PROCEEDINGS OF THE SOCIETY FOR EXPERIMENTAL BIOLOGY AND MEDICINE 145, 1215–1219 (1974)

Absorption and Secretion in the Rabbit Duodenum and Ileum[1] (37984)

VATCHARAT LIMRATANA AND GORDON J. LEITCH[2]
(Introduced by W. D. Sawyer)
Department of Physiology, Faculty of Science, Mahidol University, Bangkok, Thailand

Considerable regional functional variation is exhibited by the small intestine (1–4). The presence of Brunner's glands in the duodenum makes this area obviously different from the remainder of the small intestine. The present work describes a study of water and electrolyte movement in the rabbit duodenum and lower ileum, with particular emphasis being placed on the movement of the anions HCO_3^- and Cl^-.

Methods. Adult New Zealand white rabbits were fasted overnight prior to use. A laparotomy was performed under local procaine anesthesia, and a loop of either duodenum or lower ileum was prepared without interruption of the blood supply. The duodenal loop, about 15–20 cm long, was located between the openings of the bile and pancreatic ducts. The ileal loop, about 20–25 cm long, extended proximally from about 15 cm above where the ileum shares mesentery with the tip of the appendix. A KCl–agar bridge was secured into one end of the loop and a polyethylene catheter (i.d. 0.085 in.) into the other end. The electrical potential difference (PD) was measured using the loop lumen bridge (mucosa), a peritoneal cavity bridge (serosa), and a marginal ear vein bridge (venous blood). The mucosal PD was measured with respect to both the serosa and venous blood using a high-input impedance electrometer (model 600C, Kiethley Instruments Inc., Cleveland, OH). The two abdominal electrodes and the catheter were led out through a stab wound made in the side under local anesthesia. The laparotomy was closed and the three tubes were secured with a pursestring suture. Throughout the experiments the animals were lightly restrained in a box, and procaine was administered as required to the incision sites.

Each experiment was designed to use five 30-min periods. For each of these periods one test solution was randomly selected from five isotonic NaCl–$NaHCO_3$ solutions (HCO_3^-, 0–120 m*M* for ileal experiments and 0–160 m*M* for duodenal experiments). The solution was infused into the loop via the catheter. The luminal fluid volume was measured using the nonabsorbed marker polyethylene glycol (PEG). Five minutes after instillation of the test solution an initial sample of luminal fluid was removed and tested for PEG concentration, the concentrations of the ions under study, osmolality, and conductance. At the end of the 30-min period all loop fluid was withdrawn, its volume measured, and its contents analyzed. At the termination of the experiment the animal was sacrificed, the loop removed, and its length measured. All samples were handled anaerobically to prevent the loss of CO_2.

The PEG concentration was determined by a turbidimetric method (5). The total CO_2 content was determined using a Natelson microgasometer (Scientific Industries Inc., Springfield, MA). Chloride ion concentrations were measured using a Cotlove chloridometer (Buchler Instruments Inc., Fort Lee, NJ), and Na^+ and K^+ concentrations were measured by flame photometry (model KY-3, Baird Atomic Inc., Bedford,

[1] Supported in part by the Rockefeller Foundation.

[2] Address reprint requests to: Dr. G. J. Leitch, Evansville Center for Medical Education, Indiana University School of Medicine, 8600 University Boulevard, Evansville, IN 47712.

MA). Osmolality was measured by a freezing point-depression method (Osmette, Precision Systems Inc., Natick, MA), and luminal fluid conductivity was measured by passing the fluid through a conductivity cell of the type designed by Rothe and associates (6). All conductivity measurements were performed at room temperature. The cell was calibrated with NaCl solutions, and for this reason conductivities are expressed in millimolar NaCl concentrations. Sample pH was measured at 37°C with a capillary pH electrode system (Beckman Instruments Inc., Fullerton, CA).

Results. The net transport of HCO_3^- and Cl^- varied as a function of the $[HCO_3^-]$ initially present in both duodenum and ileum (Fig. 1). In all cases HCO_3^- was measured as total CO_2, but is expressed as HCO_3^-, as the luminal fluid was in the pH range 7.6–8.2. In both duodenum and ileum there was net Cl^- absorption when the initial $[HCO_3^-]$ was approximately 90 m*M* or less; i.e., equivalent to a luminal $[Cl^-]$ of approximately 60 m*M* or greater. In the duodenum HCO_3^- was secreted at all initial $[HCO_3^-]$ studied. In the ileum HCO_3^- secretion occurred when the initial luminal $[HCO_3^-]$ was less than 70 m*M*. The reciprocal relationship between HCO_3^- and Cl^- transports maintained the luminal concentration of the sum of these two anions approximately constant.

When the PD (either mucosa–serosa, or mucosa–venous blood) was plotted as a function of the initial luminal $[HCO_3^-]$, no statistically significant relationship could be found between PD and luminal fluid

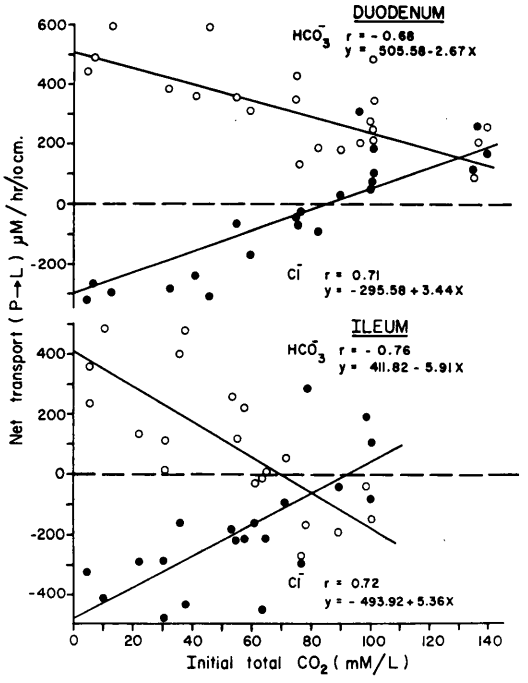

FIG. 1. Net transport of HCO_3^- (open circles) and Cl^- (closed circles) in rabbit duodenum and ileum, plotted as a function of the initial $[HCO_3^-]$ ([total CO_2]) of the luminal fluid. Positive values, secretion; negative values, absorption.

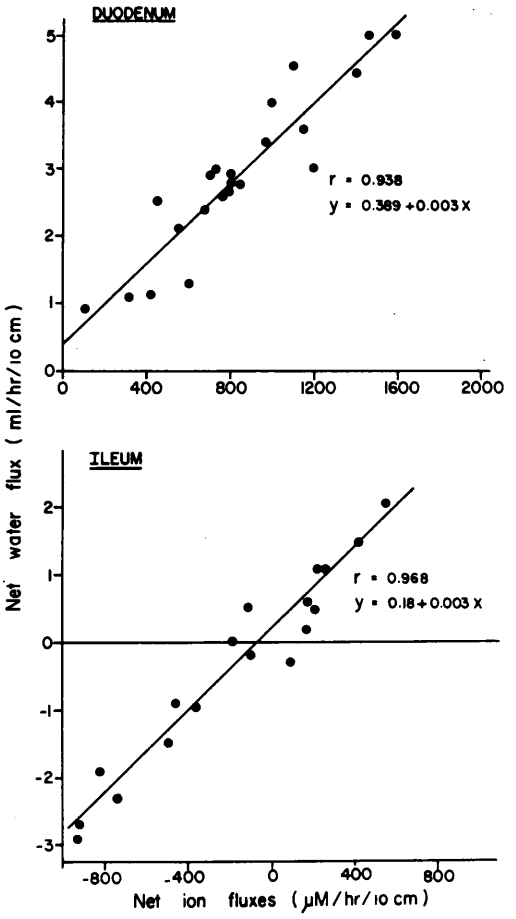

FIG. 2. Relationship between net solvent and net solute (Na^+, K^+, Cl^- and HCO_3^-) transport in rabbit duodenum and ileum. Slopes of both lines indicate transported fluid osmolality approximately 340 mOsm.

$[HCO_3^-]$, for either duodenum or ileum. In both areas of the gut the averaged mucosa–serosa and mucosa–venous blood PD values were mucosa negative, and of similar magnitude (less than 5 mV).

Figure 2 illustrates the relationship between the net solute and net solvent fluxes in both duodenum and ileum. The net solute fluxes were approximated using the algebraic sum of the net Na^+, K^+, Cl^- and HCO_3^- fluxes. The intersections of both regression lines were found not to significantly differ from the point (0, 0). The duodenum always showed secretion (enterosorption). The high incidence of secretion in the ileal loops was found due to irritation caused by the catheter and electrode bridges.

Six NaCl–$NaHCO_3$ solutions were prepared (Na^+, 160 m*M*; HCO_3^-, 0, 25, 50, 75, 100, or 125 m*M*). The conductivity, $[Cl^-]$ and [total CO_2] of each of these solutions was measured, and solution conductivity was plotted as a function of solution [total CO_2]. A reciprocal relationship was observed. For this reason luminal fluid conductivities are presented as a function of the luminal fluid [total CO_2] of that sample (Fig. 3), and the data points are divided into values of initial and final (30-min) samples. The conductivities of the initial and final duodenal fluids were compared. Both regression lines were highly significant; and while their slopes did not differ significantly ($P > 0.2$) when the coincidence was tested (7), the results indicated that the lines were significantly different from each other ($P < 0.01$). The slopes of the initial and final duodenal fluids and the artificial fluids did not differ from each other ($P > 0.2$), and the initial fluid conductivity line and artificial fluid line were coincident. This suggests that a major factor determining the conductivity of the initial luminal fluid samples was their HCO_3^-/Cl^- concentrations. In the ileal fluid the initial and final conductivity regression lines differed from each other ($0.05 > P > 0.02$) as they were not coincident, but their slopes did not differ significantly ($P > 0.1$). As with the duodenum, the initial ileal conductivity regression line coincided with that of the artificial fluids.

The $[Na^+ + K^+]$ and $[Cl^- + HCO_3^-]$ values of the initial samples were subtracted from the values of the final samples. The data are again expressed as a function of the luminal fluid [total CO_2] (Fig. 4). In

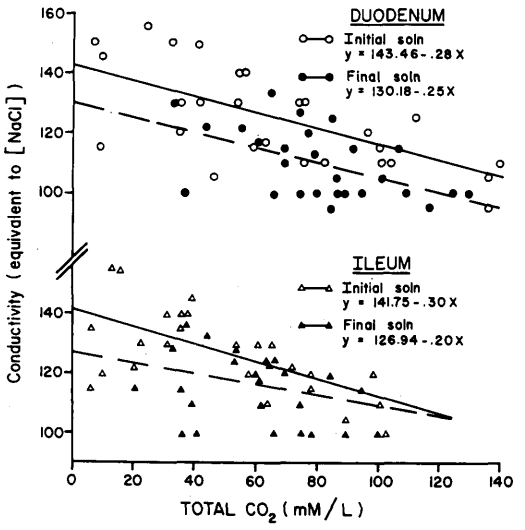

FIG. 3. Conductivities of initial and final (30-min) luminal fluid samples, plotted as a function of the $[HCO_3^-]$ of each sample.

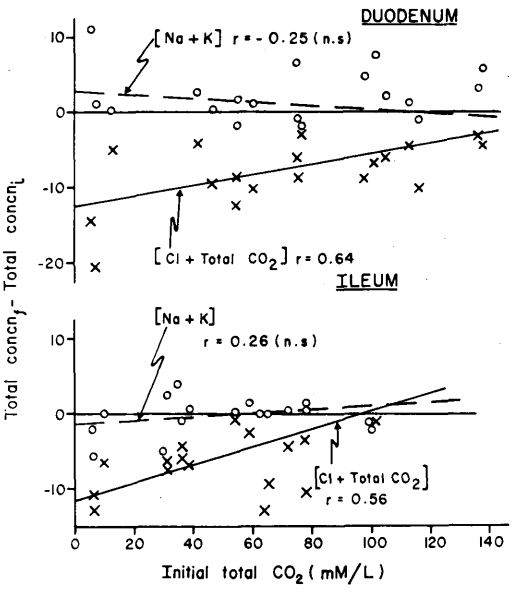

FIG. 4. Differences between final (30-min) and initial luminal fluid cation ($[Na^+ + K^+]$) and anion ($[Cl^- + HCO_3^-]$) concentrations, plotted as a function of the initial $[HCO_3^-]$.

both the duodenum and ileum allowing an isotonic NaCl–$NaHCO_3$ solution to remain in the lumen for 30 min resulted in a significant reduction in [Cl^- + HCO_3^-], but not in [Na^+ + K^+]. The extent of this anion deficit was a function of the initial [HCO_3^-]. These conclusions were drawn from the facts that the regression lines for the [Na^+ + K^+] data were not significant, neither did their *b* and *a* values differ significantly from zero; whereas both regression lines for the [Cl^- + HCO_3^-] data were significant, and both *b* and *a* values differed significantly from zero ($P < 0.02$).

Discussion. In both the duodenum and ileum there was HCO_3^- secretion against an electrochemical potential gradient. This transport differed slightly in the two areas. None of the imposed chemical gradients stopped net HCO_3^- secretion in the duodenum, while in the ileum, luminal [HCO_3^-] greater than 70 m*M* reversed the direction of the net HCO_3^- transport. The modest adverse electrical potential gradient was the same in both areas. It was not possible to distinguish between HCO_3^- secretion and H^+ absorption as the mechanism of the HCO_3^- enterosorption.

The relationship between HCO_3^- transport and Cl^- transport in the small intestine is a complex one (8–11). Luminal Cl^- is required for optimal HCO_3^- secretion to occur (9). In the present experiments more than a simple HCO_3^- – Cl^- exchange was indicated as there was net HCO_3^- secretion in the duodenum, even when there was net Cl^- secretion; and in the ileum there was the suggestion of Cl^- absorption which was independent of HCO_3^- secretion. The small intestine is known to secrete Cl^- (12, 13), but there is probably no active Cl^- absorption in the rabbit ileum (14). Electroneutrality constraints imposed by Na^+ transport, and solvent drag, also probably contributed to the movements of these anions. There was no detectable indication that the movement of either HCO_3^- or Cl^- was electrogenic.

The conductivity data indicate that during the experimental periods luminal fluid conductivity was decreased. As this occurred in both duodenum and ileum it was not the result of absorption of electrolytes from the lumen leaving mucus behind to build up and maintain near isotonic conditions; neither was it due to the increased luminal fluid [HCO_3^-], because the data illustrated in Fig. 3 are plotted as a function of the [HCO_3^-] of each sample. The reduction in conductivity might be in part explained by the anion deficit illustrated in Fig. 4. One explanation which accommodates both conductivity and [Na^+ + K^+] and [Cl^- + HCO_3^-] data is that acidic mucosubstances were secreted into both duodenum and ileum during each experimental period. Direct observation of initial and 30-min luminal fluid samples subjectively confirmed the increase in mucus.

The anion deficit that occurred in both duodenum and ileum was dependent upon the initial [HCO_3^-], suggesting a relationship between the secretion of acidic mucosubstances and HCO_3^- secretion and/or Cl^- absorption. In the duodenum the secretion of a HCO_3^--rich mucus has been attributed to the Brunner's glands (15).

Summary. In both rabbit duodenum and ileum there was secretion of HCO_3^- into, and absorption of Cl^- from, the lumen. The transport of both anions decreased with increasing luminal fluid [HCO_3^-]. The net fluxes of Na^+, K^+, Cl^-, and HCO_3^- accounted for the movement of a near isotonic fluid, whether absorbed or secreted. In both duodenum and ileum luminal fluid [Cl^- + HCO_3^-] and conductivity decreased. The data are consistent with the secretion of soluble anionic mucosubstances, of low mobility, into both areas of the gut.

---

1. Hindle, W., and Code, C. F., Amer. J. Physiol. **203**, 215 (1962).

2. Powell, D. H., and Malawer, S. J., Amer. J. Physiol. **215**, 49 (1968).

3. Powell, D. H., Malawer, S. J., and Plotkin, G. R., Amer. J. Physiol. **215**, 1226 (1968).

4. Schedl, H. P., Wilson, D. H., and Miller, D. L., Proc. Soc. Exp. Biol. Med. **129**, 511 (1968).

5. Malawer, S. J., and Powell, D. W., Gastroenterology **53**, 250 (1967).

6. Rothe, C. F., Johnson, J. A., and Moore, W. W., J. Appl. Physiol. **23**, 1010 (1967).

7. Snedecor, G. W., "Statistical Methods," 5th

ed., p. 394. The Iowa State College Press, Ames (1956).

8. Parsons, D. S., Quart. J. Exp. Physiol. **41**, 410 (1956).

9. Hubel, K. A., Amer. J. Physiol. **217**, 40 (1969).

10. Turnberg, L. A., Fordtran, J. S., Carter, N. W., and Rector, F. C., J. Clin. Invest. **49**, 548 (1970).

11. Turnberg, L. A., Bieberdorf, F. A., Morawski, S. G., and Fordtran, J. S., J. Clin. Invest. **49**, 557 (1970).

12. Tidball, C. S., Amer. J. Physiol. **200**, 309 (1961).

13. Field, M., Amer. J. Physiol. **221**, 992 (1971).

14. Schultz, S. G., Zalusky, R., and Gass, A. E., J. Gen. Physiol. **48**, 375 (1964).

15. Cooke, A. R., *in* "Handbook of Physiology—Alimentary Canal" (C. F. Code, ed.), Vol. 2, p. 1087. American Physiological Society, Washington, DC (1967).

Received July 24, 1973. P.S.E.B.M., 1974, Vol. 145.