THE INTESTINAL ABSORPTION OF SODIUM CHLORIDE SOLUTIONS AS INFLUENCED BY INTRA-LUMINAL PRESSURE AND CONCENTRATION

by

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INTRODUCTION

The question of the mechanism of absorption of food materials through the intestinal epithelium has been considered by many investigators. Much of the earlier work was done to determine whether or not the absorption phenomena could be explained entirely on the basis of physical and chemical laws. Evidence that the epithelial cells perform an active role in absorption began appearing in the early 1900's, and in recent years relatively little emphasis has been placed on the evaluation of physical forces. Instead, the interest has turned to such problems as measuring rate of absorption of a specific ion in a solution containing several other ions, determining the total anion and cation exchange, and in measuring the movements of substances in the two opposing directions between the intestinal lumen and the blood.

Much of the work on absorption, however, is inadequate for the following reasons: 1) Many of the studies involved acute experiments, on either intact or isolated intestinal segments. This method of investigation prevented periodic observations on the same animal. Most investigators have ignored the advantages of using chronic preparations under conditions which are more physiological than are those which are encountered in acute experiments. 2) Statistical analysis of results has been employed in only the most recent studies. In fact, in some of the earlier reports only "typical" data were presented. In view of these criticisms it is reasonable to doubt the validity of the results of many investigations on intestinal absorption. It seemed necessary, then, to reinvestigate the absorption of simple solutions, using more reliable methods and organizing the study so that the results might lend themselves to statistical analysis.

In the present study, therefore, an attempt was made to develop an experimental approach which would meet the requirements of the criticisms mentioned, and to provide clear evidence concerning the roles played by two variables: 1) Intra-intestinal hydrostatic pressure, and 2) Concentration of the solution. Specifically, it is important to determine whether or not intra-luminal pressure should be carefully controlled in experiments on intestinal absorption. It is also important to know which solutions can be placed in the gut for a period of time without undergoing significant changes in concentration.

In this paper the term "absorption" is used to refer to the net change in the amount of a substance during the time it is present in the lumen of the intestine. This use is in accordance with the usual interpretation, although a more specific meaning occasionally is used, such as the transfer of a substance against an osmotic gradient. The general definition is more useful for the purposes of this study.

REVIEW OF THE LITERATURE

In 1869 Voit and Bauer(1) presented the results of experiments on the absorption of protein solutions, serum, and salts. This work was cited by Goldschmidt(2) who explained that the conclusion of these authors that filtration, caused by intra-intestinal pressure, rather than osmosis is the force causing intestinal absorption was based in part upon "the erroneous premise that the passage of the solution through the intestinal wall should, if osmosis is an active factor, simulate the diffusion of the same solution through (non-living) membranes."

Intra-luminal hydrostatic pressure was studied by another early worker, Leubuscher(3) in 1885. He found that absorption was augmented as the pressure was increased up to 80 mm. to 100 mm. Hg., and above that pressure there was a decrease in absorption. He postulated that the decrease was due to the interference with intestinal blood flow caused by high intra-luminal pressure.

In 1892 Edkins(4) studied the effect of intra-intestinal pressure on the rate of absorption of 0.6% NaCl solution. Cats were anesthetized with morphine and atropine, and in each animal a section of intestine, 8 cm. to 38 cm. long, was clamped off and the lumen washed with saline. The segment of gut was then connected to an open burette system with which he could maintain a constant hydrostatic pressure. During the experiments the gut and test solutions were kept warm, but the temperature of the animal was not recorded. At the end of the absorption period, the loop was excised, its contents removed and measured, and the volume of solution absorbed was determined. The amount of secretion by the epithelium was considered to be negligible, and therefore Edkins thought that his measurements represented actual fluid movement in the gut-to-blood direction. The effect of atropine on intestinal secretion evidently was unknown at the time of Edkin's work.

Using absorption periods of 60 minutes, Edkins measured the rate of absorption of 0.6% NaCl solution from the large intestine and expressed the results in terms of a Coefficient of absorption, which equalled the volume absorbed in cc. per cm. length of gut per hour. The average of three coefficients at 10 cm. of solution pressure was 2.07, as compared with 1.09 at 5 cm. pressure in one test, and 1.29 at 15 cm. pressure in another test. On the basis of these five tests on the large intestine, Edkins decided that a pressure of 10 cm. of water pressure was optimal. No explanation was given for a higher coefficient of absorption at 10 cm. of pressure than at 15 cm.

Edkins then turned his attention to the comparison of the rates of absorption of the 0.6% NaCl solutions at different levels of the small intestine, keeping the hydrostatic pressure constant at 10 cm. Four experiments, in which the ileum was used, resulted in an average coefficient of 1.31, as compared with 0.73 which was obtained in three tests on the duodenum. The observation that the test solutions were concentrated in the gut led Edkins to conclude that water was absorbed more rapidly than salt.

It should be emphasized here that Edkins considered only the pressure variable in the first series of tests and the variable of the level of intestine in the second series. He did not take into consideration other variables such as day-to-day variation in each animal, and animal-to-animal variation.

About the same time Reid (5) attempted to provide evidence for the existence of an active process in the mechanism for intestinal absorption. His method of investigation involved the use of an excised portion of rabbit intestine, stripped of its serosa, and placed between two glass cylinders, which were sealed with "badruche." His observations on absorption usually were started 15 minutes after the death of the animal. On the basis of his results, Reid concluded that there was a transfer of saline from the inner to the outer side. He found that this transfer lasted for about one hour and that its direction could be reversed by adding pilocarpine to the test solution.

In a subsequent report (6) Reid employed isolated loops in acute studies on dogs. Using as a test solution some of the animal's own serum, he found that absorption from the gut took place even when the hydrostatic pressure of the intestinal capillaries was above that in the gut lumen. He claimed that this result could not be explained simply on the basis of diffusion and osmosis. He does not provide certain details such as the length of the loops, the volume of test solutions, the number of tests, and the pressure in the gut.

Reid also compared "normal" loops with loops in which the epithelial lining had been either damaged or removed and found that eliminating the epithelium greatly reduced absorption of serum. He concluded that the epithelial cell is an agent in the absorption of solutions by the gut.

In 1894 Heidenhain (7) found that serum having an osmotic tension equal to or higher than that of the blood was absorbed from intestinal loops. He used the acute method of investigation on dogs which had been fasted for 40 hours, and which were anesthetized with morphine, chloroform and ether. He isolated a portion of the small intestine 80 cm. to 120 cm. long which consisted of jejunum and ileum, and rinsed it with warm salt solution. Some loops were used several times, and in such cases the results of the consecutive tests were similar; however, there was considerable variation from dog to dog.

Heidenhain also studied the absorption of NaCl solutions of various concentrations ranging from 0.3% to 1.5%, and found that the ratio of salt absorption to water absorption increases as the concentration of the NaCl solution increases: s/w absorption at 0.3% equaled 0.75 to 0.79, while at 1.5% it was 2.6 to 2.75.

Wallace and Cushny (8) in 1898 compared the rates of absorption of several sodium salts. They used dogs which had been fasted for 36 to 48 hours, and which were anesthetized with a subcutaneous injection of morphine, followed by the administration of ether or chloroform. Two or more segments of small intestine, 30 cm. in length, were isolated and cannulated. These loops were not rinsed, but were emptied by "gentle" stripping. As a control solution they used "about one per cent sodium chloride," which had a freezing point depression of 0.59° to 0.64° C. Other salts tested were arranged in concentration in order to approximate this osmotic pressure. In each test 25 cc. of the test solution was placed in the loop, and allowed to remain for a period of 30 minutes.

The average volume of the NaCl solutions absorbed, in 25 tests on 3 dogs, was 20.5 cc. In one test, 19.5 cc. of NaBr solution was absorbed. An average of 16.25 cc. of NaI solution was absorbed in 4 tests on 3 dogs. Five cc. of NaF solution was absorbed in one test. The authors also observed that NaF inhibited the subsequent absorption of NaCl solution.

Goldschmidt (2) referred to this work and stated that the authors found that "readily dissociated salts, whose ions possess a great speed, are not always absorbed faster than less dissociated salts with weaker ionic speed."

Omi (9), in 1909, presented the results of a number of studies on the absorption of salt, sugar, and peptone solutions. His method involved the use of four different chronic preparations. One of the jejunal loops used by Omi was similar to the type used in the present study, in that it had a circular part fashioned by anastomosing the distal end to the side of the segment at a point about 5 cm. from the proximal end. Omi described one such preparation, and used it only for his sugar and peptone studies.

For his studies on NaCl solutions, Omi used Thiry and Thiry-Vella fistulas, and a Pavlov loop fashioned as a large circle. In each experiment the loop was filled with 100 cc. of test solution, and after a period of either 15 or 30 minutes it was emptied and the volume of solution recovered was measured. The chloride concentration was determined by the Mohr method, and the alkali of intestinal secretion was titrated with 0.1 N. H_2SO_4.

Omi studied the absorption of NaCl solutions varying in concentration from 0.25% to 1.5%. However, the series of experiments was not organized to give data which could be easily interpreted. For example, one dog was used for four tests on four different days and a different concentration of NaCl solution was used in each test. The results of these experiments are presented in a table, which shows volume and NaCl absorption and alkali secretion for 0.25%, 0.5%, 0.75%, and 1.0% solutions. Then these results are presented in a graph, along with information gained from experiments on a different dog, using a 1.5% NaCl solution. The curves show that the rate of volume absorption is high for the 0.25% solution and low for the 1.0% solution, and that the rate of NaCl absorption changes in the opposite direction up to 1.0%, and then decreases to zero at 1.5%.

This is a good example of the manner in which many early workers presented their results, and it is therefore important to inspect the data carefully in order to know the reliability of the results.

The early work in the field of intestinal absorption was reviewed rather extensively by Goldschmidt (2) in 1921. He was interested in the subject from the standpoint of elucidating the mechanism of absorption, and discussed the results and conclusions in that light because "the controversy has from the start centered around physical or physicochemical theories as a basic cause." His review includes a list of 15 possible forces responsible for intestinal absorption:

"1. Absorption through orifices in the blood vessels, especially the veins, in the intestinal wall (Hippocrates and Galen).

2. Imbibition, of the nature of water absorption by a sponge.

3. Passage through small openings into the central lymph spaces of the villi, aided by intestinal peristalsis, or by the contraction and expansion of the villi.

4. Osmosis and diffusion.

5. A mechanism similar to that of secreting glands; an inverted glandular process.

6. Ingestion by wandering leucocytes or lymphocytes. A mechanical uptake of substances.

7. Physiological activity of the epithelial cells of the intestine, or this factor combined with osmosis and diffusion.

8. Physiological activity of the epithelial cells combined with a power of the capillary wall to inhibit the passage of diffusible, dissolved substances from the blood into the gut. The first factor is entirely free of osmotic influences, while the latter may be affected by this force.

9. A purely physical process, involving intra-intestinal pressure, molecular imbibition, capillary imbibition, and a power of the blood to "suck" fluid out of the tissues.

10. A motor process of the epithelial intestinal cells. Filtration by the force of intra-intestinal pressure.

11. Dependent upon the solubility of the dissolved substances in lipoids for their passage into the cells, if insoluble in lipoids the path is by the intercellular route.

12. Absorbed in accordance with the power of dissolved substances to lower surface tension. This property is also involved in the inhibition of the passage of blood constituents into the gut. Chemical and physical forces may modify this process.

13. Determined by the mechanical affinity of the colloid of the intestinal wall for the fluid and dissolved substances, and the swelling or shrinking of the colloid caused thereby. Swelling promotes the absorptive process, while shrinking inhibits it.

14. Negative osmosis. Cataphoretic electrical fluid current, dependent upon unequal permeability of the intestinal wall for ions, or polarization of the membrane.

15. Substances, absorbed by osmosis, are changed within the in-

testinal wall to non-diffusible products which can exert a further osmotic attraction upon the absorption of other constituents in the intestine."

This list of possible mechanisms is quoted in its entirety in order to emphasize the completeness of the theoretical possibilities considered at the time of Goldschmidt's review. One of the questions which he thought had not been answered satisfactorily is the one concerning the possibility that intra-intestinal hydrostatic pressure is a factor concerned in the absorption process.

In 1919 Goldschmidt and Dayton (10) had reported absorption experiments on colonic loops in dogs. They observed that the colon acted like a permeable membrane to NaCl solution, and like a semipermeable membrane to solutions of sodium and magnesium sulfate. They also showed that one solute may affect the absorption of another. Thus the permeability of the intestinal wall might be altered without producing physiological injury. They concluded that osmotic pressure is a force involved in the absorptive mechanism. The opinion was expressed by Goldschmidt that there is no essential difference in the absorptive mechanism at different levels of the intestinal tract (2). This opinion was the basis for his frequent comparisons of his observations on the colon with the results of other investigators working on other parts of the intestinal tract.

Rabinovitch (11) studied the absorption of water and chloride as influenced by concentration, osmotic pressure, and atropine. In his experiments on the small intestine, two dogs with Thiry-Vella loops "about two feet long" were used in the unanesthetized state. The loops were washed with the solution to be tested, and the 30-minute absorption periods were alternated with 30-minute rest periods. In order to estimate the amount of intestinal secretion occurring during the absorption period, alkali determinations were made on both pure intestinal juice collected before the test and on the solutions recovered from the loop at the end of each absorption period. The estimated volume secreted could then be added to the volume of solution apparently absorbed to give a more accurate measure of movement of fluid out of the intestine.

The concentration of the NaCl solutions varied from 0.1% to 3.5% NaCl, and the procedure followed by Rabinovitch was to test three of the 18 different concentrations on each of six days. The volume of test solution introduced was 68 cc. to 75 cc. Only the data on one dog were presented, the statement being made that the other results were similar. In these tests Rabinovitch found that the greatest percentage absorption of both chloride and water occurs from solutions ranging in concentration from 0.4% to 0.6% in one dog, and from 0.2% to 0.8% in the other dog. He also observed that the absolute amount of salt absorbed increased with increasing concentration of the test solution until a concentration of 0.6% to 0.8% was reached. In the range from 0.8% to 1.5% NaCl the amount of salt absorbed remained almost the same. In one dog there was considerably less absorption of salt at concentrations of 1.8% and 3.5%.

More recently Wells[12] has investigated the absorption of water at intra-intestinal pressures ranging from -24 cm. to +16 cm. of salt or glucose solution. His experiments with negative pressure necessitated the use of a coil of aluminum wire inside the gut to prevent collapse. Another device employed by Wells was a special clamp in which the gut wall, opened along one side, could be stretched out flat and thus prevent changes in absorption area. Acute tests were conducted on dogs with isolated jejunal loops. The animals were kept warm by placing them in a metal box heated with water at 35°C. Wells tried to eliminate peristalsis in his experiments because such activity interfered with his volume measurements in the burette connected to the loop.

Under the conditions of his experiments, Wells showed that absorption occurs at sub-atmospheric pressures, and that the rate of absorption of water is proportional to increments in intra-intestinal pressure. At 16 cm. pressure, approximately 8 cc. of salt solution were absorbed in 10 minutes. The volumes apparently absorbed in some of his experiments, however, were so small as to be of questionable significance.

Using the work of Wells as a starting point, Nassett and Parry(13) studied the absorption of solutions and the intestinal secretion at negative hydrostatic pressure levels ranging from -5 cm. to -25 cm. of solution. Some of the results of Wells were confirmed by Nassett and Parry, in that they observed small volumes of solution "apparently absorbed" at negative intra-intestinal pressures. The experiments are poorly described, however, because such information as the type of test solution and the length of absorption period was not given. The experimental method used was similar to that used by Wells, although one modification involved the rinsing of loops with distilled water.

In his review on absorption from the intestine, Verzar(14) mentioned experiments conducted in collaboration with Frolicher in which the observations of Wells were confirmed. Verzar concluded that "water absorption is increased as a linear function of positive pressure, i.e. real filtration is possible."

Experiments on the absorption of water from crystalloid solutions are also discussed by Verzar. Anesthetized rats were used, and the concentration of NaCl solutions ranged from 0.425% to 1.22%, the volume always being 3.0 cc. Verzar found that water was absorbed more rapidly than salt from isotonic and hypotonic solutions, and that practically no water was absorbed from hypertonic solutions, although about one-third of the NaCl was absorbed in 60 minutes. He concluded, "From hypertonic solutions, therefore, the salt diffuses out till an osmotic equilibrium with the blood is reached." Other experiments were conducted on 20 cm. jejunal loops in anesthetized cats, using isotonic NaCl. It was found that the absorption of salt was slower in cats than in rats, but the osmotic pressure of the gut contents remained equal to that of the blood throughout the absorption period.

Summarizing his observations, Verzar states, "The optimal conditions for water absorption is a hypotonic solution of a substance which quickly diffuses into the mucosa."

The results of Omi's work were mentioned by Verzar, and the graph described previously was included also in his monograph, but no statements were made concerning the methods which Omi used, or the number of experiments which the curves represent.

The acute experiments conducted by Voit and Bauer(1), Leubuscher(3), Edkins(4), Reid(5), Heidenhain(7), Wallace and Cushny(8), Wells(12), Nassett and Parry(13) and Verzar(14) are subject to several criticisms. In general, acute experiments involve anesthesia, trauma, and changes in body temperature, each of which is probably capable of altering absorption activities. In most cases only a few tests were conducted on each animal, so that it was necessary to make comparisons between animals. This type of comparison minimizes the reliability of observed differences. Few reports provide adequate information concerning such details as length of loop, volume of the test solution, and the number of tests performed, which make it difficult to compare results of different investigators. The experiments of Omi[9], Goldschmidt and Dayton[10], and Rabinovitch[11], involving chronic preparation, are subject to less objections. However, here again some comparisons of results were made between animals, and also between different days in the same animal. All of the work can be criticized because of the lack of statistical analysis. The reports reviewed thus far do not represent the complete list of papers published on the subject of NaCl absorption. Those reports which were omitted could not have contributed any additional information of value, and would have served only to emphasize the criticisms just discussed.

Bucher, Anderson, and Robinson[15] recently reported a comprehensive study of chemical changes in sodium chloride and sodium sulfate solutions occurring in three different types of preparations of both upper and lower small intestine in the dog. The data on NaCl absorption from the upper intestine are emphasized here because of the similarity to the work done in this laboratory. The three methods used by Bucher and co-workers were: 1) the Miller-Abbott technique in anesthetized dogs, 2) the obstructuve clamp method in acute preparations, and 3) the Thiry fistula in unanesthetized dogs. The authors offer six general criticisms which apply to most of the work done on intestinal absorption. Briefly, they point out that the practice of rinsing the intestinal lumen with water injures the epithelium thereby altering absorption; variation in results from consecutive tests has not been taken into account; total ion changes have not been measured, and the data have rarely been analyzed statistically.

The NaCl solution tested was about 143 mEq/1., and 25 cc. to 40 cc. volumes were placed in the loops for a period of 10 minutes. In tests on anesthetized animals, the loops were warmed with a heating pad. Chemical determinations were made on total base, NH_3, Cl^-, CO_2, and pH.

In describing the results the authors state that "sodium chloride (143 mEq/1.) was readily absorbed from the upper and lower segments, but especially in the latter, where in 10 minutes 18% of the test solution (an average of 5.4 cc.) was absorbed." The value "18%" is the mean of 18 tests in which the results from the three different types of experiments were combined. When the results from the 18 tests on the upper intestinal segments are also combined, they show that 7% of the test solution was absorbed in 10 minutes. The authors, however, neglect to mention the fact that in this series of tests, the chronic Thiry loops give results which do not compare favorably with those of the other two preparations. In fact, in <u>no</u> test was there any water or chloride absorption, and the averages of six tests show a gain of 1.8 cc. in volume, and an 0.34 mEq increase in chloride. The practice of averaging the results of experiments on different animals and making quantitative comparisons is questionable because of the surface area variable from animal to animal.

METHOD

The type of loop used in this study was first described by Omi(9), and hereafter it will be referred to as the "Omi fistula". Apparently this type of fistula has not been used for the study of absorption except by Omi, and his work has been quoted only infrequently. Since the description of the loop given by Omi was not extensive, a detailed account of the surgical preparation is given here.[1]

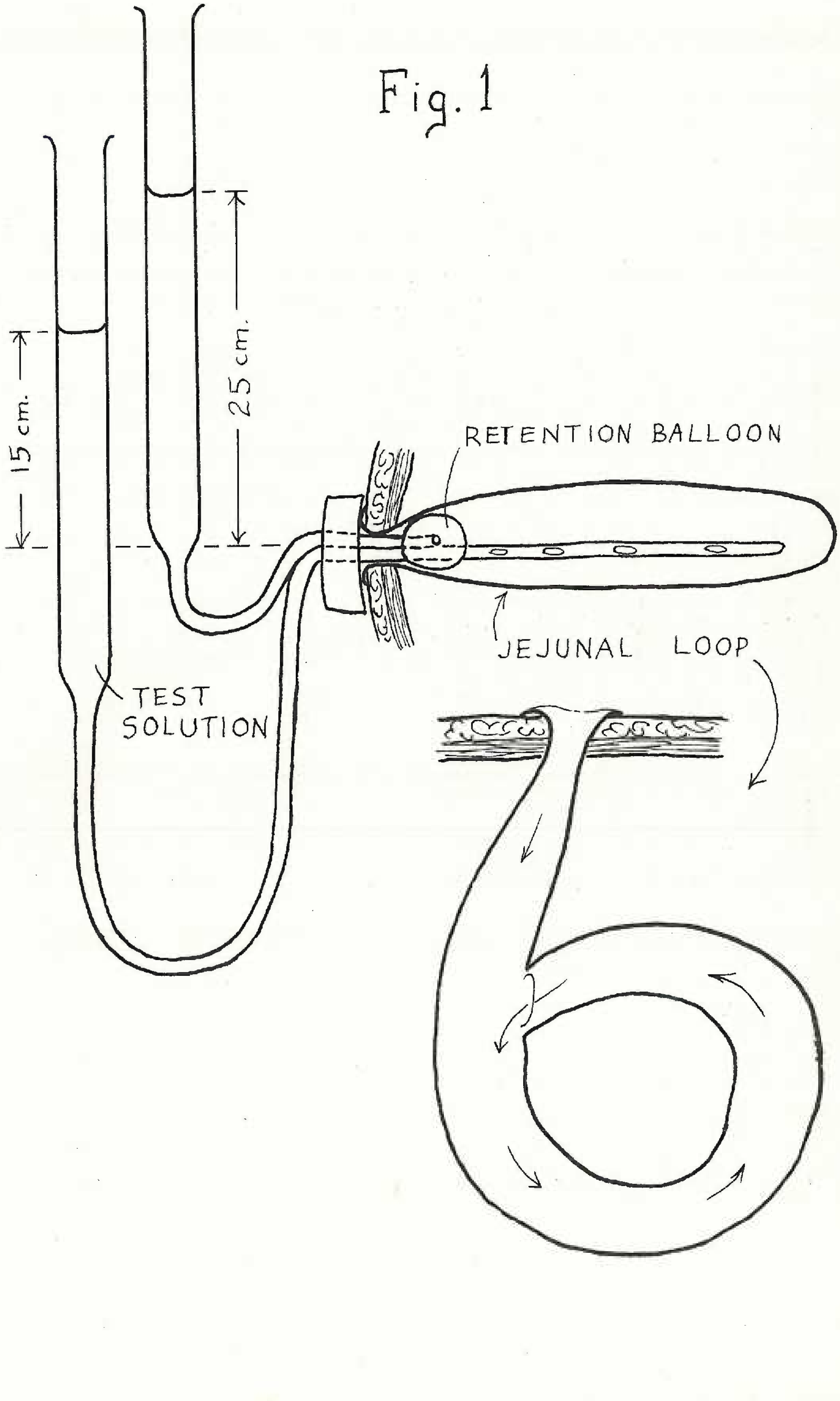
Surgical Preparation. The operation was performed on three dogs under intravenous nembutal anesthesia. The abdomen was entered through a right upper transrectus incision, and a segment of jejunum approximately 60 cm. long was isölated, beginning about 15 cm. distal to the ligament of Treitz. The continuity of the jejunum was re-established by end-to-end anastomosis, and the rent in the jejunal mesentery was closed with interrupted silk. The isolated jejunal segment was then fashioned in the shape of the number "6" by an end-to-side anastomosis of the distal stoma to the jejunal wall about 25 cm. from the proximal stoma, Fig. 1. The circular part thus formed measured about 35 cm. The proximal stoma was brought out through a stab wound to the left of the midline and above the left costal margin. In one animal the stoma was made to pass obliquely for a short distance between the costal margin and the skin, with the intention of creating some sphincter action. Peristalsis is toward the circular part, and in this portion a continuous circulation of the test solution is possible. To determine if the opening at the anastomosis was

[1]The fistulas used in this study were prepared by Dr. M. E. Steinberg before he was aware that such a loop had been used previously.

Figure 1

The Omi fistula shown with catheters and burettes

Fig. 1



patent, and a long catheter was inserted into each loop while under fluoroscopic examination. In dog "R" the catheter went around the circular part of the loop and returned to the stoma. In dogs "B" and "S" the tip of the catheter followed the circular portion of the loop for several revolutions instead of coming back out.

Testing Procedure. The dogs were fasted for 20 hours or more before each test, though water intake was permitted *ad lib*. In series I-A the animals were anesthetized with an intravenous injection of Nembutal Sodium (Abbott), 30 mgm. per kg. Additional doses of 120 mgm. were administered during the test whenever necessary. The animals were kept warm with either an electric heater or a hot water bottle, and rectal temperatures were recorded. In series I-B the same dogs were used in the unanesthetized state, and were trained to lie quietly on a table without being restrained except for a blindfold. In many cases the dogs slept during the tests.

The apparatus for regulating hydrostatic pressure, illustrated in Fig. 1, consisted of a soft rubber catheter, fashioned from a size 12 Fr. duodenal tube, with a retention balloon about 30 cm. from the end of the tube. The other end was connected to a burette. Before and after each day's testing, the retention balloon was inspected for leaks. After slowly introducing the catheter into the loop, the retention balloon was filled with water to a pressure of 25 to 35 cm. by means of a second burette. The loop was then rinsed three or more times with warmed saline, and the volumes introduced and recovered were recorded. The volume recovered on the last wash usually differed by one cc. or less from the original volume of wash solution. The loop-catheter system thus arranged permitted a constant distance to be maintained between the level of the stoma and the level of the solution in the burette. Small excursions of the burette level occurred continually, and this provided the observer with evidence that the catheter was not plugged. If leakage around the retention balloon was seen, the test was repeated.

Each absorption period lasted for 30 minutes, after which the loop-catheter system was emptied by lowering the burette to about 20 cm. below the level of the fistula. The amount of solution which was absorbed was determined by subtracting the volume recovered from the volume introduced into the burette, read to the nearest 0.5 cc. A new solution was then introduced for the next test, and the time between successive tests was about five minutes. In most cases the actual tests were preceded by a "preliminary" absorption period lasting 30 minutes to allow the loop to adjust to the experimental conditions.

An outline of the experimental plan of this study is as follows:

SERIES I. "The absorption of 0.9% NaCl solutions with intra-luminal pressure as the variable studied."

A. Dogs under anesthesia.

B. Dogs unanesthetized.

SERIES II. "The absorption of NaCl solutions with concentration as the variable studied."

Series I-A. Two methods were employed in this series of experiments. The first 90 tests were performed on dog "B" only, according to the schedule outlined in Table 1. Six different pressure levels were studied, ranging from 5 cm. to 30 cm. of saline, and fifteen individual tests were conducted at each pressure level. An average of five tests were performed at the same pressure level on each of three days, and as a result of day-to-day variations found, the method was changed. Table 2 shows the experimental plan using the revised method on all three dogs. Each of the five different pressure levels tested, ranging from 10 cm. to 30 cm. of saline, were studied in consecutive absorption periods on each day. This procedure standardizes day-to-day variation. The use of 5 cm. of pressure was discontinued in this method because it was often difficult to get any test solution to run into the loop at that pressure level.

Series I-B. The method used in this series of experiments was essentially the same as in Series I-A, except that the dogs were used in the unanesthetized state after having been trained to lie quietly on a table. The plan for these experiments is shown in Table 3.

Series II. Five different sodium chloride solutions, varying in concentration from 85.1 mEq./1/ to 216.6 mEq./1., were studied according to the plan shown in Table 4. The intra-luminal pressure was kept constant at the 15 cm. level, and the dogs were used in the unanesthetized state. The loop was rinsed one or more times with each new solution before the absorption period was started.

An allocate was saved from each test solution used, and also from each solution emptied from the loop at the end of the absorption period. Chloride determinations were made on all samples by titrating with a standard silver nitrate solution according to the method of Fajans(16).

RESULTS

The results of the experiments in SERIES I-A are shown in Tables 5 and 7, and are expressed graphically in Fig. 2. Volume measurements only are presented for the first group of experiments on Dog "B", Table 5, because chloride determinations were not performed on each individual test. Statistical analysis of variance for these data, according to the method of Dixon(17), is shown in Table 6. Comparison of the mean rates of volume absorption for the different pressure levels shows that these means are significantly different, Table 6, (a). When the means for the 10 cm. and 15 cm. pressure levels only are compared, it is seen that the difference is not significant, Table 6, (b). Inspection of the data in Table 5 suggests that the results will vary from day to day, even though the pressure level is kept constant. The analysis of the means for the three different days on which 10 cm. of saline pressure was used shows that the differences between these means are significant, Table 6, (c). Variation in the results of consecutive tests on the same day was high on some days and minimal on others. In order to determine whether or not consecutive tests showed significant differences, the data in Table 5 were re-arranged to give means for the five absorption periods, using only the results of experiments at the 10 cm. and 15 cm. pressure levels. Comparison of the means of six tests at each of five different absorption periods shows that they are not significantly different, Table 6, (d). The results of these first 90 experiments, and statistical analysis of the data were used as a basis for modifying the testing procedure in subsequent tests.

The results of 11 tests in which the revised method was used on three dogs are presented in Table 7. The rate of salt absorption was measured as chloride, and expressed in the results as NaCl. This practice may not always be justified; however, Bucher showed that the Na ions and Cl ions were absorbed at approximately the same rate in the upper small intestine(15). The results are also shown in Fig. 2, where the means for volume and NaCl absorption are plotted against intraluminal pressure, and the data for each dog are kept separate. Although the curves for the three dogs are not identical, it is clear that under the conditions of these experiments, changes in intra-intestinal hydrostatic pressure are accompanied by differences in the rate of absorption of 0.9% NaCl. Analysis of variance of these data show, however, that the only means which are significantly different are those for volume absorption in Dog "R", Table 8.

The results of the 12 tests in Series I-B are presented in Table 9, and in Figs. 3 and 4. Inspection of the curves in Fig. 3 shows that, again, the three dogs do not produce identical results. However, the shapes of the curves for these experiments are more similar than are those in Fig. 2. For example, all three curves in Fig. 3 show a general trend for absorption to increase with increments in pressure ranging from 10 cm. to 20 cm. for Dogs "B" and "S", and from 10 cm. to 30 cm. for Dog "R". Above 20 cm. of pressure, the rate of absorption decreases in Dogs "B" and "S". Although it is not evident in the graph, individual tests in Dog "R" show the same pattern, except that the maximum rate of absorption was found at a higher pressure: 35 cm. or 40 cm. of saline. The differences between the means at different pressure levels were analyzed statistically, and the information is presented in Table 10. It is seen that

Figure 2

The relation between intra-luminal pressure and the rate of absorption of 0.9% $NaCl$ solution in anesthetized dogs.

Fig. 2

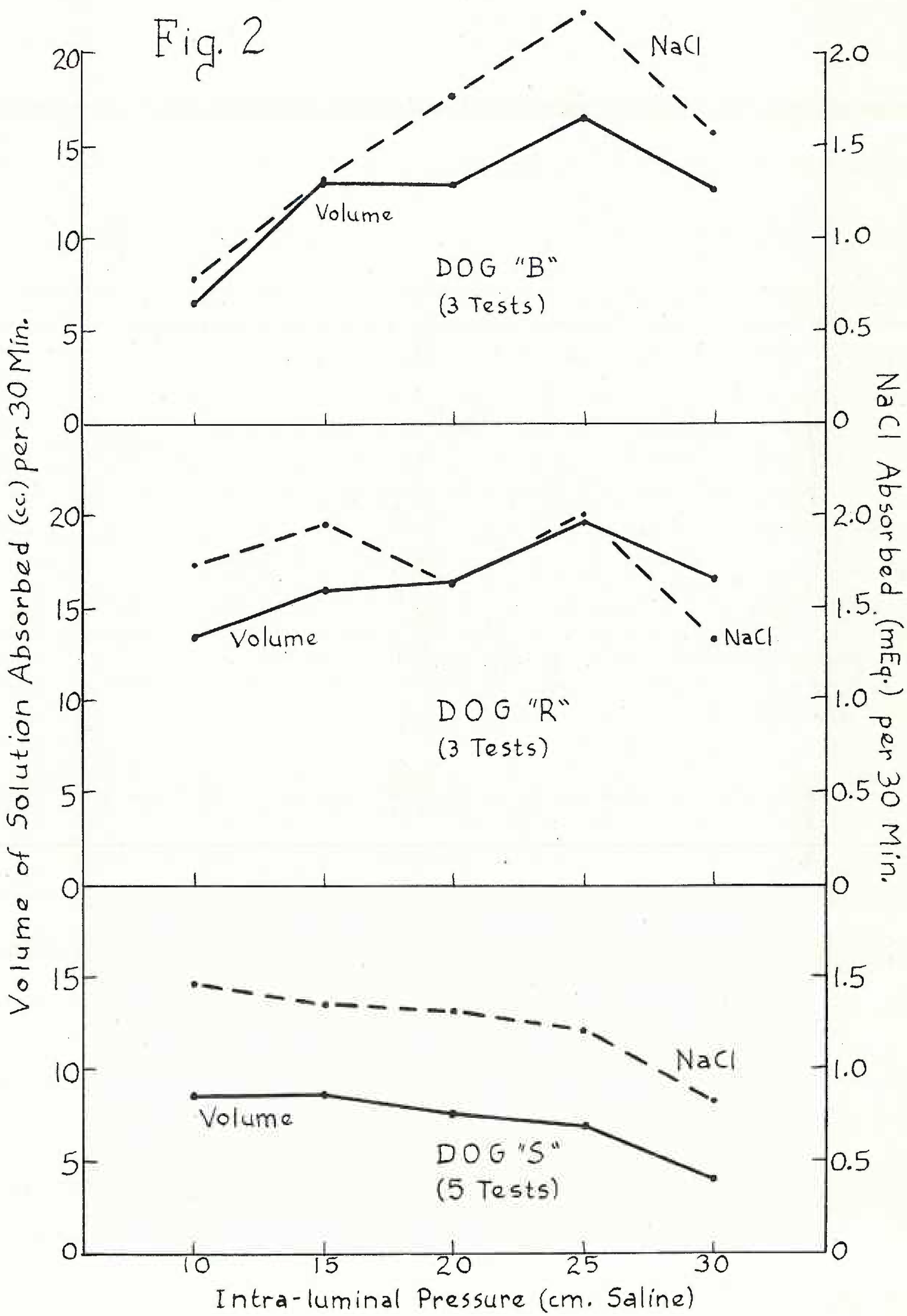

NaCl
Volume
DOG "B"
(3 Tests)
Volume
NaCl
DOG "R"
(3 Tests)
NaCl
Volume
DOG "S"
(5 Tests)
Volume of Solution Absorbed (cc.) per 30 Min.
NaCl Absorbed (mEq.) per 30 Min.
Intra-luminal Pressure (cm. Saline)

Figure 3

The relation between intra-luminal pressure and the rate of absorption of 0.9% NaCl solution in unanesthetized dogs.

Fig. 3

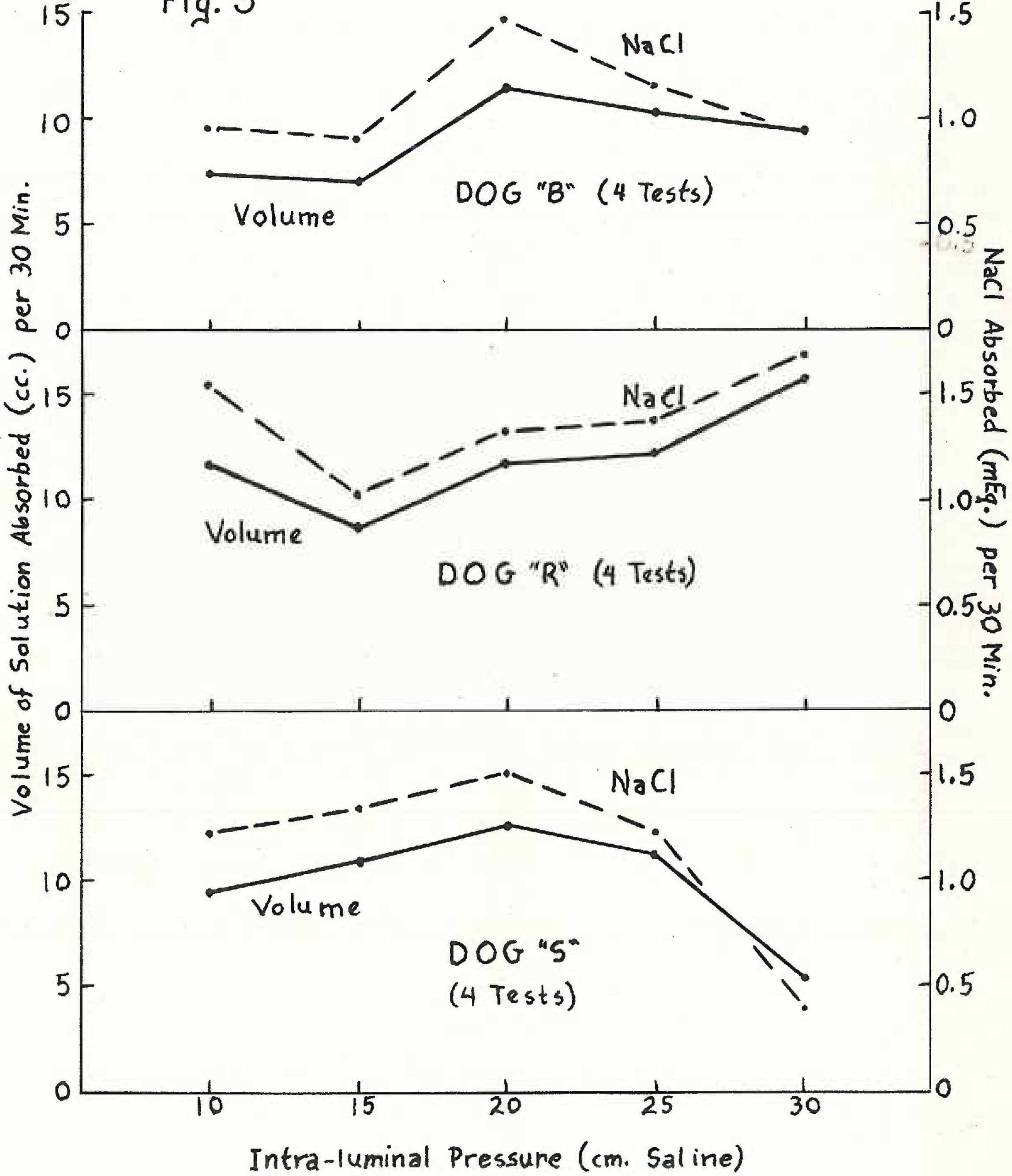
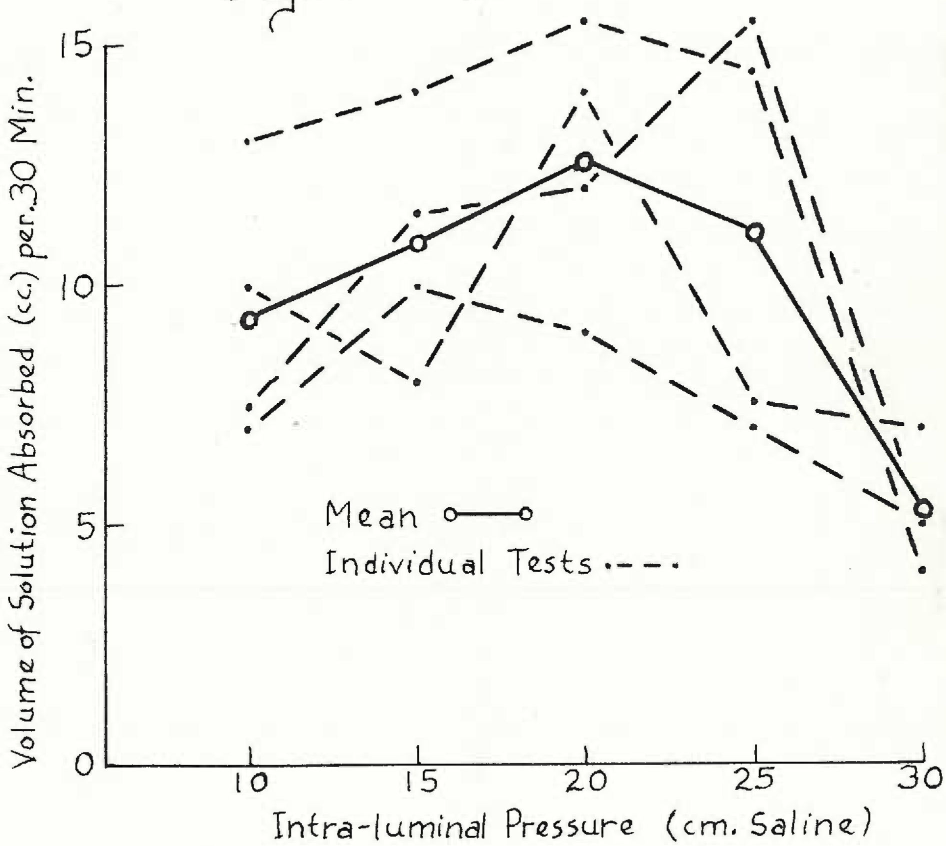

NaCl
DOG "B" (4 Tests)
Volume
NaCl
Volume
DOG "R" (4 Tests)
NaCl
Volume
DOG "S"
(4 Tests)
Volume of Solution Absorbed (cc.) per 30 Min.
NaCl Absorbed (mEq.) per 30 Min.
Intra-luminal Pressure (cm. Saline)

Figure 4

Individual tests showing the relation between intra-luminal pressure and the rate of absorption of 0.9% NaCl solution in Dog "S"

Fig. 4


15
10
5
0
10
15
20
25
30
Volume of Solution Absorbed (cc.) per 30 Min.
Intra-luminal Pressure (cm. Saline)
Mean
Individual Tests

all the means show significant differences except those for Dog "B".

In order to see how well the means represent the results of individual tests, the four experiments on Dog "S" are graphed in Fig. 4, showing only the data for volume absorption. Two of the four tests agree with the mean in regard to the pressure at which the maximum rate of absorption occurs. The best agreement among individual tests is at 30 cm. of pressure, and also at this pressure level all tests show the lowest rate of absorption.

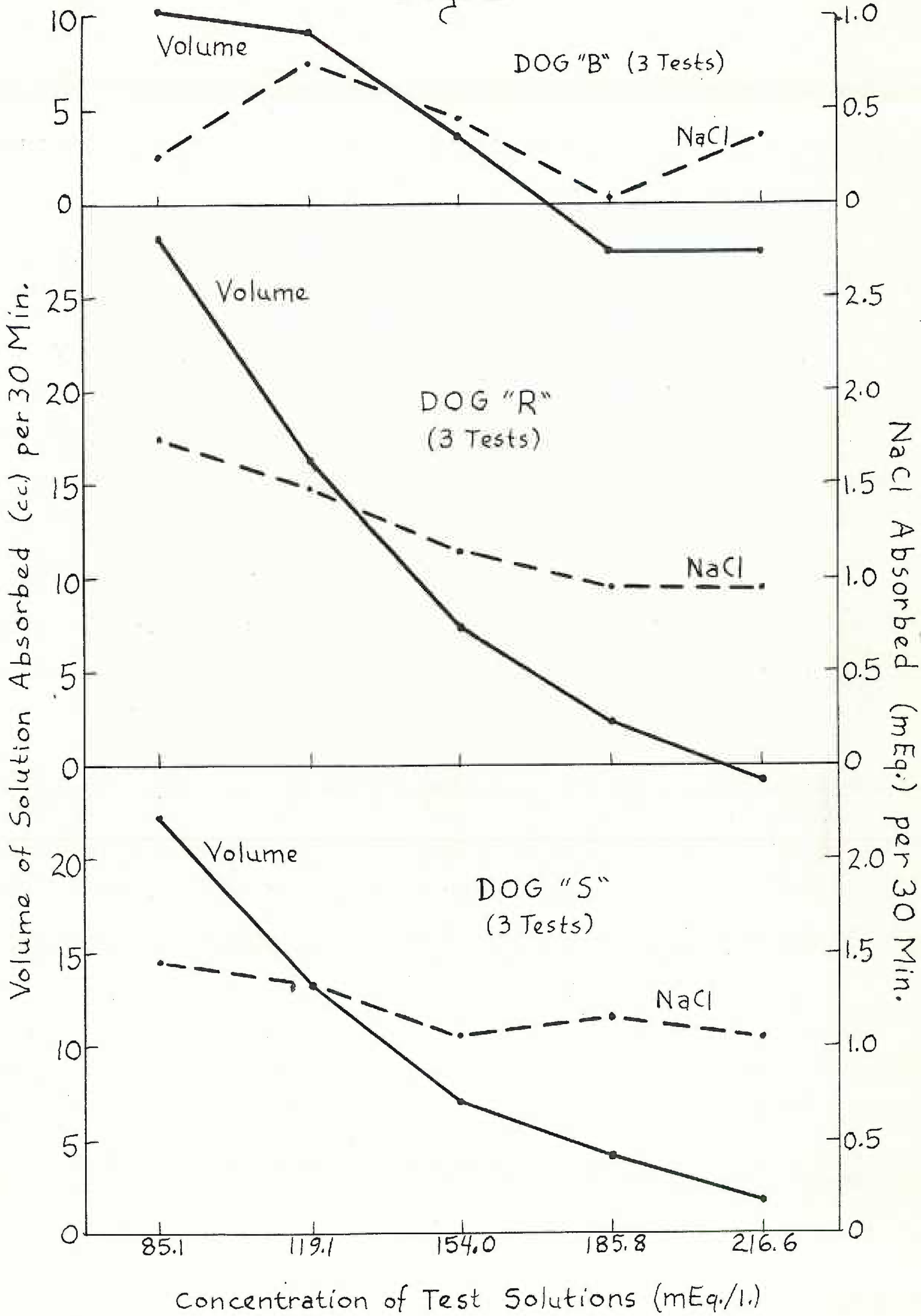
The results of the 9 tests in Series II are presented in Table 11 and in Figs. 5 and 6. Table 11 includes not only the data for volume and salt absorption, but also the calculated concentration of the solution which was apparently absorbed. The only test solution which did not change in concentration was the 154 mEq./l. solution. In Fig. 5, volume and salt absorption are plotted against concentration, and the curves show patterns which are very similar. In all three dogs the rate of volume absorption of the dilute solution was highest, and as the concentration of the test solutions was increased, the absorption rates decreased. In the case of NaCl absorption, the patterns shown by the three dogs are not so consistent. The curves for dogs "R" and "S" show a slight tendency for salt absorption to decrease as the test solutions increase in concentration. Analysis of variance for these data is presented in Table 12, which shows that the means for volume absorption are significantly different, while those for NaCl absorption are not.

The data for volume absorption in individual tests on Dog "R" are shown graphically in Fig. 6. This shows clearly that the shapes of the curves for the three individual tests are almost identical, and that they follow closely the pattern described by the mean.

Figure 5

The relation between concentration and the rate of absorption of NaCl solution

Fig. 5

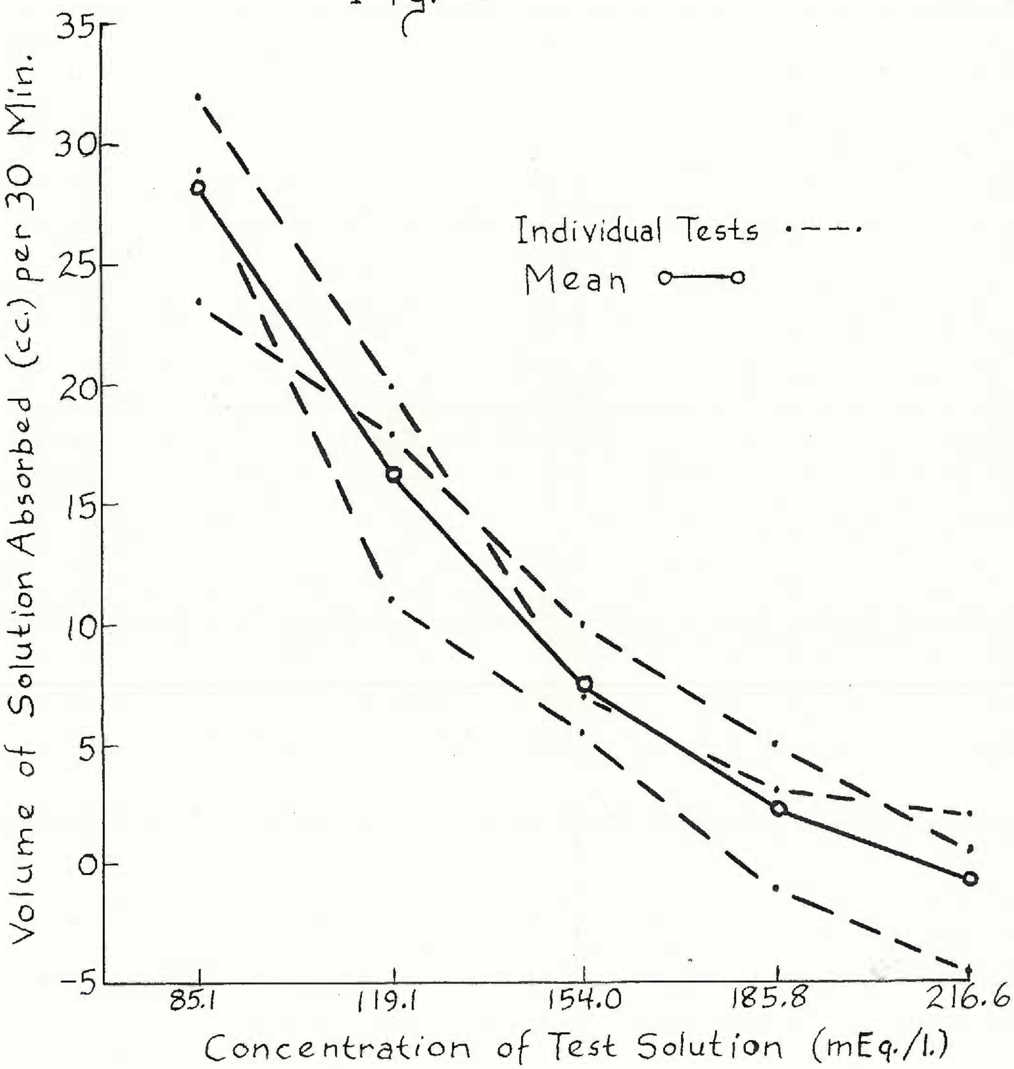


Volume
DOG "B" (3 Tests)
NaCl
Volume
DOG "R"
(3 Tests)
NaCl
Volume
DOG "S"
(3 Tests)
NaCl
Volume of Solution Absorbed (cc.) per 30 Min.
NaCl Absorbed (mEq.) per 30 Min.
85.1
119.1
154.0
185.8
216.6
Concentration of Test Solutions (mEq./l.)

Figure 6

Individual tests showing the relations between concentration and the rate of absorption of NaCl solution in Dog "R"

Fig. 6


Individual Tests
Mean
35
30
25
20
15
10
5
0
−5
85.1
119.1
154.0
185.8
216.6
Volume of Solution Absorbed (cc.) per 30 Min.
Concentration of Test Solution (mEq./l.)

DISCUSSION

The absorption measured in this study is net absorption, and can be defined as the net change in the volume of water and in the amount of NaCl which occurs in a test solution when it is placed in a segment of intestine.

The results of the experiments in which pressure was studied agree generally with those of Leubuscher[3], who showed that absorption increases with increments in intra-intestinal pressure until an optimal pressure is reached, beyond which absorption is less. The pressure level at which this change took place was much higher in Leubuscher's work (80 mm. to 100 mm. Hg.) than in the present study (15 cm. to 30 cm. of saline). The explanation given by Leubuscher that high pressure interfered with blood flow through the intestine is sound in principle, but interference with blood flow should occur at pressure levels lower than 80 mm. Hg. Dragstedt, Lang, and Millet showed that venous blood flow from the jejunum and ileum ceased when the intestine was distended with 55 mm. to 65 mm. Hg. pressure[18]. Another possible explanation for less net absorption at intra-luminal pressures higher than 15 cm. to 30 cm. saline is that pressure itself stimulates secretion by the intestinal glands. This property of the intestine is demonstrated in obstructed segments which become distended with secretion at high pressures[19]. The condition of intestinal obstruction may be approximated in the use of blind loops for the study of absorption, where peristaltic activity forces the test solution towards the blind end of the loop. In fact this should be considered as a possible explanation for the increase in volume in Thiry loops reported by Bucher et al[15]. In the present study a few individual tests showed negative absorption at 30 cm. to 40 cm. of saline pressure.

The results of experiments on Dog "S" in the anesthetized state are different from the other results in that the variation of absorption rates with different pressure levels was very slight. A reasonable explanation for these results is that the forces which have a tendency to increase absorption at higher pressures, such as filtration and increased absorption area, were balanced by forces which operate in the opposite direction, such as secretion and interference with blood flow. This situation did not exist in experiments on Dog "S" in the unanesthetized state.

There is no doubt that changes in the concentration of NaCl solutions alter the rate of volume absorption. The results of this study confirm those of Heidenhain(7), Omi(9), Rabinovitch(11), and Verzar(14) in that dilute solutions were found to be absorbed more rapidly than concentrated solutions. There is less agreement, however, on the influence of concentration on the absorption of NaCl. Omi's results indicate that the rate of absorption of NaCl and the concentration of the test solution vary in the same direction within the range of 0.25% to 0.9% NaCl. His results were criticized earlier in this paper. Rabinovitch found that within the range of 0.6% to 1.5% NaCl there was no great variation in the amount of salt absorbed. The results of the present study show that within the range of 85 mEq./l. to 217 mEq./l. (approximately 0.5% to 1.3%) the rate of NaCl absorption tends to decrease with increases in concentration of the test solution although the differences were not significant.

Rabinovitch also observed that solutions of 0.6% NaCl or lower gain in chloride concentration while present in the intestinal lumen, and that solutions of 0.7% NaCl or higher become more dilute. In the present study it was found that the 154 mEq./l. NaCl (0.9%) solution underwent negligible changes in concentration while in the gut, and that all other test solutions tended to approach that concentration during the absorption test.

There are a number of variables which the investigator must take into consideration when studying intestinal absorption. Variation in the results of experiments conducted on different animals is important. Differences between animals can be attributed mainly to differences in the size of the intestinal segment used for the study. Usually the investigator attempts to keep the size constant from one loop to another by measuring the length, but anyone who has measured bowel realizes that it is constantly undergoing changes in size, in both circular and longitudinal directions. Differences in the diameter of the loops is another source of animal-to-animal variation.

Variation from day to day in a given animal should also be considered. One possible reason for such variation is that the animal may not always be hydrated to the same extent, even though he is permitted to drink water ad lib. When intra-luminal pressure is studied, the loop may not always be in exactly the same position from day to day, which would produce differences in the mean hydrostatic pressure within the lumen. Another possible cause for day-to-day variation is fluctuations in hormone balance, especially those hormones of the posterior pituitary and the adrenal cortex in studies on water and salt absorption.

The possibility must be considered that variation from one test to another on the same day in a given animal may be a source of unreliable results. Analysis of results obtained in tests on Dog "B" showed that this type of variation was not significant. However, if such a variable exists its influence can be minimized by randomising the sequence of experimental procedures employed. This precauation was taken in the present study.

On the basis of the results of this study and a critical review of the work of other investigators, a list of requirements for a reliable experimental method can be formulated:

1) The animals should be used in the unanesthetized state. The use of chronic loop preparations permits this condition.

2) The loops should allow for the continual circulation of test solutions. The Omi loop is a suitable example.

3) Hydrostatic pressure of the solution in the intestinal lumen should be controlled.

4) Concentration of the test solution should be controlled. A suitable concentration for NaCl solution is 154 mEq./l. when variables other than concentration are studied.

5) Comparison of the results should be made only on successive tests in the same animal on the same day.

SUMMARY

Intestinal absorption has been studied by many investigators; however, much of the early work involved acute experiments on either intact or isolated segments. These methods necessitated traumatic procedures and prevented periodic studies of the same animal. Also statistical analysis of results has been employed in only a few recent studies. Therefore, it seemed desirable to re-investigate the absorption of simple solutions, using more physiologic methods and planning the experiments so that the results might lend themselves to statistical analysis. The present studies are concerned with effects of hydrostatic pressure in the intestinal lumen and effects of concentration of the solution on the rate of absorption of sodium chloride and water. The term "absorption" is used to refer to the net change in the amount of a substance during the time that it is present in the intestine.

Chronic fistulas, fashioned in the shape of the number "6", were prepared from upper jejunum in three dogs. The circular part of the fistula was constructed by making an end-to-side anastomosis at the aboral end of the segment, and the oral end was made to open through the abdominal wall. In each dog patency of the fistula was demonstrated by radiologic methods. The test solution was inserted into the fistula by means of a catheter attached to a burette which was placed so that the level of the solution could be maintained a given distance above the level of the loop.

I. In the first series of experiments the rate of absorption of approximately 0.9% NaCl solution (154 mEq./l.) was studied at six different pressure levels ranging from 5 cm. to 30 cm. of solution. In some of

the experiments of this series the dogs were anesthetized and in others they were trained to lie quietly without anesthesia. In the earlier studies the rate of absorption of NaCl solution at a given pressure level was determined repeatedly in the same animal on the same day and on different days. Considerable day-to-day variation in absorption was observed; therefore in subsequent studies all of the different pressure levels were studied on the same day.

II. In the second series of experiments intra-luminal pressure was held at a constant level, and the rates of absorption of five different NaCl solutions, ranging in concentration from 85 mEq./l. to 217 mEq./l., were studied. In this series the animals were unanesthetized and each of the different concentrations was tested on each day.

It was found that: 1) At the different levels of hydrostatic pressure studied there were statistically significant differences in the rate of absorption of NaCl and water from NaCl solution. There was an optimal pressure level at which absorption was most rapid. 2) A greater volume of solution was absorbed the more dilute the test solution; therefore concentration was an important factor in the absorption of water. In the presence of a constant hydrostatic pressure, there were no significant differences in the rate of NaCl absorption from the five solutions of different concentrations. The results concerning the effect of hydrostatic pressure on absorption agree generally with those of other investigators. The observed relation between concentration of test solution and the rate of volume absorption is also in agreement with the results of others. Some investigators have reported considerable differences in the rate of absorption of NaCl from solutions of different concentrations, whereas in this study no significant differences were observed. Further studies employing more dilute solutions would be necessary to determine the level at which the concentration of NaCl becomes a limiting factor in its rate of absorption.

Several important variables which need to be considered in studies on intestinal absorption are discussed. It is concluded that an experimental approach as follows should be used in order to control the principal variables: 1) The animals should be in the unanesthetized state and under near-basal conditions. 2) The loops should allow for circulation of the test solutions. 3) Hydrostatic pressure and concentration should be controlled within rather narrow limits. 4) Comparison and analysis of the results should be made on successive tests in the same animal on the same day.

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TABLE 1. EXPERIMENTAL PLAN FOR SERIES I-A

(Old Method on Dog "B")

Date	No. of Tests	Pressure Used
7-24-50	4	10 cm.
7-26-50	6	10
7-28-50	5	10
7-31-50	5	15
8-2-50	5	15
8-4-50	5	15
8-7-50	5	20
8-9-50	5	20
8-11-50	5	20
8-14-50	5	5
8-16-50	5	5
8-18-50	5	5
8-23-50	5	30
8-25-50	5	30
8-28-50	5	30
8-30-50	5	25
9-1-50	5	25
9-6-50	5	25

TABLE 2. EXPERIMENTAL PLAN FOR SERIES I-A

(Revised Method; All Dogs Used)

Dog	Date	Sequence of Pressures Tested					
		1	2	3	4	5	6
	11-30-50	15 cm.	30 cm.	20 cm.	35 cm.	10 cm.	25 cm.
"B"	12-26-50	15	15	20	10	25	30
	3-3-51	15	15	10	20	30	25
	2-1-51	15	15	25	10	20	30
"R"	2-8-51	15	15	10	20	30	25
	2-15-51	15	15	25	30	20	10
	10-19-50	10	20	30	25	15	—
	10-26-50	15	25	10	20	30	—
"S"	11-2-50	15	30	20	10	25	—
	11-9-50	10	20	25	15	30	—
	12-26-50	15	20	10	30	25	—

TABLE 3. EXPERIMENTAL PLAN FOR SERIES I-B

Dog	Date	Sequence of Pressures Tested					
		1	2	3	4	5	6
"B"	1-11-51	15 cm.	15 cm.	20 cm.	25 cm.	10 cm.	30 cm.
	1-19-51	15	15	25	10	20	30
	1-25-51	15	15	25	10	20	30
	3-29-51	15	15	10	25	20	30
"R"	12-28-50	15	15	25	10	30	20
	1-18-51	15	15	20	10	25	30
	1-26-51	15	15	25	30	20	10
	3-1-51	15	15	25	30	20	10
"S"	1-4-51	15	20	10	25	30	—
	1-19-51	15	15	25	30	20	10
	1-25-51	15	15	25	30	20	10
	3-3-51	15	15	10	20	30	25

TABLE 4. EXPERIMENTAL PLAN FOR SERIES II

Dog	Date	Sequence of Concentrations Tested					
		1	2	3	4	5	6
		(mEq./l.)	(mEq./l.)	(mEq./l.)	(mEq./l.)	(mEq./l.)	(mEq./l.)
	4-26-51	154.0	154.0	119.1	85.1	185.8	216.6
"B"	5-1-51	154.0	154.0	85.1	119.1	185.8	216.6
	5-12-51	154.0	154.0	216.6	185.8	119.1	85.1
	4-26-51	154.0	154.0	85.1	119.1	185.8	216.6
"R"	5-3-51	154.0	154.0	216.6	185.8	119.1	85.1
	5-10-51	154.0	154.0	85.1	119.1	185.8	216.6
	4-26-51	85.1	85.1	154.0	119.1	185.8	216.6
"S"	5-3-51	154.0	154.0	216.6	185.8	119.1	85.1
	5-10-51	154.0	154.0	85.1	119.1	185.8	216.6

TABLE 5. SERIES I-A: THE EFFECT OF INTRA-LUMINAL PRESSURE ON THE ABSORPTION OF 0.9% NaCl SOLUTIONS

(Old Method on Dog "B", Under Anesthesia. 30-minute Absorption Periods)

Test No.	5 cm. Saline	10 cm. Saline	15 cm. Saline	20 cm. Saline	25 cm. Saline	30 cm. Saline
1	11.0 cc.	17.0 cc.	16.0 cc.	19.5 cc.	15.5 cc.	-1.0 cc.
2	7.5	17.0	17.0	21.0	16.0	2.5
3	7.5	17.0	18.0	26.0	16.5	6.5
4	6.0	15.0	17.5	22.5	18.0	4.0
5	4.5	20.5	17.0	15.0	10.0	5.5
6	14.5	25.5	21.5	21.0	14.0	11.5
7	8.5	22.0	21.5	24.5	15.5	10.0
8	8.0	21.0	21.5	25.0	9.5	10.5
9	16.0	24.0	16.5	20.0	9.0	12.5
10	9.0	22.0	19.5	18.0	5.5	10.0
11	11.0	18.0	16.5	23.5	14.5	6.0
12	5.5	16.5	18.5	22.0	12.0	-1.0
13	6.5	14.5	18.5	22.5	12.0	0.0
14	8.0	18.0	21.0	20.5	8.0	4.5
15	9.5	14.0	17.5	20.5	4.5	2.0
Mean	8.87	18.80	18.53	21.43	12.03	5.57

TABLE 6. SERIES I-A: ANALYSIS OF VARIANCE FOR DATA IN TABLE NO. 5

(a) Comparison of all means

	Sum of Squares	d.f.	Variance	F Ratio
Means	2998.9	5	599.79	F = 50.36 *
Within Groups	1000.8	84	11.91	F.05 = 2.35
(b) Comparison of means for 10 cm. and 15 cm. pressures only.				
Means	0.53	1	0.53	F = 0.07
Within Groups	227.64	28	8.13	F.05 = 4.19
(c) Comparison of means for 3 different days at 10 cm. pressure Means: Day No.1 = 17.3 cc; Day No. 2 = 22.9 cc; Day No. 3 = 16.2 cc.				
Means	129.1	2	64.6	F = 17.9 *
Within Groups	43.3	12	3.6	F.05 = 3.89
(d) Comparison of means for different test periods at 10cm. and 15 cm. pressures. Means: Period No. 1 = 19.1 cc; No. 2 = 18.8 cc; No. 3 = 18.4 cc; No. 4 = 18.7 cc; No. 5 = 18.4 cc.				
Means	1.84	4	0.46	F = 0.05
Within Groups	226.33	25	9.05	F.05 = 2.76

* Significant

TABLE 7. SERIES I-A: THE EFFECT OF INTRA-LUMINAL PRESSURE ON THE ABSORPTION OF 0.9% NaCl SOLUTION IN ANESTHETIZED DOGS. (Revised Method. 30-Minute Absorption periods)

Dog	Test No.	10 cm. Saline		15 cm. Saline		20 cm. Saline		25 cm. Saline		30 cm. Saline	
		Vol. (cc.)	NaCl (mEq.)	Vol. (cc.)	NaCl (mEq.)	Vol. (cc.)	NaCl (mEq.)	Vol. (cc.)	NaCl (mEq.)	Vol. (cc.)	NaCl (mEq.)
"B"	1	0.0	-.79	18.5	2.09	14.5	1.44	31.0	3.66	22.0	2.05
	2	12.0	1.97	12.0	2.02	15.0	2.51	10.0	1.69	8.0	1.47
	3	8.0	1.21	9.0	-.09	9.5	1.40	9.0	1.33	8.5	1.23
	Mean	6.7	0.79	13.2	1.34	13.0	1.78	16.7	2.23	12.8	1.58
"R"	1	12.0	1.66	12.5	1.49	17.0	1.71	18.5	1.91	16.5	1.47
	2	14.0	1.73	18.0	2.32	16.5	1.73	21.5	2.07	18.5	1.64
	3	14.5	1.83	17.5	2.09	16.0	1.44	19.0	2.02	15.0	1.18
	Mean	13.5	1.74	16.0	1.97	16.5	1.63	19.7	2.00	16.7	1.43
"S"	1	4.5	0.85	4.0	0.58	4.0	0.89	3.0	0.70	-2.0	0.10
	2	1.0	0.22	12.0	1.88	10.0	1.66	15.5	2.51	7.0	1.21
	3	22.0	3.64	10.5	1.73	11.5	1.78	4.0	0.72	2.0	0.36
	4	8.5	1.44	8.5	1.30	8.0	1.37	8.0	1.32	8.0	1.37
	5	7.0	1.15	8.5	1.37	5.0	0.87	4.5	0.79	6.0	1.09
	Mean	8.6	1.46	8.7	1.37	7.7	1.31	7.0	1.21	4.2	0.83

TABLE 8. SERIES I-A: ANALYSIS OF VARIANCE FOR DATA IN TABLE NO.7

(a) Comparison of means for volume absorption

Dog	Sum of Squares		d.f.	Variance	F Ratio
"B"	Means Within Groups	156.49 577.24	4 10	39.12 57.72	F = 0.68 F.05 = 3.48
"R"	Means Within Groups	57.90 33.84	4 10	14.48 3.38	F = 4.28 * F.05 = 3.48
"S"	Means Within Groups	67.46 499.10	4 20	16.87 24.95	F = 0.67 F.05 = 2.87
(b) Comparison of means for NaCl absorption					
"B"	Means Within Groups	3.40 11.37	4 10	0.85 1.14	F = 0.75 F.05 = 3.48
"R"	Means Within Groups	0.67 0.57	4 10	0.168 0.057	F = 2.95 F.05 = 3.48
"S"	Means Within Groups	1.22 12.03	4 20	0.31 0.60	F = 0.5 F.05 = 2.87

*Significant

TABLE 9. SERIES I-B: THE EFFECT OF INTRA-LUMINAL PRESSURE ON THE ABSORPTION OF 0.9% NaCl SOLUTION IN UNANESTHETIZED DOGS. (30-Minute Absorption Periods)

Dog	Test No.	10 cm. Saline		15 cm. Saline		20 cm. Saline		25 cm. Saline		30 cm. Saline	
		Vol. (cc.)	NaCl (mEq.)	Vol. (cc.)	NaCl (mEq.)	Vol. (cc.)	NaCl (mEq.)	Vol. (cc.)	NaCl (mEq.)	Vol. (cc.)	NaCl (mEq.)
"B"	1	2.5	0.15	4.0	0.41	7.0	0.79	8.0	0.72	8.0	0.51
	2	13.0	1.71	11.0	1.40	15.0	1.81	18.5	2.21	17.5	1.91
	3	7.0	0.97	8.0	1.06	13.0	1.56	15.0	1.83	12.0	1.23
	4	6.5	0.97	5.0	0.74	11.0	1.62	-0.5	-.19	0.0	0.02
	Mean	7.3	0.95	7.0	0.90	11.5	1.45	10.3	1.14	9.4	0.92
"R"	1	14.0	1.78	8.5	0.80	11.0	1.11	9.5	0.82	11.0	1.03
	2	9.0	1.18	8.0	0.85	11.0	1.26	15.0	1.62	17.5	1.64
	3	13.0	1.71	7.5	0.85	13.0	1.26	11.5	1.28	19.0	1.90
	4	10.5	1.52	10.5	1.59	11.5	1.59	12.0	1.76	15.0	2.15
	Mean	11.6	1.55	8.6	1.02	11.6	1.31	12.0	1.37	15.6	1.68
"S"	1	7.5	0.75	11.5	1.09	12.0	1.35	15.5	1.47	5.0	0.02
	2	7.0	0.96	10.0	1.26	9.0	0.87	7.0	0.65	5.0	0.32
	3	13.0	1.61	14.0	1.74	15.5	1.74	14.5	1.69	4.0	0.15
	4	10.0	1.50	8.0	1.21	14.0	2.03	7.5	1.06	7.0	1.04
	Mean	9.4	1.21	10.9	1.33	12.6	1.50	11.1	1.22	5.25	0.38

TABLE 10. SERIES I-B:

ANALYSIS OF VARIANCE FOR DATA IN TABLE NO. 9

(a) Comparison of means for volume absorption

Dog	Sum of Squares		d.f.	Variance	F Ratio
"B"	Means Within Groups	59.95 494.69	4 15	14.99 32.98	F = 0.45 F.05 = 3.06
"R"	Means Within Groups	99.04 75.76	4 15	24.76 5.05	F = 4.90 * F.05 = 3.06
"S"	Means Within Groups	127.04 131.01	4 15	31.76 8.74	F = 3.63 * F.05 = 3.06
	(b) Comparison of means for NaCl absorption				
"B"	Means Within Groups	0.85 7.91	4 15	0.21 0.53	F = 0.4 F.05 = 3.06
"R"	Means Within Groups	1.00 1.00	4 15	0.250 0.067	F = 3.73 * F.05 = 3.06
"S"	Means Within Groups	2.98 2.78	4 15	0.745 0.185	F = 4.03 * F.05 = 3.06

* Significant

TABLE 11. SERIES II: THE EFFECT OF CONCENTRATION ON THE ABSORPTION OF NaCl SOLUTIONS

(30-Minute Absorption Periods)

Dog	85.1 mEq./l.			119.1 mEq./l.			154.0 mEq./l.			185.8 mEq./l.			216.6 mEq./l.		
	Vol. (cc.)	NaCl (mEq.)	Conc. (mEq/1)	Vol. (cc.)	NaCl (mEq.)	Conc. (mEq/1)	Vol. (cc.)	NaCl (mEq.)	Conc. (mEq/1)	Vol. (cc.)	NaCl (mEq/1)	Conc. (mEq/1)	Vol. (cc.)	NaCl (mEq.)	Conc. (mEq/1)
	11.0	0.15	13	2.0	0.41	205	2.0	-0.01	—	-4.0	0.06	—	0.0	-0.20	—
"B"	8.0	0.32	40	6.5	1.89	304	0.0	1.39	—	-2.5	0.18	—	-6.0	0.52	—
	12.0	0.34	28	19.0	-0.01	—	9.0	0.02	2	-1.0	-0.18	180	-1.5	0.77	—
Mean	10.3	0.27	27	9.2	0.76	255	3.7	0.47	2	-2.5	0.02	—	-2.5	0.36	—
	23.5	1.47	62	18.0	1.83	101	10.0	1.54	154	5.0	1.40	280	0.5	1.01	2020
"R"	32.0	2.38	74	20.0	1.90	95	7.0	0.98	140	3.0	1.09	363	2.0	1.14	570
	29.0	1.39	47	11.0	0.74	67	5.5	0.93	169	-1.0	0.41	—	-4.5	0.73	—
Mean	28.2	1.75	61	16.3	1.49	88	7.5	1.15	154	2.3	0.97	322	-0.7	0.96	—
	20.5	1.61	78	16.0	1.73	108	9.0	1.37	152	5.5	1.34	243	2.5	1.22	488
"S"	23.0	1.12	48	10.0	0.79	79	4.0	0.62	155	1.0	0.72	720	-1.0	0.60	—
	23.0	1.62	70	14.0	1.50	107	8.0	1.23	154	6.0	1.42	237	4.0	1.34	335
Mean	22.2	1.45	65	13.3	1.34	98	7.0	1.07	154	4.2	1.16	400	1.8	1.05	412

TABLE 12. SERIES II: ANALYSIS OF VARIANCE FOR DATA IN TABLE NO.11

(a) Comparison of means for volume absorption

Dog		Sum of Squares	d.f.	Variance	F Ratio
"B"	Means Within Groups	451.6 233.1	4 10	112.9 23.3	F = 4.84 * F.05 = 3.48
"R"	Means Within Groups	1638.8 134.2	4 10	409.7 13.4	F = 30.5 * F.05 = 3.48
"S"	Means Within Groups	761.2 109.2	4 10	190.3 10.9	F = 17.4 * F.05 = 3.48
	(b) Comparison of means for NaCl absorption				
"B"	Means Within Groups	0.9 3.86	4 10	0.2 0.39	F = 0.56 F.05 = 3.48
"R"	Means Within Groups	1.43 2.28	4 10	0.36 0.23	F = 1.57 F.05 = 3.48
"S"	Means Within Groups	0.37 1.55	4 10	0.09 0.16	F = 0.6 F.05 = 3.48

* Significant