THE RELATION BETWEEN THE CONCENTRATIONS OF BICARBONATE AND PROTEIN IN THE PANCREATIC JUICE IN THE DOG

By F. W. HENRIKSEN and H. WORNING

From the Institute of Experimental Research in Surgery,
University of Copenhagen, and the Central Laboratorium,
Blegdamshospitalet, Copenhagen, Denmark

SUMMARY

1. In accordance with the admixture theory of the exocrine pancreatic secretion a linear relation between concentrations of bicarbonate and protein in the pancreatic juice is to be expected.

2. Pancreatic juice was obtained through a Thomas cannula in three unanaesthetized dogs during digestion of a meal.

3. The actual concentration of bicarbonate and protein showed a good approximation to a straight-line relation.

4. The calculated concentration of bicarbonate in the distal secretion was nearly identical with the highest concentration of bicarbonate obtained in the pancreatic juice after stimulation with secretin.

INTRODUCTION

In the discussion concerning the secretory mechanisms in the exocrine pancreas two hypotheses have been put forward. According to the admixture theory (Thaysen, 1960), the pancreatic juice consists of a proximal secretion with a high concentration of protein, produced in the acini, and a distal secretion with a high concentration of bicarbonate, produced in the intercalary ducts. According to the exchange theory (Janowitz & Dreiling, 1962) the bicarbonate ions in the pancreatic secretion are exchanged with chloride ions during the passage of the secretion through the ducts. Bernier & Lambling (1962) have shown that the hyperbolic relation between the concentrations of chloride and bicarbonate in pancreatic juice is in accordance with both hypotheses.

If we consider the admixture theory it is possible to express a relation between the concentrations of bicarbonate and protein in the pancreatic juice:

$[P_p]$ and $[P_d]$ are concentrations of protein in the proximal and the distal secretion, $[B_p]$ and $[B_d]$ are concentrations of bicarbonate in the proximal and the distal secretion, and $[P_a]$ and $[B_a]$ the actual concentrations of protein and bicarbonate in the final pancreatic juice.

If the volume of the proximal secretion in any given period of time is x ml. and the volume of the distal secretion in the same period of time is y ml. the following equations can be written:

$$[P_a] = \frac{[P_p]x + [P_d]y}{x+y} = [P_p]\frac{x}{x+y} + [P_d]\frac{y}{x+y},\qquad (1)$$

$$[B_a] = \frac{[B_p]x + [B_d]y}{x+y} = [B_p]\frac{x}{x+y} + [B_d]\frac{y}{x+y},\qquad (2)$$

$$\frac{y}{x+y} \equiv 1 - \frac{x}{x+y}.\qquad (3)$$

By substituting (1) and (2) with (3):

$$[B_a] = -\frac{[B_d]-[B_p]}{[P_p]-[P_d]}[P_a] + \frac{[B_d][P_p]-[B_p][P_d]}{[P_p]-[P_d]}.\qquad (4)$$

On the assumption that the protein concentration of the distal secretion $[P_d]$ is zero, the equation (4) simplifies to

$$[B_a] = -\frac{[B_d]-[B_p]}{[P_p]}[P_a] + [B_d].\qquad (5)$$

It is furthermore assumed that $[P_p]$, $[P_d]$, $[B_p]$ and $[B_d]$ remain constant during secretion. On these assumptions the following observations are to be expected:

The concentrations of bicarbonate and of protein in the pancreatic juice must show a linear correlation. The maximal concentration of bicarbonate obtainable with any physiological stimulus must be the concentration in the distal secretion.

The experiments to be described were designed in order to test the validity of this hypothesis.

METHODS

The studies were performed on three unanaesthetized dogs (weight 20–26 kg) with a cannula (Thomas, 1941) in the duodenum. During digestion of a normal meal (400–450 g meat) the pancreatic juice was collected anaerobically for 2 hr, fractionated into six portions representing 10 min output and three portions representing 20 min output each. The concentration of bicarbonate was estimated immediately in all samples, and the concentration of protein after storage at $-20°$ C. Each dog was subjected to two or more investigations.

The concentration of CO_2 (total CO_2) was estimated by means of Van Slyke's manometric method (Van Slyke & Neill, 1924). To express the concentration of total CO_2 the conventional term 'bicarbonate concentration' is used. At the prevailing pH the difference between these two values is negligible. The concentration of protein was estimated spectrophoto-

metrically at 280 nm after appropriate dilution of the samples with Sørensen phosphate buffer, pH 6·8. The extinction values were converted to concentrations of protein by means of a factor empirically determined by Kjeldahl analysis on pooled canine pancreatic juice.
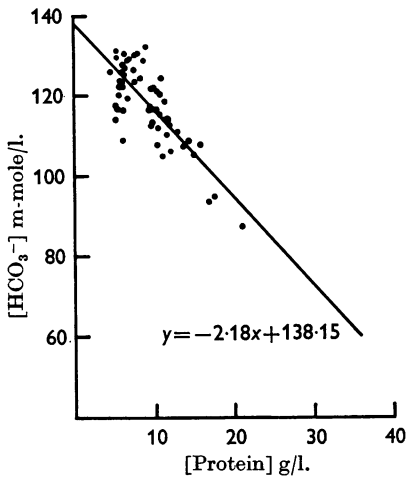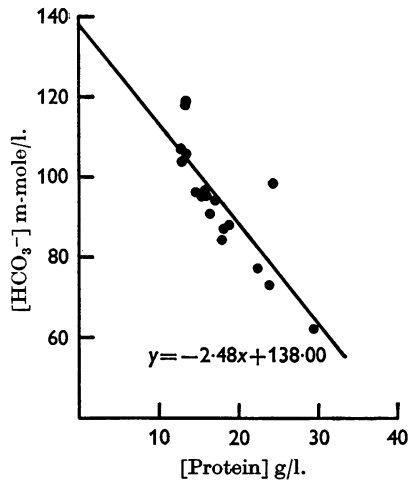
Fig. 1. Relation between concentrations of bicarbonate (y) and protein (x) in dog no. 64–208. Coefficient of correlation $r = 0·79$.

Fig. 2. Relation between concentrations of bicarbonate (y) and protein (x) in dog no. 64–224. Coefficient of correlation $r = 0·83$.
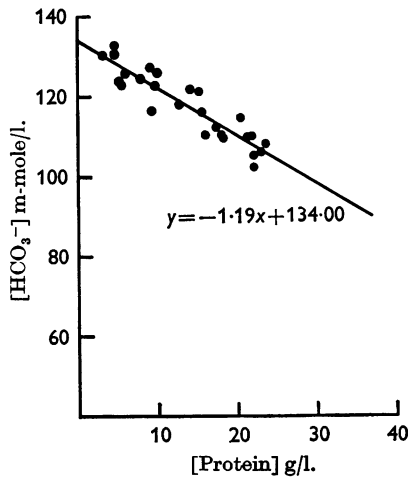
Fig. 3. Relation between concentrations of bicarbonate (y) and protein (x) in dog no. 65–231. Coefficient of correlation $r = 0·92$.

RESULTS

Figures 1–3 show the relation between the concentrations of protein and bicarbonate in all samples from the three dogs. A good approximation to a straight-line regression was obtained in all dogs with coefficients of correlation between 0·79 and 0·92.

In separate experiments different doses of secretin were administered to the same three dogs. The pancreatic juice was collected as described and the concentration of bicarbonate recorded. In Table 1 the maximal concentrations of bicarbonate obtained in the secretin experiments in each dog are compared to the intercepts at the y-axis.

TABLE 1. Maximal concentration of bicarbonate in the pancreatic juice after stimulation with secretin (B_{max}), and the intercept at the y-axis (B_y) (see figs. 1–3) in three dogs

	Concentration of bicarbonate (m-mole/l.)	
Dog no.	(B_{max})	(B_y)
64–208	138·5	138·2
64–224	140·1	138·0
65–231	136·3	134·0

DISCUSSION

The linear correlation observed between concentrations of bicarbonate and protein in the pancreatic juice during a physiological stimulus (food) supports the admixture hypothesis with the assumptions presented. If the composition of the juice were dependent on exchange of bicarbonate ions and chloride ions during passage through the ducts, no linear correlation between the concentrations of protein and bicarbonate would be expected.

The differences in the slopes of the regression lines and in the intercepts at the y-axis in the three dogs may be explained by individual differences in $[P_p]$, $[P_d]$, $[B_p]$ and $[B_d]$.

As stated earlier, the maximal concentration of bicarbonate in the pancreatic juice must be the concentration in the distal secretion $[B_d]$. In accordance with equation (5) $[B_d]$ is identical with the intercept at the y-axis. The close parallellism between the intercepts at the y-axis and the actual maximal concentrations of bicarbonate in the pancreatic juice (Table 1) seems to confirm the validity of equation (5).

REFERENCES

BERNIER, J. J. & LAMBLING, A. (1962). Relations between the volume and output of bicarbonate in pancreatic secretion. In *Ciba Symposium on the Exocrine Pancreas*, ed. DEREUCK, A. V. S. & CAMERON, M. P. London: Churchill.

JANOWITZ, H. D. & DREILING, D. A. (1962). The pancreatic secretion of fluid and electrolytes. In *Ciba Symposium on the Exocrine Pancreas*, ed. DEREUCK, A. V. S. & CAMERON, M. P. London: Churchill.

THAYSEN, J. HESS (1960). Handling of alkali metals by exocrine glands other than the kidney. *Handb. exp. Pharmak.* **13**, 424–463.

THOMAS, J. E. (1941). An improved cannula for gastric and intestinal fistulas. *Proc. Soc. exp. Biol. Med.* **46**, 260–261.

VAN SLYKE, D. D. & NEILL, J. M. (1924). The determination of gases in blood and other solutions by vacuum extraction and manometric measurements. *J. biol. Chem.* **61**, 523–573.