THE EFFECT OF BREATHING 95 PER CENT OXYGEN UPON THE INTRALUMINAL PRESSURE OCCASIONED BY GASEOUS DISTENTION OF THE OBSTRUCTED SMALL INTESTINE

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IN A NUMBER of recent communications the value of breathing 95 per cent oxygen for the relief of intractable gaseous distention of the intestine has been set forth on the basis of clinical and experimental data.[1, 2, 3, 4] The laboratory studies which provided the basis for clinical application of the method demonstrated the capacity of 95 per cent oxygen to deflate a closed loop of small intestine distended with nitrogen, which, in man, forms the major constituent of the distending gases. The mechanism by which the oxygen accomplishes this result consists in the exclusion of nitrogen from the inspired air. According to the law of gases, the diffusion of any gas through a semipermeable membrane is proportional to the difference between its partial pressure upon the two sides of the membrane. Inhalation of pure oxygen necessarily reduces the pressure of nitrogen in the lungs toward zero, so that nitrogen in the blood diffuses into the expired air; and by the same mechanism the resulting reduced partial pressure of nitrogen in the blood allows this gas to diffuse more rapidly from any body cavity or tissue space into the blood, whence it is expelled through the lungs. *The oxygen per se has no direct effect on the diffusion process. Its virtue lies only in the fact that, when properly used, it is a convenient respirable gas which prevents nitrogen from being inhaled.*

The experimental studies clearly demonstrated that: By causing an animal to breathe pure oxygen instead of air, the volume of nitrogen in a closed loop of small intestine distended with this gas can be reduced in 24 hours to about 40 per cent of its original volume. This is in contrast to an average variation of only 10 per cent of the original gas volume when the animal breathes room air for the same period of time. The pathologic changes in ileus are primarily referable to the effect of increased intraluminal tension, rather than gas volume. We propose, therefore, in this paper to supplement the observations already published[1, 2, 3, 4] on gas volume changes with experimental data on comparative intra-intestinal pressure changes in the bowel distended with air or nitrogen: (1) In animals breathing room air; and (2) in animals breathing pure oxygen.

Method.—The abdomen of cats, starved for 24 hours, was opened under intraperitoneal nembutal anesthesia and the pylorus ligated. A large glass

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cannula was securely tied into the lowest portion of the ileum and an occluding ligature placed immediately distal to the cannula. The abdominal wall was closed around the other end of the cannula, which was connected by a T-tube to a mercury manometer and to a Perusse pressure bottle. The intestine was then inflated with atmospheric air by increasing increments of pressure until a final pressure of 800 Mm. of water was established at the end of five hours. This pressure was maintained for one hour, following which the Perusse bottle was clamped off. The intraluminal pressure was recorded on a slowly moving kymograph until the animal died or was sacrificed. One group of 12 cats breathed atmospheric air, another group of 14 breathed pure oxygen from the time the Perusse bottle was clamped off until the experiment terminated. Intra-intestinal pressure tracings, data on the bowel and peritoneal fluid content, bowel weight, length, and gross appearance were compared in these two groups. A third group of four cats, in which the intestine was similarly treated except that no air was injected into the intestine, served as controls for the data on bowel weight and length, intra-intestinal and intraperitoneal fluid content. All of the animals were kept under intraperitoneal nembutal anesthesia for the duration of the experiments.

The selection of a final intra-intestinal pressure of 800 Mm. of water (60 Mm. Hg.) as a basis for a comparison of the deflating process in an animal breathing air as against one breathing oxygen, is somewhat arbitrary. It was chosen because it represents a level of intraluminal tension which, though considerably in excess of that which is ordinarily observed clinically,* may, if sustained for a number of hours, be considered sufficiently high to cause local and constitutional effects and at the same time to serve as an adequate test of the capacity of oxygen inhalations to decompress a severely distended intestine. The establishment of this degree of pressure was purposefully effected in stages over a period of five hours, rather than abruptly, in order to simulate to some degree the clinical condition in which the tension accumulates over a period of hours or days rather than minutes.

Results.—When the small intestine of the cat, ligated at the pylorus and ileocecal valve, is gradually distended with air to a pressure of 800 Mm. of water in accordance with the technic described above, the subsequent course of events, in the average instance in an animal breathing air, is as follows: There is a slow and steady decline in the intraluminal pressure for a few hours to an average minimum of 433 Mm. of water, with extremes varying from 130 to 774 Mm. of water. The physiologic processes operating to reduce

* The intra-enteric pressure in mechanical obstruction of the small intestine in man has been observed to vary between 40 and 140 Mm. of water pressure, with increases as high as 300 Mm. during peristaltic activity.[5] Such determinations of the intra-enteric pressure, unless made under constant volumetric conditions, may be considered lower than the actual values. We have observed in the cat a drop from 364 Mm. of water pressure to 277 Mm. upon the withdrawal of 2.5 per cent of the total gas volume in the bowel, and from 277 to 91 Mm. when 7 per cent was withdrawn. Hence a leak around the needle injected into the bowel, or an appreciable displacement of gas into the manometric system, will register a pressure below its true value.

the initial pressure may be threefold: (1) The nitrogen diffuses slowly into the blood stream (and possibly into the peritoneal cavity) because its tension in the intestine exceeds that in the blood stream and the surrounding tissues. (2) The oxygen fraction of the injected air is absorbed rather rapidly. The rate at which this occurs in these distended animals, however, is slower than is to be expected normally, in proportion to the extent to which the blood supply in the intestinal wall is reduced by the increased intraluminal tension. (3) Relaxation of muscle tonus or paralytic dilatation from prolonged overstretching of the bowel wall may reduce the tension.

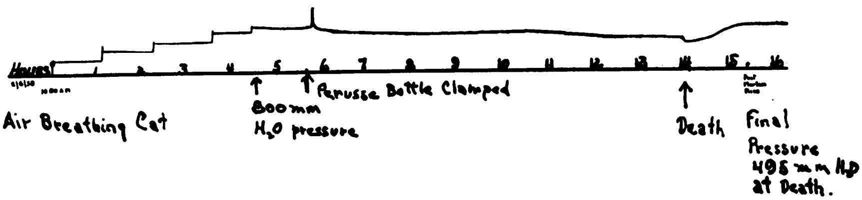


CHART 1.—Kymographic tracing of intra-enteric pressure of small intestine ligated at pylorus and ileocecal valve and inflated through a Perusse bottle with air in increasing increments each hour for five hours up to a maximum of 800 Mm. of water. At the end of the sixth hour the Perusse bottle was clamped off and the animal was allowed to deflate spontaneously. Breathing room air. Death occurred eight hours later with final pressure of 495 Mm. of water.

Once the minimum pressure is attained it usually remains unchanged until death of the animal occurs (Chart 1). In four of the 12 cats breathing air, however, a subsequent rise in pressure occurred (Chart 2), which in three cases exceeded the initial level of 800 Mm. of water. The average survival time in those cats not showing this secondary rise was 11.7 hours. The average survival time in those which did show such a secondary rise was only 5.25 hours. In one such animal, the pressure fell from 800 to 700 Mm. of water during the first hour, but in the following one and one-half hours it rose to 1,065 Mm. of water and the cat expired, a survival time of only two and one-half hours. Another showed no drop from the initial level, the pressure rising steadily from 800 to 1,690 Mm. of water in four hours, at which time death occurred.

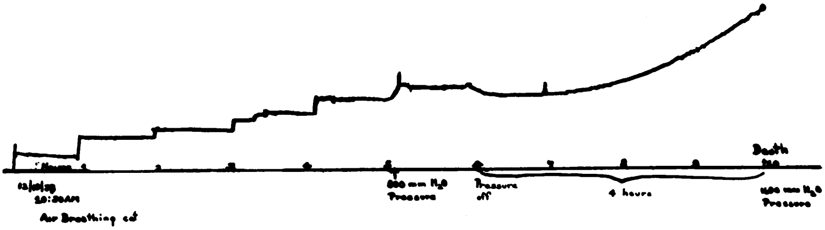


CHART 2.—Same as Chart 1. Secondary rise in pressure one hour after clamping off the Perusse bottle, and death four hours after. Breathing room air.

We have no data to explain the mechanism underlying this secondary rise in pressure. Increase in muscle tone or the formation of gases in the bowel by bacterial action may account for it. It is clear from our autopsy data that it cannot be accounted for on the basis of increased fluid in the bowel lumen (Table I). Whatever the mechanism, it is important to note that when such a secondary rise is superimposed on a long sustained high intra-intestinal pressure, death rapidly results. If such a phenomenon exists in man, its clinical importance in hastening death from overdistention is sufficiently clear and justifies unremitting effort to reduce a gaseous distention of a severe grade.

TABLE I

DISTENDED ANIMALS BREATHING ROOM AIR

Small intestine ligated at pylorus and ileocecal valve. Cannula inserted into terminal ileum. Bowel inflated with air over period of six hours, in increasing increments, to a level of 800 Mm. of water pressure by means of Perusse bottle (in all cases except Exper. 8 in which nitrogen was injected by means of a syringe to 1,015 Mm. of water).

Experiment Number	Total Survival Time in Hours	Minimum Pressure in Millimeters of Water	Pressure at Time of Death in Millimeters of Water	Peritoneal Fluid in Cubic Centimeters	Fluid Content of Bowel in Cubic Centimeters	Ratio of Bowel Weight to Body Weight in Per Cent
1	29*	130	169	17	10	2.29
2	17	260	260	33	35	2.91
3	20	325	455	21	10	2.99
4	19	390	400	33	45	2.46
5	12½*	390	390	25	2	3.12
6	13	440	440	46		2.79
7	14	494	494	43	10	1.59
8	11	728	728	59	2	2.84
9	11	494	650	59	22	2.44
10	16	364	950	27	10	2.42
11	8½	700	1,065	21	2	2.68
12	10	774	1,690	36	15	2.16

* Sacrificed at time indicated.

That reduction of the distention will prolong the life of the animal is to be expected. We wish now to present evidence that the inhalation of 95 per cent oxygen accomplishes this result by effecting a steady decline in the pressure level of the intestine distended by atmospheric air or nitrogen (Table II). Fourteen animals, prepared in exactly the same fashion as the

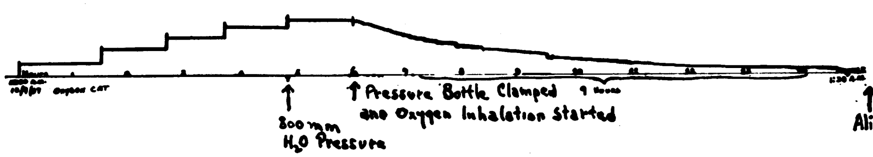


CHART 3.—Same as Chart 1, except that the cat breathed oxygen instead of air from the time the Perusse bottle was clamped off until the end of the experiment. Animal alive, deflated and in good condition nine and one-half hours later.

distended control group, were caused to breathe pure oxygen following the gradual establishment of an intraluminal pressure of 800 Mm. of water by distention with atmospheric air or nitrogen. The course of events described above as occurring in cats breathing air is in definite contrast to that occurring

TABLE II

DISTENDED ANIMALS BREATHING PURE OXYGEN

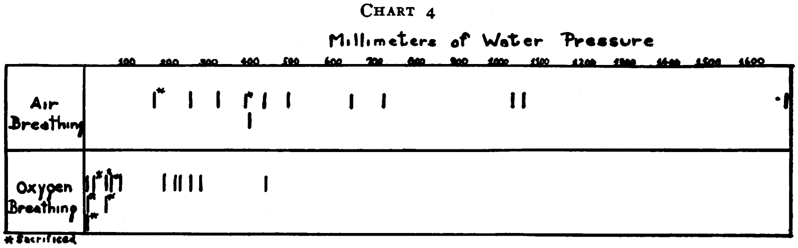
Small intestine ligated at pylorus and ileocecal valve. Cannula inserted into terminal ileum. Bowel inflated with air over period of six hours, in increasing increments, to a level of 800 Mm. of water pressure by means of Perusse bottle (in all cases except Expers. 3, 11 and 13 in which nitrogen was injected by means of a syringe to 600, 1,430 and 1,220 Mm. of water pressure, respectively).

Experiment Number	Total Survival Time in Hours	Pressure at Time of Death in Millimeters of Water	Peritoneal Fluid in Cubic Centimeters	Fluid Content of Bowel in Cubic Centimeters	Ratio of Bowel Weight to Body Weight in Per Cent
1	32*	0	24	5	3.37
2	19	0	25	0	3.01
3	18*	0	20	—	2.86
4	22*	19	8	21	1.7
5	26*	52			
6	29*	52	31	5	2.07
7	24*	65	33	0	2.49
8	27	78	23	15	1.78
9	17	195	28	10	2.14
10	19	225	29	10	2.77
11	18	234	38	10	1.59
12	14	260	19	23	2.56
13	17	286	30	15	2.62
14	17	442	46	10	3.11

* Sacrificed at time indicated.

in those breathing oxygen. In the former, the intraluminal pressure, after an initial decline, leveled off to an average minimum of 433 Mm. of water, while in the latter the pressure continued to fall until it reached a normal or nearly normal level (20 to 40 Mm. of water[5]) in eight of the 14 animals (Charts 3 and 4). The average intra-enteric pressure reached was 136 Mm. of water with extremes varying from zero in three instances to one with an

CHART 4

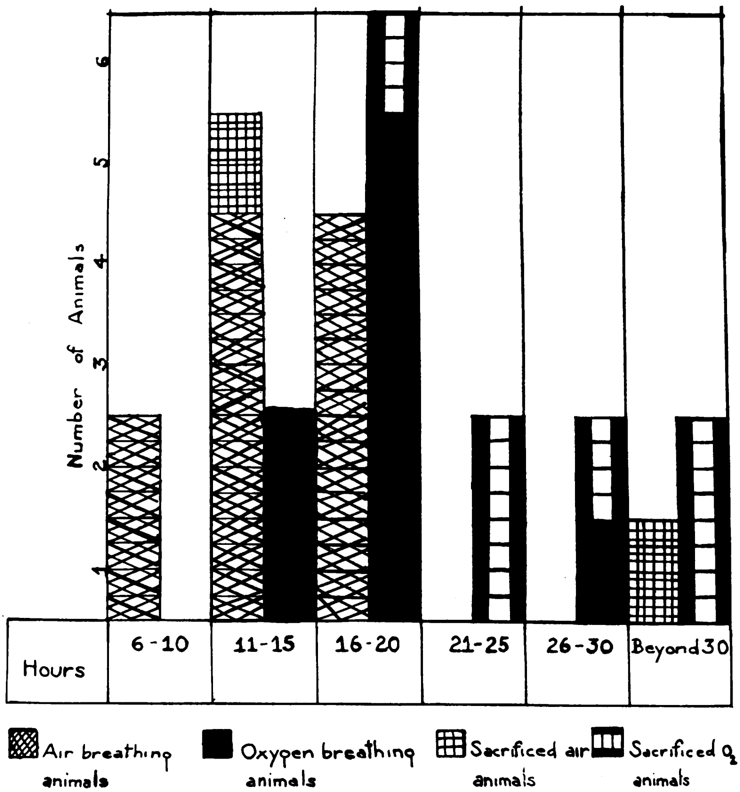


INTRAENTERIC PRESSURE AT TIME OF DEATH

exceptionally high level of 442 Mm. of water. The secondary rise in pressure observed in four of the air breathing animals did not occur in any of those breathing oxygen.

Concomitant with the greater reduction in intra-enteric pressure there was a notable prolongation of the survival time (Chart 5). Six animals died with an average survival time of 18.8 hours following the establishment of the initial pressure level of 800 Mm. of water, as against an average survival time of 8.5 hours for those animals breathing air. Six others breathing oxygen were sacrificed while still in good condition after an average survival of 25 hours. Two cats which were distended with nitrogen up to an initial level of 1,220 and 1,430 Mm. of water pressure lived 17 and 18 hours respectively.

CHART 5



SURVIVAL TIME

The initial drop in pressure during the first one to three hours was of much the same order of magnitude in both oxygen and air breathing animals (compare Charts 1 and 3), although two of the latter did not show even this preliminary drop. One might expect the oxygen breathing animals to show a more precipitous fall in pressure during this early period than those breathing air. Its failure to occur is explained by the fact that a latent interval of three to four hours, during which the blood stream becomes desaturated of the nitrogen dissolved in it, is necessary before nitrogen in any quantity begins to diffuse from the bowel lumen into the blood stream with resulting decompression.[9]

The peritoneal fluid recovered at autopsy from the animals breathing air averaged 33.3 cc., while that recovered from those breathing oxygen averaged 27.2 cc. In a corresponding group of four animals, similarly treated but not distended, the peritoneal fluid averaged 6.5 cc., which was chiefly blood incidental to operative manipulation. The distended animals, therefore, showed an average excess of 24 cc. of peritoneal fluid, which is directly attributable to the prolonged distention of the intestine. Since this fluid loss is of equal magnitude in the oxygen and air breathing animals, it cannot be regarded as a factor in the more rapid death of the latter. The volume of fluid in both groups, even if regarded as a loss of circulating blood, represents only about 11 per cent of the total blood volume and is consequently not an adequate cause for the death of the animals in either group.

If the peritoneal fluid is to be explained as a transudate from engorged capillaries resulting from partial or complete venous occlusion, one might expect for the same reason a simultaneous increase in the fluid content of the intestine above that which is found in a nondistended gut. An increase in intraluminal fluid was, however, not observed. The average fluid content of the distended intestines in the oxygen and air breathing groups was about 13 cc. as compared to 11 cc. in the series of four similarly prepared but undistended animals. If excessive intra-enteric transudate does occur at some stage in the period of distention, one should expect to find in it those animals whose pressure remained high (well above normal venous pressure) up to the time of death. The data in Table I show no parallelism between final pressure and fluid content of the bowel. This is in accord with the findings of Gatch,[6] *et al.* There is an apparent contradiction between this finding and the well known clinical fact that overdistended and obstructed intestines usually contain excessive quantities of fluid. The animals studied in these experiments were starved and their intestines were relatively empty. In man the excessive fluids are probably to a large extent due to more or less fluid and

TABLE III

UNDISTENDED CONTROL ANIMALS

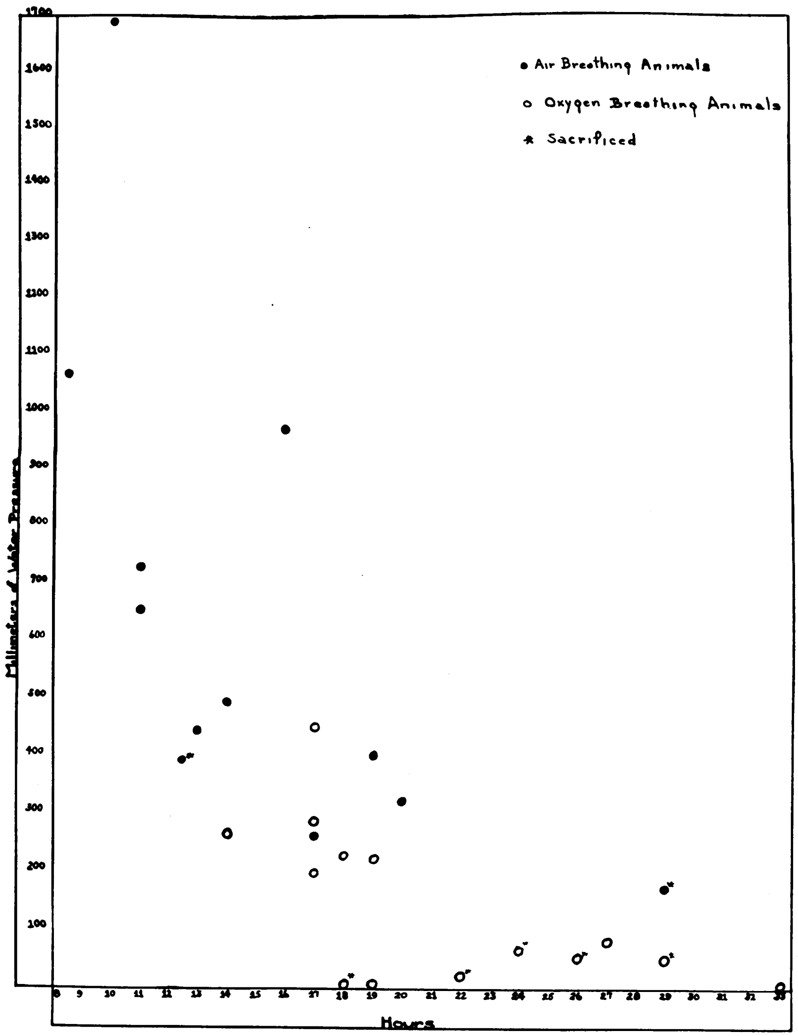
Small intestine ligated at pylorus and ileocecal valve. Cannula inserted into terminal ileum.

Experiment Number	Survival Time in Hours*	Peritoneal Fluid in Cubic Centimeters	Fluid Content of Bowel in Cubic Centimeters	Ratio of Bowel Weight to Body Weight in Per Cent
1	35	2	5	1.66
2	21	11	20	2.79
3	17	11	8	2.56
4	37	2	10	3.06

* Death in these animals due in part to regurgitation of citrate into the blood stream during continuous blood pressure observations.

food intake immediately preceding the onset or during the period of distention. There is no evidence in these experiments to substantiate Van Zwalenburg's[7] observation that the bowel mucosa at a distention pressure of 60 Mm.

CHART 6



RELATIONSHIP BETWEEN SURVIVAL TIME AND INTESTINAL PRESSURE AT TIME OF DEATH

Hg. "sweats" sufficiently to account for the increased fluid in the obstructed intestine in man. This does not, however, negate the possibility that excessive quantities of intraluminal fluid may accumulate at the pressure levels ordinarily observed in distention in man, which are very much lower than we have utilized in these experiments and which have usually been established for a much greater period of time.

An average of the ratios of the weight of the small intestine to the weight of the animal shows no significant difference between distended and undistended animals (Tables I and III). There is, therefore, no evidence of an important loss of blood volume into the wall of the distended intestine. This agrees with similar findings by Aird[8] for closed loop obstruction. The evidence, therefore, is against fluid loss into the peritoneal cavity, bowel wall and bowel lumen as an explanation of the more rapid death of animals with high degrees of gaseous distention.

Of interest is the relationship between the survival time of the entire 26 distended animals and their intraluminal pressure at the time of death. Chart 6 shows that those animals with the lowest intraluminal tension appreciably outlived those which were unable to adequately decompress themselves, while high terminal pressures, as occurred in four of the distended animals breathing air resulted in very early death.

Comment.—The pathologic changes in ileus, aside from those due to actual strangulation, are produced by intra-enteric pressure alterations resulting from the accumulation of gas and fluid within the bowel lumen. The central problem in the therapy of obstruction, whether mechanical or functional, is the relief of increased intra-intestinal pressure. When the indications for surgical relief are clear, there is no better solution of the problem. Lacking such indications, the ordinary procedures for deflation are utilized, but unfortunately fail all too often. In such cases breathing 95 per cent oxygen, in accordance with a technic already described,[3] provides a method for effective deflation. Our experimental studies prove that breathing pure (or 95 per cent) oxygen results not only in a striking decrease in gas volume[1] but also in a marked reduction in the pressure within the lumen of the intestine. The lethal effects of a sustained high grade gaseous distention are thereby delayed or entirely avoided.

SUMMARY AND CONCLUSIONS

(1) When the obstructed small intestines of a group of 12 cats were distended with air or nitrogen up to a level of 800 Mm. of water pressure, death ensued in eight of these animals within an average of 11.7 hours following the establishment of this pressure level.

The intra-intestinal pressure in these eight animals fell from the initial level of 800 Mm. of water to an average minimum of 433 Mm. of water.

In the remaining four animals of this group a secondary rise in pressure occurred with resulting rapid death after an average survival time of only 5.25 hours.

(2) In a group of 14 cats, similarly treated, but breathing pure oxygen from the time the initial pressure level was established until termination of the experiment, the survival time was much longer. The average was 18.8 hours for eight animals which died and 25 hours for six which were sacrificed while still in good condition.

Eight of this group reached a final intraluminal pressure within or close to normal limits (20 to 40 Mm. of water), while the remaining six reached an average final pressure of 273 Mm. of water pressure.

(3) Evidence is offered to show that gaseous distention produces an increase in peritoneal fluid, but no appreciable change in the weight of the bowel wall. When the entire small intestine of the starved cat is converted into a closed loop distended with air to a pressure of 800 Mm. H_2O, there is no increase in the fluid content of the intestine.

The shorter survival time of the air breathing distended animals cannot be accounted for on the basis of fluid loss into the peritoneal cavity, bowel wall and intestinal lumen.

(4) Breathing pure oxygen is an effective means of reducing the intra-intestinal pressure and of prolonging the survival time of cats in which the obstructed small intestine is distended with air or nitrogen.

REFERENCES

[1] Fine, J., Sears, J. B., and Banks, B. M.: The Effect of Oxygen Inhalation on Gaseous Distention of the Stomach and Small Intestine. Amer. J. Dig. Dis. and Nutrition, **2**, 361, 1935.

[2] Fine, J., Frehling, S., and Starr, A.: Experimental Observations on the Effect of Ninety-five Per Cent Oxygen on the Absorption of Air from the Body Tissues. J. Thor. Surg., **4**, 635, 1935.

[3] Fine, J., Banks, B. M., Sears, J. B., and Hermanson, L.: The Treatment of Gaseous Distention of the Intestine by the Inhalation of Ninety-five Per Cent Oxygen. ANNALS OF SURGERY, **103**, 375, 1936.

[4] Fine, J., Hermanson, L., and Frehling, S.: Further Clinical Experiences with Ninety-five Per Cent Oxygen for the Absorption of Air from the Body Tissues. ANNALS OF SURGERY, **107**, 1, 1938.

[5] Owings, J. C., *et al.*: Intra-intestinal Pressure in Obstruction. Arch. Surg., **17**, 507, 1928.

[6] Gatch, W. D., and Culbertson, C. G.: Circulation Disturbances Caused by Intestinal Obstruction. ANNALS OF SURGERY, **102**, 619, 1935.

[7] Van Zwalenburg, C. V.: Strangulation Resulting from Distention of Hollow Viscera. ANNALS OF SURGERY, **46**, 780, 1907.

[8] Aird, I.: Experiments in Intestinal Obstruction. The Rôle Played by the Diminution of the Effective Circulating Blood Volume in Acute Intestinal Obstruction. Edinburgh Med. J., **44**, 28, 1937.

[9] Shaw, L. A.: Personal communication.