EXPERIMENTAL CONTRIBUTION TO THE STUDY OF THE PATH BY WHICH FLUIDS ARE CARRIED FROM THE PERITONEAL CAVITY INTO THE CIRULATION.

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INTRODUCTORY.

THOUGH it has been recognised since the experiments of Magendie that fluids within the lymph spaces may enter the circulation directly through the walls of the blood vessels, the acceptation of this fact did not carry with it any serious doubt with regard to the validity of the general belief that, as a rule, it is the task of the lymphatics to carry the lymph from the lymph spaces, including the serous cavities, through the lymphatic ducts into the circulation.

Lately, however, a number of writers, stimulated by the well-known labours of Heidenhain on the secretion of lymph * and on the mode of absorption from the intestines, † have been led by their experiments to the rather remarkable conclusion that the absorption of fluids from serous cavities, especially from the peritoneal cavity, is in the main carried out by the blood vessels, the capillaries within the lymph spaces, while the lymphatics have at the utmost only a minor share in this task. We shall abstain from going over the entire literature of this subject, which is rather extensive, but shall confine our introductory remarks to a brief reference to that of more recent date, especially to the writings of Starling and Tubby, Orlow and Heidenhain, and Hamburger. These writers, though following quite dif-

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* Heidenhain, Versuche u. Fragen zur Lehre von der Lymphbildung. Pflüger's *Archiv für die gesammte Physiologie*, Bd. xlix, p. 209.

† Heidenhain, Neue Versuche über die Aufsaugung im Dünndarm. Pflüger's *Archiv*, Bd. lvi, p. 579.

ferent lines of experiment, arrived independently of one another at the above-mentioned conclusion, each method furnishing a new and apparently well-supported argument in its favour.

The experiments of Starling and Tubby * consisted in introducing certain staining fluids into the abdominal cavity and noting the exact time of their appearance in the urine and in the flow of lymph from the thoracic duct. They state that the colour appears much earlier in the urine than in the lymph, a fact which can be explained only by the assumption that the absorption takes place through the blood vessels. They are even in doubt whether the slight tinting of the lymph is not due to a resecretion from the blood.

Orlow † and Heidenhain‡ introduced a measured quantity of fluid into the abdominal cavity of dogs and removed it again after a few hours. They found that invariably a more or less large amount of the fluid was absorbed during this time, while the flow of lymph from the thoracic duct, which was measured before the introduction and after the withdrawal of the fluid, remained the same. This, again, would go to show that the fluid absorbed did not make its way through the thoracic duct. Cohnstein,# who confirms this statement, claims nevertheless that there is a difference in amount in the flow of the lymph after introduction of fluid into the abdomen, inasmuch as in a dog tied on a holder it is constantly diminished. It is obvious, however, that this slight difference is entirely out of proportion to the quantity absorbed from the peritoneal cavity. ||

Hamburger,^ finally, studied the effect of ligation of the left innominate vein, which means also the ligation of the thoracic duct, upon the absorption of fluids of different osmotic pressures, introduced

* E. H. Starling and O. H. Tubby, On Absorption from and Secretion into the Serous Cavities. *Journal of Physiology*, vol. xiv, p. 140.

† Orlow, Einige Versuche über die Resorption in der Bauchhöhle. Pflüger's *Archiv*, Bd. lix, p. 170.

‡ Heidenhain, Pflüger's *Archiv*, Bd. lxii, p. 320.

Cohnstein, Ueber Resorption aus der Peritonealhöhle. *Centralblatt für Physiologie*, Bd. ix, No. 13 (Sept. 21, 1895).

|| See Hamburger, *Centralblatt für Physiologie*, Bd. ix, No. 16 (Nov. 2, 1895).

^ Hamburger, Ueber die Regelung der osmotischen Spannkraft von Flüssigkeiten in Bauch- und Pericardialhöhle. Du Bois-Reymond's *Archiv für Physiologie*, 1895, p. 281.

into the abdominal cavity of rabbits, and comes to the conclusion that the lymphatics assist but little in the process of absorption.

Experiments with Small Quantities.

Without entering for the present into a discussion of the merits of these arguments, we wish first to report a set of experiments on absorption from the peritoneal cavity which, in opposition to those of the above-quoted authors, show, as we believe, unmistakably that the lymph is carried into the circulation more readily and much earlier by the way of the lymphatics than directly through the walls of the blood vessels. It should, however, be stated at the outset that there is one important point in which the method adopted in the experiments of the other authors differed from that employed in our research. We introduced into the abdominal cavities of rabbits mostly very small quantities, not more than 1 or 2 cubic centimetres of the fluids being employed; the absorption of such small amounts certainly afforded a greater similarity with that of the normal lymph than when the large quantities of fluids used by these other writers were employed.

Substances which produce characteristic manifestations after passing the circulation were introduced, after which the first appearance of these manifestations was noted. Thus after strychnine had been injected we watched for the appearance of the outbreak of the characteristic tetanus, or when potassium ferrocyanide had been introduced the exact time of its first appearance in the urine was duly recorded. This was done in normal animals as well as in animals with ligated lymphatic ducts and the times of the first appearance of the appropriate manifestations in the animals of both series were compared. As we were compelled for various reasons to confine our study exclusively to rabbits we did not attempt to ligate the thoracic duct itself in these animals, but resorted to the method of ligating the left innominate vein just below the juncture of the subclavian and the jugular veins. Ligation at this point serves practically the same purpose, since it entirely prevents the lymphatic duct from emptying its contents into the circulation. This same method was also employed independently by Hamburger, as stated above, but, in justice to ourselves, it should be

stated that these experiments of ours were started months before the publication of Hamburger's work. For reasons to be explained hereafter, in most of our experiments we ligated also the right innominate vein, and thus prevented also the lymph carried by the right lymphatic duct from entering the circulation.

The ligation of both innominate veins, however, not only effects an exclusion of the lymph from the circulation, but also prevents the return of the venous blood from the brain, and indeed certain of our experiments seemed to show that the venous hyperæmia of the brain exerts an influence upon the tetanic outbreak as well as upon the secretion of the urine. If, therefore, after ligation of both innominate veins some alteration in the ordinary manifestations occurs, it might be urged that these differences can just as well be ascribed to the venous hyperæmia as to the ligation of the lymphatics. To meet this objection we ligated in each control rabbit both external jugular veins, which in rabbits are the main carriers of the venous blood from the brain, the internal jugular veins being very small. In this way the rabbits in both series were put upon an equal footing with regard to the state of venous hyperæmia of their brains, but still differed with regard to their lymphatic ducts, which were open in those of the one and ligated in those of the other series. Hence we were justified in considering any variations in the manifestations in the two rabbits as being due to the difference in the state of the lymphatics.

The animals were well anæsthetized, the anæsthetic used in this set of experiments being for the most part ether, as we had occasion to learn that chloral retards or even suppresses the outbreak of the strychnine tetanus. The strychnine, as well as the potassium ferrocyanide, was mostly dissolved in a one-per-cent solution of sodium chloride, which is nearly isotonic with the serum of the rabbit. The results, however, were exactly the same when the saline solution had a hypotonic concentration of 0.6 or of 0.3 per cent.

Our procedure was then mostly as follows: Two rabbits of about the same weight and at about the same stage of digestion were tied on holders and anæsthetized. In one of the animals the innominate veins were dissected out and threads put around them. This rabbit we con-

stantly termed A. In the other rabbit, which we termed B, threads were put around the external jugular veins. The several veins in both rabbits were then ligated simultaneously. Very small incisions were next made in the linea alba leading to the peritoneal cavity. Through these fine openings a fixed amount of the fluid was introduced by means of a syringe with a blunt point, the openings being clamped after each injection, thus preventing the escape of any portion of the fluid. If, however, by any mischance a droplet did escape or was wasted, this difference was always charged to A. For the same reason the injection was always first made into A in order to give to it the benefit of the extra time which elapsed between the two injections. The urine was obtained by pressing over the region of the bladder, which very rarely failed to respond. This method was the more satisfactory, since with even the smallest droplet of urine diluted with water it was easy to demonstrate the presence of potassium ferrocyanide by means of the characteristic Prussian-blue reaction. Even in a dilution of 1 to 40,000 the addition of perchloride of iron brings out this fine blue colour.

We shall now give condensed protocols of a few of our experiments which speak for themselves:

EXPERIMENT 71.—Rabbit A, 1,750 grammes, both innominate veins ligated. Rabbit B, 1,750 grammes, both external jugular veins ligated. Injected into the abdominal cavities of each 0.6 milligramme of strychnine at 4.19 P. M. No effect. At 4.29, 0.3 milligramme of strychnine was injected again into each; eight minutes later, at 4.37, B had a characteristic opisthotonos; at 4.44, no convulsions yet in A; added 0.3 milligramme of strychnine; at 5.3, added again 0.4 milligramme of strychnine; characteristic tetanus in A at 5.20. This means that in the rabbit without the lymphatics the strychnine took effect forty-three minutes later than in the normal rabbit, and that with a dose nearly twice as large.

EXP. 75.—A, female rabbit, 1,460 grammes, both innominate veins ligated. B, female rabbit, 1,430 grammes, both external jugular veins ligated. Injected at 4.59 P. M. into the abdominal cavity of each rabbit one cubic centimetre of a five-per-cent solution of potassium ferrocyanide. Test of urine after ten minutes negative in both. At 5.18 injected again into both 0.5 cubic centimetre of same fluid. At 5.29, Prussian-blue reaction in the urine of B; the urine of both tested every ten minutes; B

retained the positive reaction. Urine of A shows for the first time the re-action of Prussian blue at 6.6. This means that in the rabbit without the lymphatics the potassium ferrocyanide reaches the urine thirty-seven minutes later than in the other rabbit. The same rabbits were then used for an experiment with strychnine. At 6.14, 0.8 milligramme of strych-nine was injected into each; B succumbed to a typical tetanus at 6.22; no convulsions in A. At 6.44 again 0.8 milligramme of strychnine injected into A. Tetanus at 6.55. The second part of the experiment gave results confirmatory of the first.

Exp. 76.—A, male rabbit, 1,266 grammes, both innominate veins ligated. B, female rabbit, 1,280 grammes, both external jugular veins ligated. At 4.30 injected into A 0.9 cubic centimetre of five-per-cent potassium ferrocyanide, and at 4.33 injected into B 0.7 cubic centimetre of same solution. At 4.43 no reaction in the urine of either. At 4.48 injected again into each 0.5 cubic centimetre of same solution; at 5.17 Prussian-blue reaction in the urine of B, absent in the urine of A. Urine of A tested every ten minutes. Till 6.14 no reaction. At 5.35 a piece of absorbent cotten pressed into the right thoracic aperture in A near liga-ture of right innominate vein, where some drops of lymph seemed to collect, showed the Prussian-blue reaction. No reaction in left aperture, where the tissue seemed to be dry. At 6.18 the testing of urine was discontinued and rabbits were used for strychnine—large doses. Again a difference in favour of B, though not as great as before.

Autopsy of A: Distinct reaction of Prussian blue all over the ab-dominal cavity, except within the bladder. Autopsy of B: No reaction of Prussian blue in the abdominal cavity; present in the urine. In this experiment it looks as if very little, if any, absorption had taken place in rabbit A, with the ligated lymphatics.

Exp. 77.—Rabbit A, 1,140 grammes, both innominate veins ligated. Rabbit B, 1,080 grammes, both external jugular veins ligated. At 4.41 injected into A 0.9 cubic centimetre of five-per-cent potassium ferro-cyanide, and into B 0.7 cubic centimetre of same fluid. At 4.52 test of urine of both negative. At 4.55 injected again into A 0.6 cubic centi-metre, and into B 0.5 cubic centimetre of same fluid. At 5.37 the urine of B showed positive reaction of Prussian blue. Testing urine of A every ten minutes continued until 6.17, but no reaction. At 5.55 there was a positive reaction on cotton dipped in right aperture of A; no reaction from left. At 6.30 animals used for strychnine with same results as in the other experiments.

Exp. 84.—Rabbit A, 2,180 grammes, both innominate veins ligated. Rabbit B, 2,150 grammes, both external jugular veins ligated. Both

holders kept slanting; heads higher. At 3.56 injected into each 1 cubic centimetre of potassium ferrocyanide. Urine tested every ten minutes. At 4.20, in the urine of B, a positive Prussian-blue reaction; testing continued every ten minutes. At 4.55 first positive reaction in urine of A. Right thoracic aperture shows positive reaction of Prussian blue at 4.30; no reaction in left aperture. At 5.20 animals used for an experiment with strychnine, with the same characteristic results as those reported above.

These experiments go to show that, in the first place, in two rabbits of about the same size an equal dose of strychnine produced a tetanic outbreak much earlier in˙ the animal with open lymphatics than in the one whose lymphatic ducts were ligated. Moreover, some of these control rabbits, as we know from experiments not mentioned here, did not show any signs of tetanus at all when no more strychnine was injected into them. It is true that when the initial doses of strychnine were large the difference between the results which occurred in A and B was less striking, and it could probably be proved that within certain limits the interval between the tetanic outbreaks in A and B increases in inverse proportion to the doses used for injection. For the purpose of establishing the presence of such a difference between the two kinds of rabbits, we have found it advisable, therefore, to begin the injections with small doses, which were followed from time to time by still smaller doses, until the first tetanic outbreak in one of the rabbits occurred. Disregarding, then, for the present, the question of the influence of the quantity injected upon the absorption, it must be conceded that our experiment goes some way toward establishing the fact that the rabbits with open lymphatics absorb strychnine from the peritoneal cavity a great deal more readily than those whose lymphatics have been rendered impassable.

It must be conceded, however, that the experiments with strychnine by themselves cannot be considered as furnishing an unassailable proof for the conclusion that peritoneal fluids are carried into the circulation mainly by the lymphatics. Against such an assumption it might be urged that rabbits of the same size and apparently in the same general condition show quite a different degree of irritability

and react differently to the same doses of strychnine, so that an effect-
ive dose for one rabbit is often subminimal for another of the same
size. Sometimes it seemed to us that by the indolence or hyperexcita-
bility of a rabbit we could predict whether it would require a large or
a small dose to produce a tetanic effect; and indeed we have often
taken the point of excitability of the animals into consideration when
comparing the effect of strychnine upon two rabbits. Now, as a mat-
ter of fact, we never saw a rabbit with ligated lymphatic ducts suc-
cumbing sooner to the effect of strychnine than a normal one. Never-
theless it might be claimed that, after all, chance had played a trick
upon us, giving us constantly indolent rabbits for series A and irritable
rabbits for series B, so that the difference of time between the tetanic
outbreak might be due only to this idiosyncrasy of the rabbit, and not
to the ligation of the lymphatics. This is, to be sure, not a very prob-
able assumption, but it suffices nevertheless to make the demonstra-
tion appear incomplete.

The complete proof, however, of the importance of the part played
by the lymphatics in the process of absorption from the peritoneal
cavity is furnished, as we think, by the experiments with the injec-
tions of potassium ferrocyanide. We see in these the Prussian-blue
reaction appearing in the urine of the rabbit with the ligated lym-
phatics (A) much later than in B, with the lymphatics open and un-
obstructed. This was a constant occurrence in all our experiments
made with potassium ferrocyanide, and the delay in A was here even
more striking than in the experiments with strychnine, the reaction
sometimes not appearing at all during the entire time devoted to the
observation. Now in these experiments with potassium ferrocyanide
there seems to be no possible ground for assuming that constitutional
variations with regard to the secretion of the urine were the cause of
the delayed reaction. Moreover, the same rabbit with ligated lym-
phatics in which a late appearance of potassium ferrocyanide in the
urine was noted shows also a retardation of the tetanic outbreak after
injection of strychnine; one could hardly go so far as to claim this
constant coincidence as merely accidental. Finally, the autopsy in Ex-
periment 76, made two hours after injection, does away with all

doubts. In the rabbit with the ligated lymphatic duct (A) Prussian-blue reaction could be obtained all over the peritoneal cavity, and no reaction was present in the fluid within the bladder, while in the rabbit with open lymphatic ducts (B) no reaction could be obtained in the abdominal cavity and a positive reaction was present in the fluid in the bladder. This finding certainly means that with open lymphatics there is excellent absorption; with ligated lymphatics there is no absorption, or, if it occurs at all, it is very slow.

To complete our experience with the injections of potassium ferro-cyanide we will append a few short protocols of experiments in which only one lymphatic duct was ligated:

EXP. 81A.—Male rabbit, 1,920 grammes, right jugular vein ligated. At 9.37 P. M. injected into peritoneal cavity 1 cubic centimetre of potassium ferrocyanide; at 9.59, twenty-two minutes after injection, Prussian-blue reaction in the urine.

EXP. 81B.—Female rabbit, 2,100 grammes, right innominate vein ligated. At 10.29 P. M. injected into peritoneal cavity 1 cubic centimetre of potassium ferrocyanide. At 10.44, 0.5 cubic centimetre of same solution was added. First reaction of Prussian blue in urine appeared at 11.20 P. M., fifty-two minutes after first injection and thirty-two minutes after second injection.

EXP. 81C.—Male rabbit, 1,560 grammes, left innominate vein ligated. At 9.58 P. M. injected into the peritoneal cavity 1 cubic centimetre of five-per-cent potassium ferrocyanide; urine tested every ten minutes. First Prussian-blue reaction at 11.8, seventy minutes after injection.

EXP. 83A.—Male rabbit, 1,430 grammes, both jugular veins and left innominate vein ligated, thoracic duct apparently torn, whitish fluid oozing. At 5.40 P. M. injected 1 cubic centimetre of five-per-cent potassium ferrocyanide; at 5.51 P. M. injected an additional 0.6 cubic centimetre of same solution. The whitish fluid in the left aperture showed at 5.50 a positive Prussian-blue reaction. At 6.34 the first positive Prussian-blue reaction appeared in the urine, fifty-three minutes after first and forty-three minutes after second injection. Lymph of thoracic duct showed Prussian-blue reaction after injection.

EXP. 83B.—Male rabbit, 1,160 grammes, both jugular veins and right innominate vein ligated. Injected into peritoneal cavity at 5.40 P. M. 1 cubic centimetre of potassium ferrocyanide. At 5.51 injected an additional 0.6 cubic centimetre of same solution; first Prussian-blue reaction

in urine at 6.18, thirty-eight minutes after first and twenty-seven minutes after second injection.

These experiments show clearly that the ligation of even one lymphatic duct retards distinctly the time of the first appearance of potassium ferrocyanide in the urine, and it is quite remarkable to find that the ligation of the right lymphatic duct also exerts a marked influence upon the absorption from the peritoneal cavity, although this influence is apparently less than that exerted by the left lymphatic duct. Although our experiments in this regard are not as yet numerous enough to satisfy us as to the conclusions which may safely be deduced from them, they certainly support those which have already been drawn from the other experiments and explain at the same time our motive for ligating both innominate veins when proceeding to show in a general way the importance of the lymph paths for the absorption of fluids from the peritoneal cavity.

Our experiments with the ligation of the innominate veins show that ligation of the lymphatic ducts retards the entrance of the fluids from the peritoneal cavity into the circulation. But they also show that the ligation merely retards, but does not prevent the final entrance of the fluid into the circulation. On the contrary, in all cases in which our time and patience permitted a sufficiently long observation, the Prussian-blue reaction finally appeared even in the animals both of whose lymphatic ducts were ligated. The final appearance of the reaction in the urine under these circumstances can not be otherwise explained than by the assumption that the potassium ferrocyanide in the abdominal cavity made its way into the circulation directly through the walls of the blood vessels.

We would insist, however, that this fact can not by any means be urged as a proof for the assumption that in normal animals also the lymph passes into the circulation not only by way of the lymphatics, but also directly through the blood vessels. One of the main causes for the lymph secretion, and certainly for the lymph movement, is to be found in the difference between the intra- and extra-capillary pressure. The pressure in the capillaries is higher than in the surrounding lymph spaces; in the lymph spaces it is higher than in the

lymph vessels; and in these, again, it is higher than in the large ducts; finally, the pressure in the lymphatic ducts is higher than in the innominate veins. Now, while it is only natural that the fluid in the lymph spaces should move through the lymphatics to a locality of the circulation where the pressure is lower, it is against reason to expect that the fluid shall move directly in opposition to an increase of pressure—viz., from the lymph spaces into the capillaries.

This rule, however, applies only to normal animals, and not to animals whose lymph ducts have been ligated. Immediately after the outflow of the lymph into the circulation is prevented the pressure within the ligated duct begins to rise; this increase is transferred backward toward the lymph spaces, and the longer the ligation lasts the higher the pressure rises all along the lymph vessels and the lymph spaces. Thus it is probable that after a certain length of time the pressure within all the lymph spaces becomes equal to the pressure within the blood capillaries, and in some lymph spaces the pressure of the fluid within them becomes even higher than that in the blood capillaries around which they are collected and into which they now discharge, impelled by the same force by which the lymph usually leaves the capillaries—by filtration. Now we have seen in our experiments that even under such favourable circumstances and with no other road open the filtration of the fluid from the lymph spaces into the blood vessels occurs somewhat slowly. How can it be expected, then, that in normal animals, where the filtration against pressure is impossible and where by the way of open lymphatics there is an easy path by which the fluid can move on, this fluid should nevertheless select its way through the walls of the blood vessels?

Before concluding this part it may be added that Cohnstein,* who is also fighting against the degradation of the lymphatics, nevertheless admits that colouring substances, hyper- and hypo-tonic salt solutions, and other " different " fluids actually enter the circulation through the walls of the capillaries. We have experimented with a five-per-cent solution of a salt—potassium ferrocyanide—which is

* Cohnstein, loc. cit.

certainly a hypertonic fluid with a high osmotic pressure and should therefore have met with no difficulty in entering into the circulation directly through the walls of the blood vessels by the simple process of osmosis. Nevertheless we have seen that our solution of this salt preferred the track of the lymphatics.

EXPERIMENTS WITH LARGER QUANTITIES.

Among the above-mentioned writers on this subject, Hamburger * holds the most decided views as to the secondary rôle played by the lymphatics in the act of absorption of fluids from the peritoneal cavity. Hamburger's opinion is founded chiefly upon the results of his own experiments. Some months previous to the publication of his article we started a series of experiments which were, so far as the question of absorption from the peritoneal cavity is concerned, quite similar to those of Hamburger, but which do not by any means bear out the conclusions at which this author arrived. Before entering, however, upon the report of our own experiments we wish, on account of the importance of the subject, to adduce a few reasons to show that, in our opinion, Hamburger's own experiments do not justify his far-reaching conclusions. In the first place, the method employed by Hamburger is not adapted to furnish precise results. In nearly all the experiments which have a bearing on the present question he introduced the fluid into the abdominal cavity through a sharply-pointed canula which was inserted into the lumbar region of the rabbit, and removed the fluid again by inserting a wider trocar. Our own experience has confirmed the assertion made by many writers before us, that in plunging a sharp canula into the abdomen, in many cases the needle gets into the intestinal lumen. This happens more especially when working with rabbits. Furthermore, the inserted trocar certainly does not remove all the fluid from the abdomen, and, despite the assertions of Hamburger, we must affirm that our experience has shown to us that by this method sometimes even more than half of the quantity remains in the abdomen. Under such circumstances

* Hamburger, Du-Bois-Reymond's *Archiv*, 1894.

it is impossible to say whether the lacking fluid in one or the other experiment was entirely absorbed, or whether it was simply improperly introduced or unsatisfactorily removed.   Again, Hamburger never mentions the size of the rabbit employed in his experiments.   This, however, is quite an important point, since two animals of a different size might show a difference in the rapidity of absorption, as has indeed been claimed by G. Wegner.*   But supposing that two rabbits of different sizes be found to show the same rate of absorption; this might be attributed to a difference in the results due to the ligation of the lymphatic ducts in one of the rabbits.   Finally, the number of experiments which Hamburger reports are by far too small to permit such a sweeping conclusion as the exclusion of the lymphatics from taking part in the absorption of lymph.   In fact, this author offers only one experiment for each of the fluids employed, and does not state whether or no he made others which are not included in his report.   It may be worth while to quote all his experiments which have any bearing on our subject.

† A. EXP. 8.—Injected into a normal rabbit 150 cubic centimetres of a solution of sodium chloride (0.94 per cent); removed after half an hour 89 cubic centimetres; absorbed 61 cubic centimetres.

† B. EXP. 26.—Injected 150 cubic centimetres of the same solution into a rabbit whose innominate vein was ligated; removed after half an hour 93 cubic centimetres; absorbed 57 cubic centimetres.

A. EXP. 13.—Injected into a normal rabbit 150 cubic centimetres of concentrated horse serum; removed after two hours 140 cubic centimetres; absorbed 10 cubic centimetres.

B. EXP. 27.—Injected into a rabbit whose left innominate vein was ligated 150 cubic centimetres; removed after two hours 144 cubic centimetres; absorbed 6 cubic centimetres.

A. EXP. 14.—Injected into a normal rabbit 150 cubic centimetres of two-per-cent sodium chloride; removed after an hour 109 cubic centimetres; absorbed 41 cubic centimetres.

B. EXP. 28.—Injected into a rabbit whose left innominate vein was

* G. Wegner, *Archiv für klinische Chirurgie*, Bd. xx.

† The letters A and B are our additions to show the corresponding experiments for one and the same fluid which do not follow one another in Hamburger's article.

ligated 150 cubic centimetres of the same fluid; removed after an hour 133 cubic centimetres; absorbed 17 cubic centimetres.

A. EXP. 18.—Injected into a normal rabbit 150 cubic centimetres of rabbit serum, diluted with half as much water; removed after an hour 89 cubic centimetres; absorbed 61 cubic centimetres.

B. EXP. 29.—Injected into a rabbit whose innominate vein was ligated 180 cubic centimetres; removed after an hour 138 cubic centimetres; absorbed 42 cubic centimetres.

A. EXP. 20.—Injected into a normal rabbit 150 cubic centimetres of 0.5-per-cent sodium chloride; removed after half an hour 89 cubic centimetres; absorbed 61 cubic centimetres.

B. EXP. 30.—Injected 150 cubic centimetres of same fluid into a rabbit whose left innominate vein was ligated; removed after half an hour 85 cubic centimetres; absorbed 65 cubic centimetres.

We have here altogether five pairs of experiments, each pair dealing with a different kind of fluid. The one with the concentrated horse serum counts for little, as hardly any absorption was noted in either of the experiments. Of the remaining four parallel experiments, two show a decided diminishing effect of the ligation of the thoracic duct upon the absorption, while two show no such an effect. And yet these two parallel experiments are the only ones upon which Hamburger bases his categorical conclusions.

Our experiments which chronologically preceded those reported in the first part were also made on rabbits which were narcotized with chloral. The injections were made, just as in other experiments, by means of a syringe with a blunt point being introduced into the abdominal cavity through a small opening, which was then sutured and clamped. The fluid had a temperature of 99° F.; the rabbit remained on the holder during the entire time given for absorption, which was in all cases forty minutes. After killing the rabbit and opening the abdomen, the collecting of the remaining fluid was done very carefully, partly by means of a syringe or a pipette, and partly by means of absorbent cotton, which is well adapted for taking up every drop of fluid from all the corners and folds in the abdominal cavity. In the majority of the experiments a 0.75-per-cent solution of sodium chloride was employed, but 0.92-per-cent, 0.6-per-cent, and

0.3-per-cent solutions, respectively, were also tested, as will be seen in some of the protocols. It is unnecessary to recite the protocols of all our experiments or to report them chronologically as they were made. We shall only select certain examples from among them to report briefly, arranging them in such a manner as to bring out more clearly what can be learned and what can not be learned from this line of experimentation.

A series of experiments, accidentally following one another, seemed to demonstrate the importance of the lymphatics in the process of absorption. These experiments will be reported first:

Exp. 31.— Female rabbit, 1,960 grammes; injected into abdominal cavity 100 cubic centimetres of 0.75-per-cent sodium chloride; killed after forty minutes; collected from peritoneal cavity 65 cubic centimetres; absorbed 35 cubic centimetres.

Exp. 32.—Female rabbit, 2,100 grammes; right innominate vein ligated; * injected 100 cubic centimetres of 0.75-per-cent sodium chloride; killed after forty-five minutes; collected again 87 cubic centimetres; absorbed 13 cubic centimetres.

Exp. 33.—Female rabbit, 1,920 grammes; left innominate vein ligated; injected 100 cubic centimetres of same solution as before; killed after forty minutes; collected 81 cubic centimetres; absorbed 19 cubic centimetres.

Exp. 34.—Female rabbit, 2,400 grammes; right and left innominate vein ligated; injected into abdominal cavity 98 cubic centimetres of the same solution; killed after forty minutes; collected 86 cubic centimetres; absorbed 12 cubic centimetres.

This series of experiments seemed to demonstrate that the lymphatics exert quite a preponderating influence upon the removal of the fluids from the peritoneal cavity, the ligation of both innominate veins reducing the absorption by about 66 per cent. And it was rather surprising to find the right lymphatic duct taking such a prominent share in the absorption. Experiments giving results similar to the above were met with more than once and also under

* It is hardly necessary to state again that the ligations of the innominate veins were made for the purpose of preventing the lymphatic duct from emptying its contents into the circulation, as a direct ligation of the duct is hardly practicable in rabbits.

different conditions; we saw in parallel experiments a distinct influence of the ligation upon the absorption of fluids like 0.92-per-cent sodium chloride, the absorption of which is very slow, and also upon the absorption of 0.3-per-cent sodium chloride, which disappears quite quickly from the peritoneal cavity. It is obvious, however, that the small quantities observed to be absorbed after ligation would only warrant the claim of a diminution in the absorption due to the ligation, provided that it could first be shown that there is quite a stable coefficient for the absorption of fluid of a certain density and in a certain time from the abdominal cavity of normal animals. Hamburger seems to have presupposed such a stability without further proof, or else he would not have been satisfied with only one experiment for each sort of fluid. We have made quite a large number of observations on the absorption in normal animals. At first, indeed, it seemed that the absorbed quantities did not vary very much, and that the smallest quantity absorbed in normal rabbits was still distinctly larger than the quantities absorbed in those with ligated veins. For the 0.75-per-cent solution of sodium chloride, which we employed most frequently, 35 cubic centimetres seemed to be the average amount absorbed in forty minutes. We will illustrate this by two experiments:

EXP. 18.—Female rabbit, 1,520 grammes; starved for twenty hours; injected 98 cubic centimetres of 0.75-per-cent sodium chloride; killed after forty minutes; collected 61 cubic centimetres; absorbed 37 cubic centimetres.

EXP. 28.—Male rabbit, 2,400 grammes; not starved; injected 100 cubic centimetres of 0.75-per-cent sodium chloride into peritoneal cavity; killed after forty minutes; collected 65 cubic centimetres; absorbed 35 cubic centimetres.

Other experiments showed similar results. In the further course of our researches, however, we encountered results entirely at variance with the above. As will be seen in the following group of experiments, among our normal rabbits there were not only instances in which the absorbed quantities were not larger than those found in rabbits with ligated veins, but some animals from which we collected more than we had injected into their abdominal cavities:

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EXP. 36.—Female rabbit, 1,700 grammes; injected 100 cubic centimetres of 0.75-per-cent sodium chloride; killed after forty minutes; collected 75 cubic centimetres; absorbed 25 cubic centimetres.

EXP. 30.—Female rabbit, 1,200 grammes; injected 100 cubic centimetres of 0.75-per-cent sodium chloride; killed after forty minutes; collected 80 cubic centimetres; absorbed 20 cubic centimetres.

EXP. 34.—Female rabbit, 1,800 grammes; injected 100 cubic centimetres; killed after forty minutes; recovered 82 cubic centimetres; absorbed 18 cubic centimetres.

EXP. 38A.—Male rabbit, 2,300 grammes; injected 100 cubic centimetres of 0.75-per-cent sodium chloride; killed after forty minutes; recovered 87 cubic centimetres; absorbed 13 cubic centimetres.

EXP. 40B.—Rabbit, 1,080 grammes; starved forty-eight hours; injected 100 cubic centimetres of 0.75-per-cent sodium chloride; killed after forty minutes; collected 90 cubic centimetres; absorbed ten cubic centimetres.

EXP. 39A.—Female rabbit, 2,400 grammes; injected 100 cubic centimetres of 0.75-per-cent sodium chloride; killed after forty minutes; recovered 104 cubic centimetres. No abnormal condition discoverable. Recovered 4 cubic centimetres more than injected.

The following pair of experiments, which were made exactly at the same time and under the same conditions, are very instructive:

EXP. 35A.—Female rabbit, 1,780 grammes; not starved; ligated right innominate vein; injected 100 cubic centimetres of 0.75-per-cent sodium chloride; killed after forty minutes; collected 93 cubic centimetres; absorbed only 7 cubic centimetres (influence of ligation?).

EXP. 35B.—Female rabbit, 1,800 grammes; injected 100 cubic centimetres of 0.75-per-cent sodium chloride; killed after forty minutes; recovered 112 cubic centimetres. Nothing abnormal; recovered 12 cubic centimetres more than injected.

For these remarkable differences in the amount of absorption during the same length of time and with the same kind of fluid we could make responsible neither the size nor the sex of the rabbit, nor the state of its digestion, nor, in fact, any other recognisable condition. It seemed simply that in rabbits each individual has its own degree of capability of absorption, depending upon certain, as yet unknown, conditions, which vary considerably in different individuals.

This condition was established not only for the saline of 0.75 per cent, but also for saline of a concentration of 0.92 per cent, which is, according to Hamburger, isotonic with the serum of the rabbit; and also for hypotonic salt solutions of the concentrations of 0.6 and of 0.3 per cent. The difference in the absorption between the isotonic and hypotonic fluids is striking enough to be recognisable even in the great variety of the absorbable quantities of each sort of fluid. This point is well illustrated by the two following experiments, which show in addition the interesting fact that an individual which absorbs less of one kind of fluid also absorbs less of another kind of fluid:

Exp. 51.—Rabbit, 960 grammes; starved twenty hours; injected 97 cubic centimetres of a 0.92-per-cent solution; after forty minutes rabbit put into deep ether narcosis; abdomen opened, all the fluid collected, recovered 75 cubic centimetres; absorbed, 22 cubic centimetres; the abdominal incision sutured carefully; injected 99 cubic centimetres of 0.3-per-cent sodium chloride; after forty minutes rabbit killed; recovered 30 cubic centimetres; absorbed 69 cubic centimetres.

Exp. 52.—Rabbit, 1,200 grammes; starved twenty-four hours; injected 99 cubic centimetres of 0.92-per-cent sodium chloride; etherized; after forty minutes abdomen opened and fluid collected; recovered 91 cubic centimetres; absorbed 8 cubic centimetres. Abdomen closed, injected 100 cubic centimetres of 0.3 per-cent sodium chloride; after forty minutes rabbit killed; collected 77 cubic centimetres; absorbed 22 cubic centimetres.

The first experiment shows the most ready absorption for the isotonic fluid (22 cubic centimetres), and also a good absorption for the hypotonic fluid (69 cubic centimetres). In the second experiment the isotonic fluid is poorly absorbed (9 cubic centimetres), and the hypotonic fluid is also comparatively scantily absorbed (23 cubic centimetres).

We shall append here a few more experiments showing the difference in the absorption between the isotonic and hypotonic fluids and the variability of the absorption for each kind of fluid:

Exp. 45.—Rabbit, 1,170 grammes; not starved; injected 99 cubic centimetres of 0.92-per-cent sodium chloride; killed after forty minutes; collected 85 cubic centimetres; absorbed 14 cubic centimetres.

EXP. 44.—Rabbit, 1,170 grammes; starved twenty-four hours; ligated right innominate vein; injected 97 cubic centimetres of 0.92-per-cent sodium chloride; after forty minutes collected 85 cubic centimetres; absorbed 12 cubic centimetres.

EXP. 46.—Rabbit, 1,440 grammes; starved twenty-four hours; ligated right and left innominate veins; injected 100 cubic centimetres of 0.92-per-cent salt solution; killed after forty minutes; collected 97 cubic centimetres; absorbed 7 cubic centimetres.

The largest quantity of the isotonic solution of sodium chloride which we have seen absorbed in forty minutes was 22 cubic centimetres. It is surprising to find that in the one experiment recorded by Hamburger with the isotonic solution of 0.94-per-cent sodium chloride, absorption during only thirty minutes was 61 cubic centimetres. And it is still more surprising to see that also for the hypotonic solution of 0.5-per-cent sodium chloride, Hamburger records the absorption of 61 cubic centimetres during thirty minutes. Our experiments have certainly convinced us that nothing in this entire question of absorption is so constant as the striking difference in the quantities absorbed according as the fluids are isotonic or hypotonic. This difference in the absorption can be already recognised unmistakably in fluids that present such a small difference in concentration as that between 0.92 per cent and 0.75 per cent. The quantity absorbed becomes markedly increased with the decrease in the concentration of the salt solutions, as is clearly demonstrated in Experiments 51 and 52 quoted above, and also in the following experiments:

EXP. 56.—Male rabbit, medium size; injected 95 cubic centimetres of 0.6-per-cent sodium chloride; killed after forty minutes; collected with absorbent cotton 45 cubic centimetres of a bloody fluid; absorbed 50 cubic centimetres.

The next two experiments, the protocols of which are given more in detail, seem to demonstrate quite positively that the lymphatics have no influence at least upon the absorption of hypotonic solutions of 0.6 per cent. This point, however, will be dwelt upon later on.

EXP. 57.—Rabbit, 1,440 grammes; thread around right innominate vein not tied; injected 100 cubic centimetres of 0.6-per-cent salt solution; etherization after forty minutes; abdomen reopened; fluid collected

by means of absorbent cotton held in forceps; fluid very bloody; collected
56 cubic centimetres; waste estimated 5 cubic centimetres; absorbed
about 39 cubic centimetres. Ligature around right innominate vein tied;
abdominal wound sewed up and clamped; injected again 93 cubic centi-
metres of 0.6-per-cent salt solution; reopened after forty minutes; fluid
bloody; collected in the same manner as before 54 cubic centimetres;
waste, about 4 cubic centimetres; absorbed about 35 cubic centimetres.
Autopsy: The blood came from injury to liver; ligature included phrenic
nerve.

EXP. 58.—Rabbit, 2,140 grammes; threads round both innominate
veins not tied; injected 100 cubic centimetres of 0.6-per-cent salt solu-
tion; after forty minutes etherized; fluid collected with cotton, 40 cubic
centimetres; waste, 8 cubic centimetres; absorbed about 52 cubic centi-
metres. Abdomen closed; right innominate vein ligated; injected 99
cubic centimetres of same fluid; abdomen reopened after forty minutes;
after a few minutes of artificial respiration by tracheal cannula and
bellows, collected with cotton 47 cubic centimetres; waste, 2 cubic centi-
metres; absorbed 50 cubic centimetres. Abdomen closed again; left in-
nominate vein also ligated; injected 100 cubic centimetres of the same
fluid; after forty minutes reopened; for a few minutes artificial respira-
tion again employed; rabbit, however, alive; clear fluid collected 43
cubic centimetres; no waste; absorbed after ligation of both veins 57
cubic centimetres. Autopsy: Some fluid in pleural cavity; nothing ab-
normal otherwise.

It must be stated that for the salt solutions of 0.6 per cent there
has been quite a remarkable constancy in the quantity absorbed dur-
ing forty minutes; it varied only between 57 and 50 cubic centi-
metres, 39 cubic centimetres in Experiment 57 being the only ex-
ception, and in this case there was some blood oozing from the injured
liver, so that it is impossible to say how much of the absorbed solution
was compensated for by the blood.

The difference in the absorption between the solutions of 0.6 per
cent and 0.3 per cent in our experiments was less striking than that
existing between the solutions of 0.92 per cent and 0.75 per cent,
or between the solutions of 0.75 per cent and 0.6 per cent. Parallel
experiments have shown an apparent influence of the lymphatics upon
the absorption of the 0.3-per-cent salt solution, as will be seen from the
following experiments:

Exp. 41.—Female rabbit, 2,100 grammes; starved twenty hours; injected 100 cubic centimetres of 0.3-per-cent sodium chloride; killed after forty minutes; collected 41 cubic centimetres; absorbed 59 cubic centimetres.

Exp. 42.—Female rabbit, 1,620 grammes; starved twenty hours; right innominate vein ligated; injected 100 cubic centimetres of 0.3-per-cent salt solution; killed after forty minutes; collected 54 cubic centimetres; absorbed 46 cubic centimetres.

Exp. 43.— Female rabbit, 1,100 grammes; not starved; ligated right and left innominate veins; injected 100 cubic centimetres; killed after forty minutes; collected 67 cubic centimetres; absorbed 33 cubic centimetres.

The coincidence of the ligation of the lymphatics with the diminished absorption in the last two experiments, again would seem to indicate that the lymphatics influence the absorption. But it must be remembered that the absorption of the 0.3-per-cent salt solution in the normal rabbit shows also quite a variation in the quantities disappearing in forty minutes. The largest quantity we have noted was 69 cubic centimetres and the smallest 23 cubic centimetres.

Thus far we have pointed out the variability in the absorption of fluids in normal rabbits. We will now touch upon this point as it affects rabbits with ligated lymphatics. Here we have to speak mainly of our experience with the salt solution of 0.75 per cent, as the experiments made with fluids of other concentrations were not numerous enough to justify us in speaking of rules and exceptions. In rabbits in which either the right innominate vein alone or both the right and left veins were ligated we have noted without any exception an absorption of only comparatively small quantities—22 cubic centimetres being the largest and 7 cubic centimetres being the smallest quantity thus far noted. But with the left innominate vein alone ligated other results were observed. We find on record the two following experiments where the quantities absorbed were as large as in the normal animals:

Exp. 12.—Medium-sized rabbit, left innominate vein ligated; injected 95 cubic centimetres salt solution; rabbit breathed spontaneously, but apparently principally with right side; killed after forty minutes;

collected about 51 cubic centimetres; absorbed 44 cubic centimetres. Left phrenic included in ligature. This was the very first experiment in which we tried the ligation of the innominate veins.

EXP. 17.—Male rabbit, 1,635 grammes; tracheotomy; left innominate vein ligated; injected 98 cubic centimetres salt solution; artificial respiration; abdomen opened after forty minutes; collected 68 cubic centimetres; fluid somewhat bloody; absorbed 30 cubic centimetres. Experiment continued for ligation of vena cava inferior, etc.

This last experiment, however, can be excluded on account of the artificial respiration, which, as we often saw, is a great help to the absorption. But there remains the first experiment with the unusual absorption of 44 cubic centimetres, a quantity which we met in normal rabbits with a solution of 0.75 per cent only once, and this was in the experiment following closely the other one.

EXP. 13.—Medium-sized rabbit; injected 75 cubic centimetres salt solution; killed after forty minutes; collected 30 cubic centimetres; absorbed 45 cubic centimetres.

In both of these experiments, and only in these two, sponges were used for the collection of the fluid. It is possible that the sponges were not pressed out sufficiently.

In summing up the results which can possibly be derived from this line of experiments, our attention is engaged in the first place by the question of the participation of the lymphatics in the act of absorption of fluids from the abdominal cavity. In this respect we learn, in the first place, two negative points.

Although in one or two parallel experiments the rabbit with ligated thoracic duct may show as much absorption as the rabbit whose thoracic duct was not ligated, this does not justify the conclusion that the lymphatics do not aid perceptibly in the act of absorption, because the quantities absorbed at the same time in the normal rabbits vary considerably; and it is quite possible that the rabbit whose duct was ligated would, without ligation, have shown a much larger absorption. Hamburger's conclusion, based upon only two experiments, that the ligation of the right duct does not affect the absorption, is therefore assuredly not justified.

On the other hand, although a number of our experiments have shown us a diminished absorption in rabbits with ligated lymphatic ducts, we have also no right to deduce with absolute certainty that the ligation was the cause of the diminution in absorption, because the animal might by accident have been one of that class of rabbits which, even without ligation, would have shown the same poor absorption.

Our experiments (57 and 58) with the 0.6-per-cent salt solution, where we have seen in one and the same animal after ligation about the same quantities absorbed as before ligation, would certainly appear to be conclusive against any participation of the lymphatics in the process of absorption if the experiment could have been carried out without any flaw. This, however, was not the case. The deep etherization and the extensive handling of the peritonæum for the purpose of collecting all the fluid from the first injection affected the vitality of the rabbit to such a degree as to require some artificial respiration to keep the animal alive; and there can be no doubt that artificial respiration tends greatly to increase the absorption and might even overcompensate for the diminution caused by the ligation of the lymphatic ducts; and then there was always some waste, and the fluid was more or less bloody.

It may, however, be remarked incidentally that the fact that the absorbed quantities before and after ligation are the same does not necessarily mean that the paths of absorption must have been the same. As has been already stated in the first part, the ligation of the lymphatic duct raises the pressure within the lymph spaces, and thus facilitates the filtration of the lymph directly into the capillaries. It could, therefore, be claimed that absorption takes place before ligation by the route of the lymphatics and after ligation directly by filtration into the blood vessels, both modes of absorption being equally good, so that the absorbed quantities are in the end the same.

Thus far we have derived from our experiments only negative results—i. e., they have taught us that this line of experimenting can not furnish us with a decisive proof for either of the conflicting theories as to the mode of absorption from the peritoneal cavity. We

think, however, that our experiments have demonstrated a positive fact which gives at least some support in favour of the theory that the lymphatics are of essential value in the act of absorption.

If the absorbed quantities be arranged in tables, according to the density of the fluid experimented with (0.92, 0.75, 0.6, 0.3 per cent), it will be seen at a glance that for each fluid there is a considerable fraction among the number of experiments in which the quantities vary but little. Thus for the 0.75-per-cent salt solution, with which we experimented most often, we found in more than one half of our experiments that the quantity which disappears in forty minutes varied between 30 and 40 cubic centimetres, though the remainder of our experiments have shown a great variability, but only in a descending order, of the missing amounts of fluids. The same results were obtained also in our experiments with 0.92- and 0.3-per-cent solutions of sodium chloride. And it is by the character of the quantities in the majority of the experiments and also by their upper limit that we recognise the difference in the absorbability of fluids of different concentrations. (In the experiments with the 0.3-per-cent solution the largest absorbed quantity was 69 cubic centimetres; in the 0.75-per-cent, 45 cubic centimetres; and in the 0.92-per-cent, 22 cubic centimetres.)

Now, if we glance at the records of the quantities absorbed in the rabbits whose innominate veins were ligated, we notice that the table as a whole differs strikingly from that obtained from normal rabbits, though for both series of experiments one and the same fluid was used. In the large number of rabbits in which a solution of 0.75 per cent was injected and in which either both innominate veins were ligated or the right one alone, the largest quantity absorbed was 22 cubic centimetres. The same applies also to all cases in which the left innominate vein was ligated, except in our very first experiment, in which 44 cubic centimetres were absorbed.*

* In the latest number of Virchow's *Archiv* (Bd. cxliii, Heft 1) we find in an article by Maximilian Sulzer the statement (p. 104) that in a few cases he found a branch of the thoracic duct entering the innominate vein 0.5 centimetre below the entrance of the main duct. This branch was considerably dilated in cases in which the thoracic duct was ligated. Could not the

We do not think, however, that this single experiment, in which the methods employed in collecting the fluid were still imperfect, can change materially the impression to be derived from the entire table. The fact therefore remains that from a comparatively large number of experiments with ligated lymphatic ducts we obtain a table of absorbed quantities which is markedly on a lower scale than that derived from experiments with normal rabbits.

In other words, though we could not accept the single experiments with ligation as a positive proof in favour of the lymphatics, we believe that the bulk of our experiments show, at least with considerable probability, that the lymphatics exert a perceptible influence upon the act of absorption of fluids from the peritoneal cavity.

If the preceding conclusion is correct, it implies also another positive point of interest—viz., that the absorption is visibly impaired by the ligation of the right lymphatic duct. We had reason to arrive at a similar conclusion from a few of the experiments we made with potassium ferrocyanide.

Aside from the significance of the lymphatics for absorption there are a few other points bearing upon the question of absorption which are to be learned from our experiments and which deserve special mention.

We have already repeatedly referred to our observation that the quantities absorbed from the abdominal cavity during forty minutes increased with the decrease in the concentration of the fluid introduced. The difference in the absorption between salt solutions of 0.92 per cent and of 0.75 per cent is striking, and there is a still more marked difference between the results with the 0.75-per-cent solution and those of the 0.6-per-cent solution. The difference between the solutions of 0.6 per cent and 0.3 per cent is less pronounced in our experiments. This fact demonstrates the importance of the rôle played by osmosis in the absorption from the peritoneal cavity. In the few experiments of Hamburger * we do not find any difference in the

exceptional existence of such a branch explain the exceptional failure of the ligation of the left innominate vein, which was certainly applied above this branch?

* Hamburger, loc. cit.

absorption of solutions of 0.92-per-cent and of 0.5-per-cent sodium chloride.

In the experiments of Orlow,* however, the effect of concentration upon absorption was so easily recognizable that this author did not hesitate to draw the general inference that the absorption of the fluid increases in inverse ratio to its concentration.

Another point of interest is the variation in the absorption of fluids of the same concentration. Other authors before us have spoken of this inconstancy in absorption, and have laid great stress upon the proportion of the quantity of the introduced fluid to the weight of the body. We took almost constantly the same quantities for our injections, and, as far as our experiments upon rabbits go, the size of the body seemed to have very little influence upon the amount of absorption; we have seen small rabbits absorb quite large quantities and large rabbits absorb only quite small quantities. In fact, the variation in the absorption seemed to be entirely independent of the size, sex, stage of digestion, or any other condition accessible to our observation. And not only was the absorption sometimes exceedingly scanty, but in a few cases even more was collected than had been put in when no morbid or abnormal condition could be discovered which could be held responsible for this striking occurrence. As yet it is impossible to decide whether these wide variations in the absorption are due to some individuality in the rabbits—i. e., whether the same rabbit would always show the same degree of absorption, or whether they are due to unknown but transitory conditions in the animals—i. e., whether one and the same rabbit would at different times absorb different quantities.

Without attaching much importance to the fact, it may nevertheless be mentioned that all our animals which showed a scanty absorption were obtained from one source, while all those showing a higher absorption came from elsewhere.

* Orlow, loc. cit.

SOME EXPERIMENTS ON ABSORPTION FROM THE PERITONEAL CAVITY
OF DEAD RABBITS.

To Hamburger * belongs the credit of being the first to discover the remarkable fact that fluids disappear from the peritoneal cavity even in the case of dead animals. Now, if this disappearance is due to absorption—i. e., to the entrance of the fluid into the blood—its occurrence would seem to demonstrate that absorption can be accomplished without the assistance of the vital forces. Heidenhain, however, who with Orlow believes in vital force for the act of absorption from the abdominal cavity, and who was naturally startled by the communication of Hamburger, claims in his latest article that absorption, according as it takes place in the living or in the dead body, is a radically different process, and he refers us to a future article for particulars on this point.

This question of absorption in the dead body is probably destined to excite general attention and to provoke much discussion. As yet there are on record only the few experiments published by Hamburger. In finding an explanation of the fact, it would seem that we should not encounter any difficulty provided only that we assume that absorption is carried on by the lymphatics, since, according to Heidenhain ‡ and others, the flow of lymph from the thoracic duct continues for a long time after death. Hamburger, however, denies the truth of such an assumption on the ground that the ligation of the thoracic duct does not influence absorption. But here again this author offers only one experiment with ligation of the thoracic duct.

We find in our protocols a number of observations on the absorption in dead rabbits, of which a few will be recorded here. The experiments were made exclusively with solutions of 0.75-per-cent sodium chloride, which had, of course, only room temperature.

EXP. 35.—Quoted above; 35 cubic centimetres absorbed in forty minutes during life. Abdomen sewed up; injected 100 cubic centimetres;

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* Hamburger, loc. cit.
† Heidenhain, Pflüger's *Archiv*, Bd. lxii, p. 320.
‡ *Ibid.*, Bd. xlix.

opening clamped; collected after forty minutes 70 cubic centimetres; absorbed 30 cubic centimetres; tissue a little imbibed.

EXP. 18.—Quoted above. Absorbed during life 37 cubic centimetres. Abdomen sewed up; injected 100 cubic centimetres; after one hour and forty minutes collected 20 cubic centimetres; absorbed 80 cubic centimetres. Stomach and intestines much distended with gas.

EXP. 39.—Quoted above. While alive injected 100 cubic centimetres, and recovered after forty minutes 104 cubic centimetres. Abdomen sewed up; injected 100 cubic centimetres coloured with Prussian blue; after four hours and fifteen minutes recovered only 10 cubic centimetres; absorbed 90 cubic centimetres. Intestines and stomach exceedingly distended.

The absorption in these rabbits, which took place after death, was certainly not inferior to that which occurred during life. It was thought, however, that the marked distention of the intestines might have served as a mechanical factor to produce filtration. In the following experiments, therefore, the viscera were removed:

EXP. 29.—Rabbit, 2,030 grammes; injected 94 cubic centimetres; killed after forty-five minutes; collected 74 cubic centimetres; absorbed 20 cubic centimetres. Rabbit exceedingly fat. Stomach and intestines removed, abdominal cavity cleansed, sewed up; injected 80 cubic centimetres; after two hours and a half collected 64 cubic centimetres; absorbed 16 cubic centimetres.

EXP. 30.—Rabbit, 1,200 grammes; injected 100 cubic centimetres; killed after forty minutes; collected 80 cubic centimetres; absorbed 20 cubic centimetres. Stomach and intestines removed, cavity cleansed and sewed up; injected 80 cubic centimetres; after two hours and a half collected 60 cubic centimetres; absorbed 20 cubic centimetres; posterior wall of cavity œdematous.

From these and other of our experiments, it could be seen that with the removal of the viscera the absorption was considerably diminished. The fluid gathered on both sides of the spinal column without any pressure. It must be remembered, however, that the diminution of absorption might also be attributable to the removal of the visceral peritonæum.

The experiments with ligation of the lymphatic ducts did not give

uniform results. The following seemed to demonstrate that the lymphatics control the absorption from the abdominal cavity of the dead rabbit also:

EXP. 22.—Male rabbit, 1,080 grammes; right innominate vein ligated by a bowknot; rabbit killed: injected 97 cubic centimetres; collected after two hours and three quarters 89 cubic centimetres; absorbed 8 cubic centimetres. Knot around vein untied, abdomen closed by continuous suture; injected 94 cubic centimetres, some fluid escaping; overflow carefully collected, 47 cubic centimetres; waste liberally estimated 10 cubic centimetres. Abdomen reopened after two hours and three quarters; collected 7 cubic centimetres; estimated absorption, 30 cubic centimetres. Abdomen closed again carefully by interrupted suture; injected 64 cubic centimetres. No escape; waste estimated 7 cubic centimetres. Reopened after two hours and three quarters; collected 7 cubic centimetres. Absorption, 50 cubic centimetres; intestines much distended.

In some other experiments, however, the ligation did not seem to exert any influence upon the absorption.

EXP. 32.—Quoted above. Right innominate vein ligated; absorption in forty minutes while alive only 13 cubic centimetres. Abdomen of dead rabbit carefully sutured; injected 98 cubic centimetres; no escape and no waste of fluid; reopened; collected after forty minutes 65 cubic centimetres; absorbed 33 cubic centimetres. Tissue of abdominal cavity, especially of posterior wall, exceedingly imbibed.

EXP. 34.—Quoted above. Both innominate veins ligated; absorbed in forty minutes while alive 12 cubic centimetres. Abdomen sutured; injected 100 cubic centimetres; no fluid escaped; reopened after forty minutes; collected 73 cubic centimetres; absorbed 27 cubic centimetres.

In these and other experiments we have seen that when the veins were ligated there was more absorption during the same period in the dead than in the living body.

Our experiments on absorption in dead rabbits do not permit of a full comparison with this process as it occurs in the living animals, since in only a few of the former was the fluid removed after forty minutes, the time which was uniformly maintained in our experiments on the living. In these few experiments there was hardly any difference in favour of the dead, except in the animals with ligated

veins. In the experiments in which we removed the fluid after hours there was certainly a marked absorption. Even in Experiment 39, in which in forty minutes during life there was an increase of 4 cubic centimetres in the amount of the fluid, we find after death an absorption of 90 cubic centimetres in four hours and a half. But in all cases in which the fluid remained for hours the intestines were exceedingly distended with gas, thereby exerting a considerable pressure upon the fluid within the peritoneal cavity, and thus affecting the absorption like a strong constant massage. In the experiments in which the viscera were removed there was indeed constantly a strikingly diminished absorption, but of course this could be ascribed to the diminished pressure as well as to the removal of the visceral peritonæum with its absorbing lymphatics or blood capillaries.

The ligation of the innominate veins has not shown, at least in the majority of the experiments, any constant influence upon the absorption; on the contrary, in one and the same rabbit with ligated veins there was noted a good deal less absorption during forty minutes during life than after death, when the absorption seemed to be the same as in a normal rabbit.

It is a noteworthy fact that in our protocols of the experiments upon the living animals we find only now and then the remark that the tissue was somewhat imbibed.

In the protocols of the observations on the dead rabbits, however, we often find the remark that the tissue was exceedingly imbibed and œdematous, especially the posterior wall.

Discussion of the Results obtained.

Before attempting an interpretation of the results obtained from our experiments we shall recapitulate briefly the problem and the solutions which have been suggested by some other authors.

The fact was observed that fluid disappeared from the abdominal cavity. This disappearance having without any discussion been assumed to be identical with absorption into the blood, it remained only to decide whether the fluid entered into the blood by the way of the lymphatics or directly through the walls of the blood vessels. As,

according to one statement, the flow of lymph from the thoracic duct did not increase during this absorption, and as, according to another statement, the ligation of the thoracic duct did not influence the absorption, the conclusion was drawn by these authors that the fluid enters into the blood directly through the walls of the blood vessels.

But there is, as it would seem, an important gap in this reasoning. In the first place, nobody has proved or even attempted to prove that the fluid really enters the blood; and all that can be said for certain is that the fluid disappears from the peritoneal cavity. In the second place, the fluid within the peritoneal cavity can never enter directly into the blood vessels, as these are not directly exposed within the peritoneal cavity, but are embedded within the lymph spaces which are separated from the serous cavity by an epithelial membrane, just as the blood within the capillaries is separated from the lymph space by an endothelial membrane. The first question which confronts us when we see fluid disappearing from the abdominal cavity is: By what force does this fluid enter into the lymph spaces? And the next problem is not how does the new fluid within the lymph spaces enter the blood vessels, but rather, does it enter the blood? It is certainly conceivable that the fluid remains within the lymph spaces, and that its only effect upon the blood consists in the prevention of the usual transudation from the capillaries into the lymph spaces. Before these questions have been satisfactorily solved, the statement that the fluid does not go through the lymphatics, and consequently penetrates directly the walls of the blood vessels, must be considered as premature.

The origin of this oversight is to be found, as we believe, in the general practice of confounding the lymph spaces with the lymphatics, although every one, whatever his theories about the function of the lymphatics may be, will admit that the function of the lymph spaces is entirely different from that of the lymphatics, and certainly every one will concede, as a matter of course, that the structure of the lymph spaces is just as different from that of the lymphatics as from that of the blood vessels; nevertheless we do not know of any writer who assigns to the system of the lymph spaces a position independent of and separate from the lymphatics. Again and again

we find it stated in the literature that the lymph spaces are merely the roots of the lymphatics, which again many consider only as a branch current of the circulation. According to this view there are then at the disposal of any fluid in the body only two systems: the blood vessels and the lymphatics. Therefore if it is assumed as a proved fact that the fluid within the abdominal cavity does not enter the lymphatics, then the conclusion that it enters the blood vessels directly is inevitable. Furthermore, a study of the recent literature on the relations between blood pressure, lymph flow, and lymph formation has shown to us that the conclusions drawn from these experiments could only have been arrived at by underrating the importance of the lymph spaces as an independent system. It is not our purpose to enter into any particulars on the subject of lymph formation, but we mention these facts only as a further excuse for dwelling here at some length on our conception of the lymph spaces as an independent system and as an intermediate territory between the blood vessels and the lymphatics. We do not propose to offer any new experiments or histological observations, but shall take, on the contrary, the old well-known facts as a basis for our point of view against which, as we hope, the only objection which can be urged is that it is not new.

The so-called lymph spaces are those gaps, clefts, chinks, and interstices of all kinds naturally present between the elements or the groups of elements of the tissues of the entire body. They are of variable shape and size. The fine capillary space between two muscular fibres is certainly much smaller than the space between two muscle bundles, and the spaces in loose connective tissue are certainly much larger than those present in dense tissue, such as, for instance, is found in ligaments. Some of the spaces are lined with a few endothelial cells, but these are never sufficiently numerous to separate one space from another, though the freedom of communication varies considerably between the spaces of the same organ, and probably still more so between those of different organs. Certain strata of connective tissue extending over large areas of the body present convenient paths, connecting the parenchymatous spaces of several

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organs. We may thus assume that all these spaces are more or less completely connected throughout the entire body and present a unity, and, as it were, a system of canalization. Throughout the course of this system and at all times are present variable quantities of fluid containing the nutrient material for the tissues as well as their waste products. In loose tissue the accumulation of fluid can be enormous. In fact, the size of lymph spaces seems to depend more upon the quantity of fluid present than upon structural limitations. The fluid spreads with more or less ease from one lymph space to another, the propelling forces being diffusion and mechanical pressure. The latter is caused, first, by contracting the muscles surrounding the lymph spaces, and, secondly, by gravity and external mechanical pressure (massage). Mechanical pressure is perhaps also produced by the chemical activity within the tissue, just as we see the chemical activity in the salivary glands producing a pressure which exceeds that found within the carotid arteries.

In these lymph spaces are embedded the capillaries of the blood vessels as well as of the lymphatics. Though the larger tubes of both kinds of vessels are well separated from their surroundings by membranous walls, the capillaries are separated from the lymph spaces only by a thin endothelial layer, and even this may possibly be provided with stomata, so that they are all well adapted to give up fluid to or receive it from the lymph spaces. In only a few exceptional cases does the fluid from the blood capillaries enter directly into the lymphatics, as happens in the case of the perivascular lymphatics of the central nervous system. As a rule, the fluid on leaving the blood enters the lymph spaces, and thence passes to the lymph capillaries; it never enters directly from the blood capillaries into the lymph capillaries. There is always some space between both kinds of capillaries, and they are said to be sometimes separated even by more than one lymph space.

Both systems of fluid-carrying vessels, blood vessels and lymphatics, possess in common many features which distinguish them sharply from the system of the lymph spaces. Both have the tubular character, the abundance of muscular and elastic fibres in the mem-

branes, the nervous control, the more or less limited capacity, the free and unembarrassed movement of the fluid, the possibility of free communication between all sections, and the unipolar direction of the constantly moving fluid. The arrangement of the three systems is suggestive of a tract of marshy land in a swamp separating two rivers, the larger one of which as it passes by sends out only fine arms into the swamp, while the smaller one, which originates there, collects its water from the marshy land to bring it back after a short course into the main river.

An important distinguishing feature is the difference in function. The real process of nutrition goes on within the so-called lymph spaces, but not in the blood vessels or in the lymphatics, which only serve as routes for transportation. A comparison with different portions of the alimentary tract will bring out these points more distinctly. The system of the lymph spaces may be compared to the stomach and the intestines, where the chief object of alimentation—digestion—is going on; while the blood vessels are to be compared with the œsophagus, the road for the food delivery; the lymphatics, finally, may thus be considered analogous to the rectum, the canal for the removal of the waste products.

There are certainly abundant reasons for considering the lymph spaces as an independent system for itself, and not as an appendix to either class of tubulated vessels. The reason for the general usage of classing the lymph spaces with the lymphatics is probably to be found in the fact that the fluids of the lymph spaces as well as those of the lymphatics have two striking features in common, their colourless appearance and their poverty in corpuscular elements, which are in striking contrast to the red colour and abundance of corpuscles in the blood. Such a classification, however, implies also the sweeping and unfounded assumption that both fluids not only present a similar outward appearance, but are actually of one and the same character, and that it is simply the fluid of the lymph spaces which is found flowing through the lymphatics and the thoracic duct. In fact all the analyses of " lymph " were made from the fluid coming from the lymphatic ducts or from the large lymphatic vessels, and it has been tacitly as-

sumed, and entirely without proof, that this lymph and the fluid within the tissue are one and the same in character.

We have no experiments to offer showing that the fluids are different or the nature of the difference if such exists. But, even as it is, there are good reasons against the supposition that the lymph in the thoracic duct is the unaltered fluid from the tissues. This latter is surely an admixture of three different elements: (1) The fluid transuding from the blood into the lymph spaces; (2) the same fluid minus the material taken out for the anabolism of the tissue; and (3) the products furnished by the catabolism of the tissue. Now the organs and tissues of different structures possessing different functions require a different material for their nutrition, and give up different waste products. The natural conclusion, then, must be that the fluid within the lymph spaces varies considerably according to the particular tissue and organ concerned. In contrast to these specific fluids of the tissues, the thoracic duct carries an admixture of all these fluids together, and also the fluid taken up from the intestinal canal, which even in a state of inanition is never quite empty.

It is, then, quite evident that the fluid coming from the thoracic duct can not be taken as representative of the fluid within the tissues even if it were admitted that the tissue fluid entered into the lymph capillaries as through an open gate without any change of character— an assumption, however, which is in the highest degree improbable, since the fluids in the lymph spaces are separated from the lumen of the capillaries by an endothelial membrane through which they can permeate only with the aid of some physical or " vital " force.

The identification of lymph with the tissue fluid leads to another error. In measuring the quantity of lymph coming from the thoracic duct, some writers think they determine with it also the quantity of fluid passing through the tissues. This would be equivalent to saying that the whole amount of fluid which transudes from the blood into the tissue, and which is there called lymph, leaves the tissue by way of the lymphatics. That this is a mistake is evident from the fact that large quantities of the tissue fluid pass out again by way of the glandular secretions without the intervention of the lymphatics

at all. It must be remembered that the secretion of saliva alone sometimes amounts to as much as two litres in twenty-four hours, not to mention all the other secretions and " juices " of the alimentary canal. Then again mucus, sweat, tears, milk, and other fluids must all be considered. The amount of milk alone secreted in twenty-four hours probably at times does not fall short by much of the amount of lymph coming from the thoracic duct, and in any case all the secretions taken together form a considerable quantity which is possibly larger than the whole amount of lymph flowing through the ducts. Now, since all these secretions derive their fluid directly from the lymph in the lymph spaces, it is impossible that the flow from the thoracic duct should give us any exact information as to the consumption of this lymph.

Again there are two other factors, though of undetermined character, of which the flow of lymph from the ducts can not give us any account. In the first place, the amount of fluid which is always present in the interstices of the tissue can vary within certain limits, the difference nevertheless being imperceptible or certainly not measurable. The semisolid character of most of the tissue is based not only upon the fluid within its elements—for instance, within the sarcolemma or neurolemma—but also upon the constant presence of fluid between them. The observation made by v. Brasol * and by Leathes † of the rapid entrance of large quantities of fluid into the blood following the injection of solutions of sugar or salt into the blood, while the flow of lymph from the thoracic duct is also increased (Heidenhain ‡), shows the presence of such labile fluid in the tissue. The second unknown quantity is the exact amount of fluid which at certain times and in certain places is undoubtedly returned directly back into the blood vessels.

In referring to this subject it may not be out of place to note the apparently contradictory position of Heidenhain. In his first article # on the subject of lymph formation he says that it is inconceivable that

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* v. Brasol, Du Bois-Reymond's *Archiv für Physiologie*, 1884, p. 211.

† Leathes, *Journal of Physiology*, vol. xix, p. 1.

‡ Heidenhain, Pflüger's *Archiv*, Bd. xlix, p. 219.

Pflüger's *Archiv*, Bd. xlix, p. 219.

under normal circumstances a part of the lymph should be returned directly to the blood, whereas in his last article * he says that it is his conviction that the blood capillaries are the essential paths for absorption from the peritoneal cavity. Whether Heidenhain has given up his first position or makes a distinction between the absorption of lymph and the absorption of other fluids from the peritoneal cavity, it is impossible to understand.

We thus see that the lymph coming from the lymphatic ducts represents neither in quantity nor in quality the fluid which is contained in the lymph spaces.

We shall therefore, to avoid further misconceptions, discard the terms " lymph spaces " and " lymph " for the spaces within the tissue and the fluid therein, and apply to them instead the commonly employed terms " interstitial spaces " and " tissue fluid," which are more appropriate, as they do not carry with them any hypothetical meaning.

Recapitulating our statement briefly, our position is as follows: The tissues of the body are permeated by a system of interstitial spaces which contain the tissue fluid. This system is, by virtue of its structure, its function, and its contents, an independent apparatus by itself, and not an integral part of either of the two systems of vessels, and the fluid within this system is likewise in many important respects different from the fluid of the blood vessels as well as from that of the lymphatics. The system receives fluid from the blood vessels which is applied in different organs and in different tissues in a specific way. Aside from its use for metabolic purposes for the tissues within the body, a part of the fluid is given up to the glands as material for their specific secretions, a part conveyed into the lymphatics, while possibly, under certain circumstances, a part is returned directly into the blood vessels. This process of transudation and distribution of the fluid is in the first place controlled by the physical forces of filtration and osmosis. Whether these are sufficient is just now a matter of discussion. We must say, however, that as yet we have not sufficient knowledge of the actual process, nor do we know enough of the laws of osmosis, especially in their application to living tissue, to justify

* Pflüger's *Archiv*, Bd. lxii, p. 330.

the establishment of such a far-reaching conception as a " vital force."
For transformation of the tissue fluid into the glandular secretions,
there are indeed a number of facts which justify the assumption that
the glandular cells influence the process in a manner not explainable
by our present knowledge of physical laws. The same can not be
claimed, or at least not to the same extent, when we come to discuss
the process of transudation of the fluid of the blood into the interstitial
spaces. We are not going to criticise here the reasons which have
led to the hypothesis that the capillary endothelia are endowed with
a secreting capacity. We wish only to call to mind that in the experi-
ments upon this question " interstitial spaces " and lymphatics, as well
as " tissue fluid " and lymph, have not been kept apart. With regard
to the mechanism of the entrance of fluid from the interstitial spaces
into the lymphatics little can be said, as this subject has been studied
least of all. That filtration may have an influence seems to be shown
by the fact that the lymphatics can be injected simply by injecting
the tissue. It is probable that osmosis also has something to do with
the passage of fluid from the interstitial spaces through the endo-
thelial membrane of the lymph capillaries. However, if we assign
to the lymphatics the task of carrying off the waste products from the
tissue fluid, a theory favoured somewhat by the absence of oxygen
and the presence of carbonic-acid gas, there will be need of a more
complicated mechanism to accomplish this selection of materials. For
reasons to be stated later we are indeed inclined to favour the theory
that the lymphatics drain off from the system of interstitial spaces such
substances as are in their present state either foreign or useless or
harmful to the tissue, and deposit them in the lymphatic glands,
or carry them into the blood to be rebuilt there or to be excreted.

Returning now to our problem in hand, we repeat that the fact
of the disappearance of fluid from the peritoneal cavity suggests as the
very first point that the fluid entered into the interstitial spaces, and
the first question to be answered is, By which means was this accom-
plished?

There are three possible explanations. The fluid of the peritoneal
cavity can enter into the surrounding interstitial spaces: (1) Through

the stomata, which are claimed by some authors to exist between the epithelia of the peritoneal membrane; (2) by filtration; (3) by osmosis. With reference to the stomata, it is to be remarked that the latest writers, Kolossow * and Muscatello,† deny their existence, so that it may be best not to enter into a discussion of their availability for the purpose in question.

As for filtration, this process would presuppose that the pressure in the peritoneal cavity is higher than in the interstitial spaces, and we have no data which enable us to make a positive statement with regard to this point. We can offer, however, the following considerations: In a state of absolute rest the fluid in the peritoneal cavity of the living body stands probably under atmospheric pressure, while the fluid in the interstitial spaces is influenced by the pressure within the blood capillaries, which is probably somewhat higher than the atmospheric pressure. But the living body is very rarely at rest and the abdominal cavity more especially is nearly constantly under the influence of muscular contraction during inspiration as well as during expiration, which, in rabbits at least, is always active. In the dead body, again, the rapid development of gases within the intestines forms a new factor which exerts quite a considerable pressure upon the contents of the abdominal cavity, while, on the other hand, there is no increased elevation of pressure in the interstitial spaces due to the elevated blood pressure. We might then presume that there is in the living animal, as well as in the dead body, enough surplus pressure to bring some of the fluid of the abdominal cavity by filtration into the interstitial spaces. In support of this hypothesis we can quote a few facts which show the favourable influence of mechanical pressure upon the disappearance of fluid from the abdominal cavity. In experiments which we have not quoted we saw that massage of the abdomen, the application of a light bandage around the abdomen, or even the keeping of the rabbit upon its stomach increased the quantity of the missing fluid. All these facts, however, show only that a certain degree of mechanical pressure can accomplish an increase in the disappearance of fluid from the abdominal cavity; but there is noth-

* Kolossow, *Archiv für mikroskopische Anatomie,* 1894.
† Muscatello, Virchow's *Archiv,* Bd. cxlii, p. 327.

ing to show to exactly what extent the disappearance in our case was actually due to simple pressure—i. e., to filtration.

It is different with regard to osmosis. Here we have the positive proof that the fluid disappeared in inverse proportion to its osmotic pressure; the less concentrated the solution of sodium chloride injected, the more of it disappeared during the same period. The highest quantity which disappeared from the solution of 0.92 per cent was 22 cubic centimetres; the highest quantity from the solution of 0.75 per cent was 45 cubic centimetres; and from the 0.6 per cent, 69 cubic centimetres. Similar observations were made by Orlow,* in whose protocols we also find that hypertonic solutions were not absorbed as such, the solutions within the abdomen having first to become at least isotonic before any absorption took place.

We see also, in Orlow's protocols, that when isotonic fluids are introduced the remaining fluid within the abdomen has invariably a hypotonic pressure. And it has not as yet been investigated whether the isotonic fluid does not turn in the first few minutes hypotonic before the absorption takes place. We may thus state that the entrance of hypotonic fluid from the abdominal cavity into the interstitial spaces occurs mainly by osmotic pressure, perhaps assisted somewhat by filtration. The isotonic fluid, which is absorbed poorly, either first turns slightly hypotonic and is also absorbed by osmosis, or what little absorption occurs is caused entirely by filtration.

As the process of absorption goes on also through dead and prepared peritoneal membranes, we may assume that the fluid in the peritoneal cavity in dead animals enters into the interstitial spaces in the first place by osmosis, and in the second place by mechanical pressure (filtration) exerted upon the fluid by the rapidly developing gases within the intestines; but it is also possible that in the dead body osmosis has a smaller and filtration a larger share in the removal of the fluid in the living body.

With regard to the application of the laws of osmosis to our special problem, and to the process of absorption in the animal body in general, a few remarks may be added. The osmotic pressure of 0.92-per-

* Orlow, loc. cit.

cent sodium chloride, which is now, following the lead of Hamburger, generally taken as being equal to the osmotic pressure of the body fluid, has been established only for the blood serum. For the lymph flowing from the thoracic duct Leathes * found a somewhat higher degree, and for the lymph flowing from the cervical duct in horses Hamburger † records a much higher osmotic pressure than in the blood serum. For the tissue fluid within the interstitial spaces we have no knowledge whatsoever about the osmotic pressure. With reference to this point, it may be insisted again that fluid of any osmotic pressure brought into the abdominal cavity attains earlier or later invariably a certain uniform osmotic pressure. But the two statements which we have on this point differ as to what this pressure amounts to. While Hamburger, who employs the red-blood-corpuscle method, states that the fluid invariably attains the same osmotic pressure as the blood serum, we find in all the protocols of Orlow, who simply made chemical analyses of the fluid, that the solutions in the abdomen were constantly within the limit of 0.75- and 0.73-per-cent sodium chloride. This would mean that they become hypotonic with regard to the osmotic pressure of the blood serum. This is important when we remember that the fluid in the abdominal cavity is influenced in the first place by the tissue fluid.

Above all, however, we have to remember that we are handling osmotic laws as they are seen in final osmotic pressures and applying them to the process in the living body, where we have principally relations between initial or unsettled rates of osmosis. In this connection we would refer to a recent very instructive article by Lazarus-Barlow. ‡ He studied the ratio between the initial rates of osmosis of glucose, sodium chloride, and urea and their final osmotic pressure. He reaches the conclusion (p. 165) " that it is impossible to state from a determination of their freezing points that one solution is hypertonic, isotonic, or hypotonic as regards another solution of a different composition at pressures within the limits possible in the animal

* Leathes, loc. cit.
† Hamburger, Ziegler's *Beiträge zur pathol. Anatomie*, Bd. xiv.
‡ Lazarus-Barlow, *Journal of Physiology*, vol. xix, p. 140.

body." From his results (p. 160) " follows the paradox that if so-called isotonic solutions be placed on the two sides of a peritoneal membrane under conditions such as those we are now considering, osmosis can nevertheless occur. One may go even further and say that osmotic flow may take place from a solution having a higher final osmotic pressure toward a fluid having a lower final pressure."

The results were different when the equimolecular solutions were watery, faintly albuminous, or highly albuminous; and the results were again different when the separating membrane was copper ferrocyanide or prepared peritonæum. And we can reasonably assume that the difference is probably still greater when the separating membrane is unprepared peritonæum in the living body. We need therefore not be in despair if we can not explain all the particulars of the phenomenon under consideration by our present meagre knowledge of osmosis in its working in the complex condition of the animal body. Above all, we have certainly no right to appeal to " vital " force as long as we know so little of the working of the physical force we attempt to apply.

Our answer to the first question, therefore, is that the fluid which we have seen disappearing from the peritoneal cavity in the living as well as in the dead body entered the interstitial spaces by the process of osmosis assisted by filtration. The next question in order is: What becomes of this fluid within the interstitial spaces? The natural answer is that the fate of this fluid is probably the same as that of any other fluid present in excess within the interstitial spaces. Any accumulation of fluid in any region of the system of interstitial spaces has three ways open by which it can escape: (1) It can spread within the system of interstitial spaces into the neighbouring regions, either not affecting the blood and lymph vessels at all or affecting the blood vessels sufficiently to reduce the transudation into this region; (2) it can enter into the blood vessels through the walls of the capillaries or the veins; and (3) it can enter the lymphatics through the walls of the lymph capillaries.

When considering the further spreading within the neighbouring interstitial spaces, we must remember that the abdominal cavity

is surrounded with strata of muscular and connective tissues which are very appropriate for this purpose. The working forces for this spreading are, as we have pointed out above, diffusion and mechanical pressure, the latter being rendered quite considerable in the region in question by the respiratory motions and other factors. We should also remember that the entrance of fluid into the interstitial spaces occurs mainly by osmosis, which works well also against mechanical pressure. Now if a comparatively large quantity of a hypotonic solution enters rapidly into adjacent interstitial spaces, it can produce there quite a high mechanical pressure which might even exceed the pressure within the blood vessels, and certainly within the lymph vessels. This fluid, then, would not only suppress the transudation from the blood vessels, but it would enter also into the blood vessels by filtration, even against osmotic pressure. The same reasoning, of course, applies also to the lymphatics. Our answer to the second question raised above would then be, *a priori*, that the fluid which entered from the peritoneal cavity into the adjacent interstitial spaces partly spreads within the system of interstitial spaces from the neighbouring to the more distant tissues, partly enters the lymphatics, and partly invades also the blood vessels. If it is proved by experiment, as is indeed claimed by Heidenhain and Orlow, that during such a disappearance of fluid from the abdominal cavity the lymph flow from the thoracic duct is not increased, and if, further, we accept this as a proof that the disappeared fluid did not enter the lymphatics, our answer would have to be modified only with regard to the lymphatics, and we should say that the fluid spreads partly into the interstitial spaces and partly enters into the blood vessels. The conclusion which Heidenhain and Orlow have formed, that the whole of the fluid which has disappeared has entered directly into the blood vessels, is not warranted by the results of their experiments. That the fluid does not enter into the lymphatics is no proof that it enters into the blood vessels, so that their conclusion is, in fact, only a mere hypothesis. While it is certain that the disappeared fluid entered into the interstitial spaces, there is no proof whatever that it leaves the tissue spaces to enter into the blood vessels, a course which is the more open to

doubt since we see that filtration and osmosis are ineffective in bring-
ing the fluid into the lymph capillaries. However, we think that the
blood vessels possess an advantage over the lymphatics in their
stronger current, which carries away every trespassing molecule to
make room for another one.

As to the strength of the conclusion from the experiments of
Heidenhain and Orlow with regard to the lymphatics themselves,
we would only say here that the thoracic duct is not the only canal
which carries the lymph from the abdominal cavity. In our experi-
ment with larger quantities of salt solutions, as well as with the potas-
sium ferrocyanide, we saw that the right lymphatic duct exerts also a
decided influence upon the absorption from the abdominal cavity. In
the experiments of Heidenhain and Orlow it is possible that the right
lymphatic duct vicariously assumed the task of removing the share of
the surplus allotted to the lymphatics, inasmuch as the lymph flowing
from the thoracic duct through a cannula under atmospheric pressure
is less equal to its task, as it is deprived of a helpful factor, the nega-
tive pressure which is supplied by the suction occurring in the jugular
veins during each inspiration.

Our own experiments have shown that the ligation of the lym-
phatic duct certainly reduces the quantity of fluid that disappears
from the abdominal cavity in a given period of time and to a notice-
able degree. While insisting, on the one hand, that the experiments
of Heidenhain and Orlow do not prove absolutely that the lym-
phatics do not carry off any of the fluid, we admit, on the other hand,
that our experiments do not necessarily mean that the lymphatics
carry off some share of the fluid. The influence of the ligation can
be interpreted also by the assumption that the prevention of the re-
moval of the usual quantity of lymph from the interstitial spaces
causes there so many changes in the mechanical and osmotic pressures
that only a smaller part of the normal quantity can be taken up by
the interstitial spaces from the abdominal cavity. Thus the positive
conclusions which we can draw from our experiments with the salt
solutions must be restricted to the bare statement that the ligation of
the lymphatics exerts a restricting influence upon the quantity of

fluid disappearing from the abdominal cavity, but the experiments do not indicate whether or not the lymphatics carry away a part of this fluid.

It is different, however, with our experiments made with strychnine and potassium ferrocyanide. Here we have seen distinctly that when the lymph ducts were open the effect of the strychnine upon the nervous system and the excretion of potassium ferrocyanide by the kidneys occurred much earlier than when the lymphatic ducts were ligated. This shows unmistakably that in the normal state strychnine and potassium ferrocyanide leave the interstitial spaces mainly, and perhaps exclusively, by the way of the lymphatics. When the lymph ducts are ligated the substances linger for some time within the interstitial spaces until the mechanical or osmotic pressure, or rather both, reach a condition which enables these foreign substances to enter directly into the blood vessels.

It was our experience with strychnine and potassium ferrocyanide which made us inclined, as stated above, to support the hypothesis that to the lymphatics, among other duties, is assigned the special task of carrying off from the interstitial spaces such products as are either foreign, useless, or harmful to the tissue, and to deposit them in the lymphatic glands or to convey them to the blood, to be rebuilt there or to be excreted.

Our position with regard to the lymphatics can be briefly defined as follows: Our experiments prove that strychnine and potassium ferrocyanide are carried mainly or exclusively by the lymphatics. It is further quite certain that ligation of the lymph duct on the one hand restricts the entrance of fluid from the abdominal cavity into the interstitial spaces, and on the other hand even assists foreign substances, like strychnine and potassium ferrocyanide, present in the interstitial spaces, in finally entering into the blood through the walls of the blood vessels. Of the hypotonic and isotonic solutions of sodium chloride introduced into the abdominal cavity, we merely know for certain that they enter with more or less ease into the interstitial spaces; of their final fate we can only state hypothetically that they partly enter also into the lymphatics, selecting those ducts which are

open and offer the best facilities for their transference into the circulation.

As to the absorption of fluid from the peritoneal cavities of dead animals, we have to admit that even without the vital force as an active factor in the absorption there are indisputable changes in the dead bodies which undoubtedly alter in some respects the mechanism of absorption in them. Though we know very little of the working of osmosis in animal bodies, we know enough to enable us to recognise the fact that in the living body we have to deal nearly always with relations between more or less initial rates of osmosis, while in the dead bodies we deal with conditions approaching more the final rates of osmotic pressure. There is no transudation of fluid from the blood vessels into the interstitial spaces, and there are no anabolic processes going on within the tissue. Furthermore, there are no longer muscular contractions to produce mechanical pressure for filtration, and there is no current either within the blood vessels or lymphatics. With respect to this last statement, it is true that the lymph flows from a cannula in the thoracic duct for some time after death; but this does not show that the lymph is moving through the thoracic duct when it is normally connected with the jugular vein any more than the flow of blood from a cut would prove that the blood is flowing within the uncut vein. The fact that there is no current in the innominate veins proves our assumption that the thoracic duct does not discharge its contents into the jugular vein.

These changes, however, apparently influence but very little the entrance of the fluid from the peritoneal cavity into the interstitial spaces. The laws of the final osmotic pressure permit the absorption by osmosis of hypotonic fluid, which was exclusively employed in our experiments with dead animals. Besides, the rapid development of gases within the stomach and intestines of dead animals forms a new and efficient factor for filtration. Thus we may say, as already stated above, that the entrance of the fluid into the lymphatic spaces occurs in dead animals also by osmosis assisted by filtration, and that, though filtration may have a larger and osmosis a smaller share in the process here than in a similar process in the living body, the final effect is

about the same. That the ligation of the lymphatic duct has no influence upon the quantity of fluid which disappears from the peritoneal cavity is natural enough, for even without ligation there is no current of lymph within the lymphatics of the dead body.

It must be different with the further disposal of fluid within the interstitial spaces of the dead animals. None, or almost none, of the fluid will enter either the blood or the lymph capillaries. Even if there should be enough of osmotic and mechanical pressure to make some molecules pass through into the lumen of the vessels, there is no current to carry off these molecules to make room for others, and the effect of simple diffusion within these minute vessels is exceedingly small. The fluid which has entered the interstitial spaces must, therefore, remain there, but in this case again there are no respiratory movements or other muscular contractions to effect a wider distribution over a larger area and through the entire thickness of the tissues. The fluid, therefore, remains in a superficial layer of a limited space of the tissue next to the peritoneal cavity. In this fact is to be found an explanation for the often noted " exceedingly imbibed and œdematous condition of the tissue, especially of the posterior walls " in the dead rabbits.