THE ACID-BASE COMPOSITION OF GASTRIC SECRETIONS.*

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Excepting as concerns hydrochloric acid, very few measurements of inorganic factors in the composition of gastric secretions have been published. Gamble and Ross (1) found sodium in vomited stomach secretions from a dog following experimental obstruction of the pylorus to the extent of quite one-half the equivalence of the chloride ion present. In a study of the effects of pyloric obstruction in rabbits, Gamble and McIver (2) showed that more than twice the entire plasma content of fixed base was lost into the stomach during the survival period. They regard this extensive withdrawal of fixed base as the cause of the accompanying rapid dehydration of the blood and interstitial body fluids. The data to be here presented were obtained with the purpose of learning whether or not fixed base is contained in stomach secretions, produced under approximately normal conditions, to an extent which would explain a large loss of base in the presence of circumstances preventing reabsorption of these secretions.

So far as we are aware, the only satisfactorily complete analyses of gastric juice are those of Rosemann (3). The material studied was "hunger juice" obtained from dogs by the sham feeding method of Pawlow. An appreciable amount of fixed base was found. The secretion of an alkaline juice by the mucosa of the pyloric antrum was noted by early workers and has recently been confirmed by Ivy and Ayama (4), and by Limb and Dott (5). The production of an alkaline mucous secretion is of course not confined to the pyloric region. Beaumont (6) noted that the inner coat of the stomach of his amiable *voyageur* was "constantly covered with a very thin, transparent, viscid mucus, lining the whole interior of the organ," and that "on applying the tongue to the mucous coat of the stomach, in its empty, unirritated state, no acid taste can be perceived."

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The animals used in our experiments were cats. The secretions analyzed were obtained from isolated pouches constructed in the fundic and pyloric regions of the stomach. The animals were operated under ether anesthesia with aseptic technic. During the recovery period, they were cared for in warm, well bedded cages. The pouches were provided with external fistulæ and were found to retain secretions entering them until removed by catheterization. The greater part of the material studied was obtained from an animal in which a pouch of the Heidenhain type had been established in the fundus of the stomach. Samples of juice were taken from this pouch over a period of 2 months, the animal remaining in an excellent state of nutrition and apparently suffering no discomfort.

Chemical Methods Used.

Total fixed base, Fiske (8); *chlorides,* Fiske (9); *inorganic phosphate,* Fiske and Subbarow (10); *potassium and calcium,* Tisdall and Kramer (11). *Sodium* was taken as total fixed base—(potassium plus calcium). The magnesium factor in total fixed base, which according to the measurements of Rosemann (3) is relatively minute, was disregarded. *Nitrogen* was determined by the micro Kjeldahl method of Folin and Denis (12).

The secretions obtained from the pouch during active digestion of food in the stomach were colorless and water-clear. It was found that if the pouch was well drained of these secretions no material could be obtained from it by subsequent catheterization after intervals of fasting. Evidently the secretion of the resting mucosa did not accumulate sufficiently to permit obtaining a sample for analysis. The existence of this secretion could however be made clearly evident by allowing juice produced after ingestion of food to remain in the pouch past the period of active digestion in the stomach. This juice, on being withdrawn, instead of being water-clear always showed a faint but definite white cloudiness, and on analysis a relatively extensive gain in organic material and in fixed base was found. In Table I are given the results of analyses of three large specimens of secretions taken from the pouch at differing intervals after ingestion of food. Each specimen was composed of a number of separate collections of juice. The table also contains Rosemann's data from pooled collections of "hunger juice" from a dog. As may be seen in the table, the inorganic factors in the juice collected during active digestion of food in the stomach (Specimen 1) correspond closely with the values found by Rosemann for "hunger juice" in the dog. In the specimens composed of juice allowed to remain in the pouch after completion of active gastric function (Specimens 2 and 3) relatively much larger amounts of organic material and of fixed base were measured. This finding together with the change in the physical

TABLE I.

Data from Secretions Taken from Isolated Pouch in Gastric Fundus of Cat and Rosemann's Data for "Hunger Juice" from a Dog.

		Specimen 1 2–4 hrs. after food. Water-clear	Specimen 2 8–12 hrs. after food. Faint milkiness	Specimen 3 18 hrs. after food. Moderate milkiness	Hunger juice from dog. Rosemann
		gm. per 100 cc.	*gm. per 100 cc.*	*gm. per 100 cc.*	*gm. per 100 cc.*
Dried substance		0.169	0.282	0.649	0.387
Ash		0.121	0.179	0.384	0.131
Organic substance		0.048	0.103	0.265	0.256
Nitrogen		0.010	0.018	0.041	
Protein (N × 6.25)		0.063	0.113	0.256	
Inorganic substances	Cl	0.588	0.574	0.552	0.630
	P	0.00016	0.00019	0.00055	0.00027
	Na	0.028	0.045	0.128	0.022
	K	0.045	0.053	0.053	0.037
	Ca	0.0106	0.0057	0.0041	0.00015
	Total	0.672	0.678	0.781	0.689
Organic + inorganic substances		0.720	0.781	1.003	0.945

appearance of the specimens from water-clear to "faint" and "moderate" milkiness would seem definitely to indicate admixture of the mucous secretion of the resting mucosa with the acid juice from the fundic glands. The increase of fixed base, it may be noted, is composed of sodium, the values for potassium remaining approximately stationary.

In Table II are given measurements of chloride ion, of fixed base and in a few instances of potassium obtained from single collections of juice from the pouch. The first two groups of measurements are

TABLE II.

Data from Secretions Taken from Fundic Pouch of the Heidenhain Type.

Specimen No.	Food	Interval after food	Volume	Cl′	B·	H·	K·
		hrs.	*cc.*	*cc. 0.1 N per 100 cc.*	*cc. 0.1 N per 100 cc.*	*cc. 0.1 N per 100 cc.*	*cc. 0.1 N per 100 cc.*
1	Meat	1	2	160	22	138	
2	"	2	7	166	17	149	
3	"	3	4	167	24	143	
4	"	6	8	168	44	124	
5	Fish	1	17	177	49	128	
6	"	2	9	156	31	125	12.5
7	"	2	14	169	75	94	
8	"	4	3	157	39	118	
9	"	2	9	171	32	139	
10	"	2	11	169	30	139	11.7
11	"	2	21	173	24	149	11.8
12	"	4	3	152	35	117	11.6
13	Milk	4	28	174	46	128	
14	Bread and milk	2	10	156	41	115	
15	" " "	3	18	176	25	151	
Average		**3.7**	**11**	**166**	**36**	**140**	**12**
16	Cream	1	3	161	49	112	
17	"	2	2	160	42	118	
18	"	3	2	162	38	124	
19	Cereal and cream	6	10	160	72	88	14.6
20	" " "	6	14	162	77	85	10.4
21	" " "	8	8	157	83	74	9.6
22	" " "	6	7	151	80	70	8.9
23	" " "	2	8	167	71	96	10.9
24	Bread and water	2	4	165	65	100	
25	" " "	4	3	186	55	131	
26	" " "	2	6	162	48	114	
Average		**3.8**	**6**	**163**	**62**	**101**	**11**
27	Morning specimens	18	45	160	53	107	
28		18	24	155	72	83	12.1
29		18	13	158	89	69	
30		18	8	157	139	18	15.6
31		18	5	164	142	22	11.8
Average		**18**	**19**	**159**	**99**	**60**	**13**

from samples of juice taken from the pouch within 6 hours after ingestion of food, with the single exception that Specimen 21, was collected 8 hours after feeding. The food given the animal before collecting the samples in the first group was meat, fish or milk. These were the foods given while collecting the pooled material from which the measurements in Table I were obtained. The second group of data in Table II are from samples of juice produced following ingestion of food low in protein and without appreciable amounts of buffer salts. From the measurements of phosphate and the estimations of protein given in Table I it is evident that these anions are, as compared with chloride, present in negligible amounts. The concentration found for chloride ion minus that for fixed base will therefore closely describe the concentration of hydrogen ions. This datum, taken as Cl'-$B^{\cdot}$, is also given in the table. The third group of measurements in Table II are from samples of juice taken from the pouch in the morning before feeding, different amounts of food having been given the evening before.

The outstanding finding from these data is a wide range of fixed base concentration in the presence of a fairly stationary concentration for chloride ion. It is thus evident that variation in acidity of the juice as measured by concentration of hydrogen ions is referable to change in fixed base. The data in the first and second sections of the table are from samples taken from the pouch during active digestion of food in the stomach. The considerable difference in the average values for fixed base for the two groups suggests an adjustment of this factor according to the character of the ingested food. The juice produced during digestion of acid-binding foods contains appropriately less of fixed base than is found when foods low in protein and buffer salts are given. It must be noted however that the individual measurements are in both groups often wide of the average value. If the fixed base in the juice is wholly or partly derived from the mucous secretion of the fundus, the collection interval used and the volume of the specimen obtained are probably factors in the extent to which fixed base is added to the juice from the fundic glands. As may be seen in the table, the intervals allowed for secretion of the specimen following ingestion of food were not uniform and also there was an unaccountable variation in the amounts of juice produced. No regularity of relationship between these factors and the concentrations of fixed base found, can be made out from these data. By prolonging the collection period past the period of active digestion there occurs, as has already been noted, an increase of fixed base concentration. The data from the "morning specimens" given in the third section of Table II will serve to indicate that the increase of fixed base is fairly closely proportional to the size of the specimen and this finding may be taken as additional evidence that the fixed base found is, in great part at least, derived from the mucous secretion of the fundus. In Table III are given data from specimens of juice collected from the pouch during the digestion of food to which had been added a relatively

TABLE III.

Data from Secretions taken from Fundic Pouch during Digestion of Food Containing Added Sodium Bicarbonate.

Specimen No.	Food	Interval after food	Volume	Cl′	B·	H·
		hrs.	*cc.*	*cc. 0 1 N per 100 cc.*	*cc. 0.1 N per 100 cc.*	*cc. 0.1 N per 100 cc.*
32		2	4	166	60	106
33	Fish, 30 gm.,	4	8	166	73	93
34	+	6	6	176	50	126
35	$NaHCO_3$, 2 gm.	2	7	173	53	120
36		4	2	158	43	115
Average......................		3.6	5	**168**	**56**	**112**

large amount of sodium bicarbonate. As may be seen, there was no compensating increase in the acidity of juice.[1] The fixed base concentrations found are actually somewhat higher than when the same food without added alkali was given (first section of Table II). It is thus evident that we cannot regard the data given in the first and second sections of Table II as dependably indicating that gastric juice acidity is regulated with reference to the character of the food intake by adjustment of fixed base. The differing amounts of fixed base found are probably due to admixture in varying degree of the

[1] This finding is perhaps of some clinical significance with regard to bicarbonate therapy in gastric hyperacidity in that it may be taken to indicate that sodium bicarbonate is not an aggravating stimulus.

mucous secretion with "true" juice. An accurate control of gastric acidity by a regulated mixing of these two secretions is a conception rather difficult to accept.

The results of an experiment given in Table IV indicate that the production of the mucous secretion of the fundus may be greatly increased by the presence of an injurious agent and suggest that an important rôle of this secretion is protection of the mucosa against

TABLE IV.

Data from Secretions Taken from Fundic Pouch Following Irritation by Alcohol.

Interval after irritation by alcohol	Volume of specimen	Cl′	B·	H·
	cc.	*cc. 0.1 N per 100 cc.*	*cc. 0.1 N per 100 cc.*	*cc. 0.1 N per 100 cc.*
15 min.	2	124	119	5
1 hr.	4	135	99	36
2 hrs.	2	141	90	51

TABLE V.

Data from Secretions Taken from Fundic Pouch Constructed According to the Technic of Pawlow.

Specimen No.	Cl′	B·	H·
	cc. 0.1 N per 100 cc.	*cc. 0.1 N per 100 cc.*	*cc. 0.1 N per 100 cc.*
37	170	36	134
38	170	30	140
39	175	32	143
40	166	32	134
Average...........	**170**	**32**	**138**

harmful irritation. The experiment consisted in introducing into an empty fundic pouch a small quantity of 95 per cent alcohol which was then almost immediately withdrawn.[2] This procedure induced secretions to an extent sufficient to provide several successive samples large enough for analysis. As may be seen in the table, the chloride

[2] This experiment was carried out with the animal from which the data in Table II were obtained.

ion concentration was greatly below the usual value and was almost covered by fixed base. Over an interval of 2 hours there occurred a considerable increase of chloride and a decrease of fixed base. These data suggest that measurements of fixed base as well as of chloride ion might be informative in the study of gastric anacidity.

In Table V are given data from several specimens taken from a pouch constructed according to the technic of Pawlow, by which vagus innervation of the pouch is preserved. The food given this animal was fish and the specimens were collected 4 hours after ingestion. As may be seen in the table the values found for chloride and fixed base agree fairly closely with those obtained from juice taken from the Heidenhain type of pouch.

In a third animal, a pouch was constructed in the region of the pyloric antrum and from it small amounts of a colorless and viscid secretion were obtained by prolonged catheterization. From a specimen composed of a number of separate collections, the following measurements per 100 cc. were obtained: $B^{\cdot}$, 169 cc. 0.1 N, Cl', 158 cc. 0.1 N, $K^{\cdot}$, 8.8 cc. 0.1 N, dried substance, 2.49 gm. The reaction of the material as determined colorimetrically was pH 8.4. Doubtless, however, this degree of alkalinity was in part due to loss of CO_2. This secretion is thus seen to contain fixed base at approximately the concentration found for chloride ion in juice from the fundus of the stomach, and to owe its alkalinity to a slight recession of chloride ion from this level. The extent to which fixed base is in excess of chloride ion, 11 cc. 0.1 N, may probably be taken as an approximate measurement of bicarbonate ion. In Table II, as in Table I, it may be noted that the values for potassium being approximately stationary, variation in the amounts of fixed base is evidently referable to sodium. The specimen from the pyloric pouch contains potassium at about the level found in the secretions from the fundus. The probability that the mucous secretion of the resting mucosa of the fundus has the same composition as that of the pyloric antrum is thus indicated.

The above data describing the acid-base composition of the gastric secretions are graphically summarized in Fig. 1. In the diagrams, the anions compose the right-hand and the cations the left-hand column. The figure also contains a diagram of the acid-base composition of cat's blood serum.[3] The first three diagrams illustrate clearly the range of hydrogen ion concentration in secretions from the fundic pouch produced by change in fixed base in the presence of an approximately stationary concentration of chloride ion. It is perhaps interesting to note that whereas in the blood plasma the total ionic content is determined by the fixed base concentration owing to the

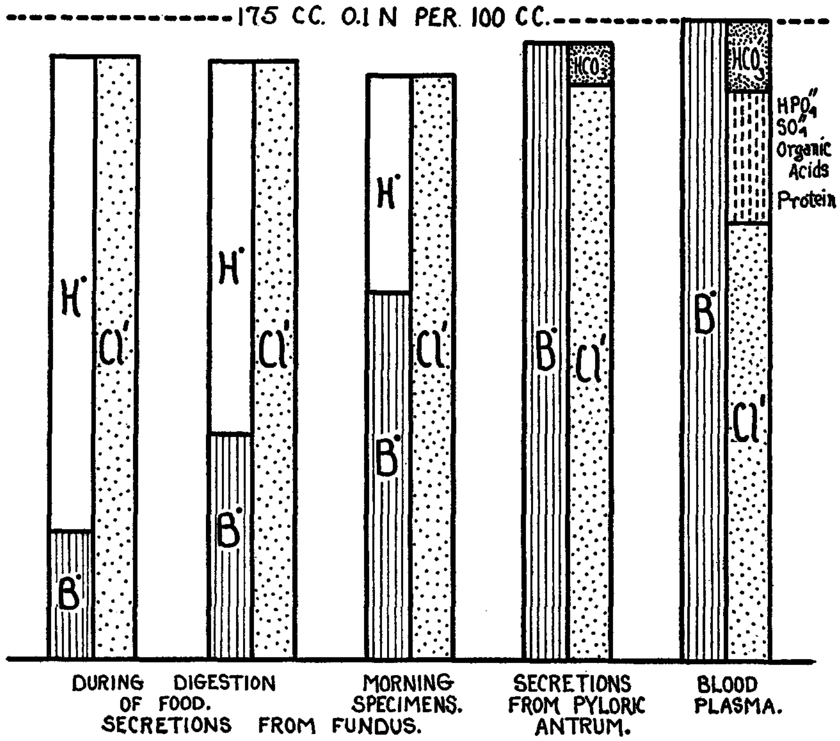

FIG. 1. From data in Table II.

adjustability of the acid factor (HCO_3'), in the secretions of the gastric fundus this value is established by chloride ion and the movable factor sustaining acid-base equivalence ($H^{\cdot}$) is on the base side of the diagram. An approximate isotonicity of gastric juice and blood

[3] Except for the bicarbonate value which is the average of a few measurements made in this laboratory, the data published by Baumann and Kurland (7) were used in constructing this diagram.

serum has been indicated by measurements of freezing point depression. By comparing the heights of the diagrams in the figure it is evident that according to these data the total ionic content of cat's blood serum is appreciably greater than was found for the gastric secretions. A Donnan relationship between physiological solutions separated by secreting cells would not be expected. The fact, however, that the total of ions is here greater in the solution containing protein and that the chief anion chloride is found at higher concentration in the protein-free solution might be taken as a vague hint of Donnan control of at least the factors defining total ionic content.

A glance at the composition of the gastric secretions as displayed in these diagrams will make easily understandable the large withdrawal of fixed base as well as of chloride ion from the blood plasma which may occur when reabsorption of these materials is prevented. Irritant circumstances in a fasting animal, experimental obstruction of the pylorus for instance, may be expected to produce a relatively large amount of the alkaline mucous secretion. It is therefore not surprising that, as has been found, a chloride loss may be accompanied by more than half its equivalence of fixed base.

SUMMARY.

The chief inorganic factors in secretions obtained from isolated pouches constructed in the fundus and in the pyloric antrum of the cat's stomach were found to be chloride ion and fixed base. In a series of samples obtained from the fundic pouch, chloride ion was approximately stationary at 165 cc. 0.1 N per 100 cc. During digestion of food in the stomach, secretions from the pouch contained fixed base in amounts varying considerably from an average of 47 cc. 0.1 N per 100 cc. Material allowed to remain in the pouch after the completion of food digestion in the stomach showed an increasing content of fixed base, to as much as 140 cc. 0.1 N per 100 cc. A stationary total ionic content of secretions of the fundus is thus seen to be sustained by the chloride ion concentration, and changes in hydrogen ion concentration to be caused by variation of fixed base. The differing amounts of fixed base found are regarded as probably due to admixture of a mucous secretion with the juice from the fundic glands. The alkaline secretion taken from a pyloric pouch contained

fixed base in excess of chloride ion. Variation of fixed base in the secretions from the fundic pouch were found to be referable to change in sodium content, the smaller factor, potassium, remaining approximately constant at about the value found in material from the pyloric pouch. This suggests that the mucous secretion of the fundus has the same composition as that produced by the pyloric antrum. These data will serve to explain the extensive withdrawal of fixed base, as well as of chloride ion, from the blood plasma in the presence of circumstances causing a continued loss of stomach secretions.

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