25	65 0	.32	"	5.28	.63	1.58	1.26	+ .63		325
	13	131		18.5	3	9.00	72.0	.42	"	5.28	.63	2.09	1.67	+1.03		360
	14	131		20	4	14.00	84.0	.46	"	5.28	.63	2.32	1.86	+1.23		420
				2	3	8.00	64.0	.23	"			1.17	.94	+ .31		320
	15	131		5	2.5	7.00	67.2		"	5.28	.63					336
	16	131		4	3	6.25	50.0	.17	"	5.28	.63	.84	.67	+ .04		250
	17	152		1	5.75	7.00	29.3	.13	"	5.81	.73	.66	.53	− .20		146
	18	152		0	3	3.50	28.0	.13	"	5.81	.73	.63	.50	− .23		140
	19	152		18	3	20.50	164.0	.86	"	5.81	.73	4.29	3.43	+2.70		820
				2	3	3.50	28.0	.14				.68	.54	− .19		140
	21	152		16	3	7.00	56.0	.52	"	5.81	.73	2.61	2.09	+1.36		280
				0	4.5	5.00	26.6	.11				.56	.45	− .28		133
	22	152		22	3	4.50	36.0	.42	"	5.81	.73	2.11	1.69	+ .96		180
				2	3	2.25	18.0	.11				.57	.46	− .16		90
Dog 4.	1910															
	July 30	122	7.13	19	4	5.00	30.0	.30	4.33	3.44	.31	2.47	2.17	+1.86		243
	31	122		21	4	5.00	30.0	.27	"	3.44	.31	2.17	1.90	+1.59		243
	Aug. 1	122		19	4	5.00	30.0	.29	"	3.44	.31	2.39	2.10	+1.79		243
	2	122		20	4	5.00	30.0	.34	"	3.44	.31	2.78	2.44	+2.13		243
	3	122		19	4	8.00	48.0	.56	"	3.44	.31	4.53	3.97	+3.66		389
	4	122		19	4	4.00	24.0	.31	"	3.44	.31	2.53	2.22	+1.91		195
				1	4	10.00	60.0	.13				1.07	.94	+ .63		486
	5	214		19	4	4.00	24.0	.08	"	2.93	.31	.67	.59	+ .28		195
				1	4	8.00	48.0	.22				1.79	1.57	+1.26		389
	6	214		19	4	3.00	18.0	.08	"	2.93	.31	.62	.54	+ .23		146
				1	4	5.00	30.0	.18				1.49	1.31	+1.00		243
	7	214		1	4	10.00	60.0	.23	"	2.93	.31	1.88	1.65	+1.34		486
	8	214		21	4	4.00	24.0	.15	"	2.93	.31	1.18	1.03	+ .72		195
				1	4	3.50	21.0	.10				.82	.72	+ .41		170

* Value estimated, not determined.

diet of hashed lean meat, lard, cracker meal, bone ash, and water. The animals throve, ate heartily, and seemed none the worse for the operation. About six weeks after the insertion of the canula, there were, in one instance, signs of pressure necrosis about the canula, necessitating the discontinuance of the experiment.

In order to collect the succus entericus from the intestinal loop, the dog was suspended from a frame by means of a canvas sling in which were holes for the legs and a hole corresponding with the site of the fistula; a small funnel leading into a graduate was fastened beneath the fistulous opening and the succus entericus was collected for the period. The dogs were kept in this sling for as long as six hours without apparent discomfort, and usually slept during a part of the time.

The nitrogen was determined by the Kjeldahl method, and the ammonia according to Steel and Gies's modification of Folin's method.[2] The nitrogen content and the quantity of the succus entericus secreted by the entire small intestine of the dog for twenty-four hours were estimated by multiplying the amounts obtained during the given period by two factors: (1) by the figure necessary to bring the number of hours up to twenty-four, and (2) by the figure necessary to compensate for the length of the dog's small intestine, as determined at autopsy.

Summarizing the protocols which are given in detail in Table I, on page 320, the following figures are obtained.

TABLE II.

Averages of Observations.

Dog.	Number of observations.	Weight of dog in kilos.	N intake in gms.	N of succus entericus calculated for 24 hours in gms.	N of feces in gms.	N of urine in gms.	The per cent. the N in the succus entericus bears to the N in the			Amount of succus entericus in 24 hours, in c.c.
							Intake.	Feces.	Urine.	
1	3	13.9	8.81	3.14	0.80*	8.00*	35	393	39	2431
2	5	11.7	6.96	2.36	0.60*	5.02	34	393	47	398
3	15	7.0	7.35	1.53	0.68	5.60	21	225	27	282
4	14	7.13	4 33	1.88	0.31	3.18	43	607	59	276

* Value estimated, not determined.

[2] Steel and Gies, *Jour. Biol. Chem.*, 1908, v, 71; Steel, *idem*, 1910, viii, 365.

At the first glance the remarkable fact becomes apparent that the nitrogen secreted by the small intestines exceeds considerably that excreted in the feces. It is probable, however, that the nitrogen content of the succus entericus as given here is too small rather than too large, for the following reasons:

1. The secretion collected from a Thiry fistula does not represent the full quantity poured forth by the intestinal mucous membrane, since some of the material is reabsorbed before collection.[3] This is well shown in dog 1. In this animal the opening of the fistula was so wide that it was impossible to keep the canula in position, and after a week's observation prolapse of the loop occurred through the large stoma. This wide opening, however, evidently permitted a freer flow of juice with less reabsorption, and accounts for the greater amount of fluid as compared with those from the other cases.

2. After a lapse of time the Thiry fistula secretes less actively than at first.[4] This is apparent in the complete protocols, where the later periods show diminished secretion. The table of averages includes the late as well as the earlier observations.

3. The amount of succus entericus secreted in the upper portions of the small intestine is greater than that produced in the regions approximating the ileocecal valve.[5] In the present series of operations, the loops were taken from the lower ileum and may be considered to have yielded the minimal quantity of succus entericus obtainable from an equivalent section of the small intestine. Thus the excess of the nitrogen secreted by the small intestine over that excreted in the feces for any given period is very probably even greater than is indicated in the charts.

It has been known for some time that the gastro-intestinal tract secretes nitrogen, which may make up the whole or a great part of the nitrogen contained in the feces. Hermann[6] and F. Voit[7] paved the way for the recognition of this fact by very suggestive experi-

[3] Frouin, *Compt. rend. Soc. de biol.*, 1905, lviii, 653. O Cohnheim, Nagel's Handbuch der Physiologie des Menschen, Braunschweig, 1907, ii, 593.

[4] Frouin, *Compt. rend. Soc. de biol.*, 1904, lvi, 461.

[5] Frouin, *Compt. rend. Soc. de biol.*, 1904, lvi, 461.

[6] Hermann, *Arch. f. d. ges. Physiol.*, 1890, xlvi, 93.

[7] F. Voit, *Ztschr. f. Biol.*, 1892, xxix, 325.

ments. Both of these observers worked with dogs in which loops of small intestine had been isolated and sewed end to end to form a ring (Hermann), or closed at either extremity (Voit), and subsequently dropped back into the peritoneal cavity. At the end of several weeks such loops contained a feces-like material, identical in appearance with the feces of starvation and those of a meat diet. Voit on further investigation found that, per square meter of intestinal surface, this retained secretion, on the one hand, and the feces, on the other, had a like weight and nitrogen content. This indicated that there was no food residue in the intestine after a meat diet; that the salivary, gastric, biliary, and pancreatic secretions were completely reabsorbed; and that the feces were derived, under these dietary conditions, solely from the secretion of the small intestine. These deductions have been corroborated by numerous experiments. They are also borne out by the observations presented in this paper. The succus entericus contains waste products, which, on a readily absorbable diet furnish the nitrogen of the feces, equal in amount to about 10 per cent. of the ingested nitrogen. The succus entericus may contain other substances as well, since Voit has shown that the bulk of the feces may very readily be accounted for by the succus entericus.

On glancing at the figures in table II it is seen that the nitrogen secreted by the small intestine varies between 225 and 607 per cent. of that found in the feces. The greater portion of it is, therefore, reabsorbed. The succus entericus contains nitrogen to the amount of 21 to 43 per cent. of the nitrogen intake. Averaging these figures (see table II), it is found that the nitrogen contained in the juice of the small intestine is equal to 34 per cent. of the total nitrogen intake; deducting the 10 per cent. lost in the feces (somewhat less in these cases), it is clear that the remaining 24 per cent. is reabsorbed. Adding to this amount the nitrogen of the bile, pancreatic juice, gastric juice, and saliva, it is evident that nitrogen equal to more than one quarter of the food nitrogen passes into the physiological exterior of the body—the alimentary canal—to be subsequently reabsorbed. In view of this fact, it seems probable that the intestine has, in addition to its excretory function, resulting in the production of the feces, and its digestive function, resulting

in the absorption of the food, a third function, *i. e.*, that of forming a link in the "circulation" of various products, such as the nitrogen or the bile pigments.[8] That this reabsorption is of great metabolic importance is indicated by the amount of nitrogen involved, this being the equivalent, on a mixed diet, of 25 per cent. of the nitrogen intake.

Previous observations and experiments have shown that a part at least of the fecal nitrogen is an excretion, since nitrogen occurs in the feces of starvation. In three instances of experimental starvation in man, the fecal nitrogen amounted to 0.32, 0.11, and 0.2 gram.[9]

In dogs there is a similar excretion in starvation.[10] The passage of food through the alimentary tract increases the amount of fecal nitrogen, regardless of the nitrogen content of the food. This is another indication of the excretory power of the intestines, which is readily appreciated when the amount of nitrogen in the feces on a nitrogen-free diet is compared with that in starvation. Thus in man, on a nitrogen-free diet, 0.54, 0.87, and 0.78 gram of nitrogen[11] were found daily in the feces, these amounts showing a considerable increase over the starvation figures quoted above. In dogs similar conditions have been observed. A 17.5 kilogram dog, whose feces during starvation contained daily 0.14 gram of nitrogen, produced 0.24 and 0.57 gram when taking 132 and 305 grams of nitrogen-free food.[12]

Thus it is seen that the nitrogen in the feces is, to a very great extent, a secretion of the alimentary tract. On the other hand, this is not true under all conditions. The notable exception is found in cases of vegetarian diet which results in a large amount of unabsorbed food residue. On a mixed vegetarian diet, nitrogen equal to 34 per cent. of the nitrogen intake was found in the feces;[13] in a similar case, during two weeks' observation, 42 per cent. was

[8] Howell. A Textbook of Physiology, Philadelphia, 1909, p. 785.

[9] F. Müller, *Arch. f. path. Anat.*, 1893, cxxxi, Suppl., 18, 67; *Berl. klin. Wchnschr.*, 1887, xxiv, 433.

[10] F. Müller, *Ztschr. f. Biol.*, 1884, xx, 327.

[11] Tsuboi, *Ztschr. f. Biol.*, 1897, xxxv, 68.

[12] Rieder, *Ztschr. f. Biol.*, 1884, xx, 378.

[13] Rumpf and Schumm, *Ztschr. f. Biol.*, 1900, xxxix, 153.

found;[14] and on a diet of rye bread, 40 per cent.[15] Many other results might be cited, showing how some forms of food leave large fecal residues and how their remnants may be readily identified in the feces. On an average diet, however, very little of the fecal mass can be attributed directly to the food. Thus the feces from an individual on a meat or sugar diet have approximately the same appearance as those of starvation, both being a pitchy black mass in which microscopical examination shows no food residues.

The fecal nitrogen does not increase in direct proportion to the amount of nitrogen ingested in the meat. Thus in dogs, after successive feedings of 500, 1,000, 1,500, 2,000, 2,500 grams of meat, the fecal nitrogen instead of increasing in the proportions 1 : 2 : 3 : 4 : 5, as we should expect if there were an unabsorbed residue, shows an increase according to the proportions 1 : 1.8 : 2.0 : 2.2 : 3.0.[16]

Another example of the independence of fecal nitrogen, on a readily absorbable diet, is seen in the case of a nursing infant which in two different three day periods received respectively 8.06 and 3.30 grams of nitrogen in its milk. The fecal nitrogen for the former period was 0.62 gram, for the latter 0.61 gram.[17] On two diets containing respectively 0.31 and 0.22 grams of nitrogen, an individual excreted 1.52 and 1.50 grams of fecal nitrogen.[18] Many similar illustrations of the importance of intestinal secretion as a factor in the origin of the feces might be cited. Wherever careful work has been done, the same facts are indicated.

Thus the evidence of the experiments here reported toward a proof of nitrogenous secretion on the part of the small intestine is seen to be wholly in accord with the results of earlier experiments. F. Voit, in the report referred to above, assumed that a reabsorption of bile and pancreatic juice occurs. These two secretions contain a considerable amount of nitrogen. In dogs the biliary nitrogen amounts to 0.5 to 2.5 per cent.[19] of the urinary nitrogen; according to another observer, it equals 6.0 to 6.5 per

[14] C. Voit, *Ztschr. f. Biol.*, 1889, xxv, 232.
[15] Rubner, *Ztschr. f. Biol.*, 1901, xlii, 261.
[16] F. Muller, *Ztschr. f. Biol.*, 1884, xx, 327.
[17] Orgler, *Monatschr. f. Kinderheilk.*, 1908, vii, 135.
[18] Renvall, *Skandinav. Arch. f. Physiol.*, 1904, xvi, 94.
[19] C. Voit, *Ztschr. f. Biol.*, 1894, xxx, 523.

cent.[20] In man the pancreatic juice contains as much as 0.5 gram of nitrogen per day.[21] If these materials are reabsorbed, as Voit claims, we may likewise assume that a reabsorption of the nitrogen of the succus entericus takes place.

It is not intended to give the impression that the nitrogen found in the succus entericus on a mixed diet is constantly 35 per cent. of the nitrogen intake. The methods here employed of collecting the intestinal secretions and making calculations therefrom for twenty-four hour periods for the whole animal, are open to some obvious objections. They are, however, the best available at the present time, and probably yield results which at least approximate the truth. Therefore, emphasis is laid on the fact that considerable nitrogen is reabsorbed from the intestine, and the percentage figures, in spite of their limitations, give some conception of the amounts of nitrogen involved.

The quantities of the succus entericus, as calculated for these animals, are considerable, being comparable to the volume of the urine. The figures given above for the estimated amounts are probably too small rather than too large. The volume of the succus entericus obtained from dog 1 probably gives a truer indication of the average total quantity than that taken from the other animals. In this instance the succus entericus, calculated for twenty-four hours, was equivalent to about one-fifth of the animal's body weight. That all of the secretions of the gastro-intestinal tract are very copious is a well-known physiological fact. It has been claimed that the combined secretions for twenty-four hours are more than equal in volume to the individual's blood serum,[22] thus pointing to a general extensive reabsorption.

The amount of secretion from the small intestine was found to some extent to be dependent upon the food intake. In dog 3 the volume was distinctly less shortly after a meal than when the collections were made some hours later. At times dog 4 showed the same condition as dog 3; in other instances, however, these differ-

[20] Spiro, *Arch. f. Anat. u. Physiol., Physiol. Abt.*, 1880, Suppl., 50.

[21] Glässner, *Ztschr. f. physiol. Chem.*, 1903, xl, 465; Schumm, *idem*, 1902, xxxvi, 292.

[22] O. Cohnheim, Nagel's Handbuch der Physiologie des Menschen, Braunschweig, 1907, ii, 557.

ences in quantity were reversed, and the periods immediately following food intake showed a larger amount of intestinal juice than those observed several hours later. The experiments point, in general, to a more active secretion on the part of the small intestine at the time that it might be expected to contain food, but the results are not sufficiently uniform to warrant insistence on this point.

In some experiments previously reported, it was claimed that the succus entericus was absent at certain times. In the present series of experiments this phenomenon was never observed. Since the distal portion of the intestinal loop was sewed into the abdominal wall, normal peristalsis was sufficient to expel the contained secretions, especially as the fistula was constantly kept patulous by the inserted canula. A neglect of these two factors might result in reabsorption of succus entericus and thus lead to the assumption that no secretion had taken place during a given period.

Only one attempt was made to obtain an analysis of the succus entericus. In three observations on dog 2 the percentage of ammonia nitrogen of the total nitrogen of the succus entericus varied from 1.55 to 3.28.

SUMMARY.

Nitrogen equivalent to about 35 per cent. of the nitrogen intake, though not necessarily derived directly from it, is daily secreted in the succus entericus in dogs on a mixed diet; about 10 per cent. is excreted in the feces, and about 25 per cent. is reabsorbed. The amount of reabsorbed nitrogen-containing material is considerably larger if the bile and pancreatic secretion are included.

The metabolic significance of this reabsorption can only be surmised. That it is probably of great importance is indicated by the fact that in the experiments here recorded the amount of nitrogen reabsorbed equaled approximately 25 per cent. of the nitrogen intake.