RESEARCHES ON ASPHYXIA;
WITH
OBSERVATIONS ON THE EFFECTS PRODUCED BY THE HOT
BATH IN ASPHYXIATED ANIMALS,
AND ITS
USE IN THE TREATMENT OF SUSPENDED ANIMATION.

BY
A. T. H. WATERS, M.R.C.P.,
LECTURER ON ANATOMY AND PHYSIOLOGY IN THE LIVERPOOL ROYAL
INFIRMARY SCHOOL OF MEDICINE, PHYSICIAN TO THE
LIVERPOOL NORTHERN HOSPITAL, ETC.

COMMUNICATED BY
DR. SHARPEY.

Received April 4th.—Read May 14th, 1861.

ALTHOUGH numerous investigations have been made with reference to the nature of asphyxia and the influence of various modes of treatment in restoring suspended animation, I am not aware that any previous observers have directed their attention to one of the points which it was the object of the experiments referred to below, more particularly to inquire into.

Of the intimate pathological changes which take place in asphyxia, our knowledge is still imperfect, and we are not yet agreed as to the best modes of treatment in the more acute forms of the affection. The various societies, which direct their efforts to the saving of human life, issue rules for restoring suspended animation, of the most opposite character; for whilst some recommend the use of the warm bath, others expressly forbid it, as not only worthless, but dangerous.

Physiologists concur as to the order in which the arrest of the vital actions takes place when the entrance of air to the

lungs is cut off. They agree that the function of respiration is stopped, and that animal life (so called) becomes extinct, before the cessation of the heart's action. With regard, however, to the period during which the latter organ continues to contract after asphyxia has commenced, opinions do not so fully accord.

The success which, in many instances, has attended the efforts to restore animation, where the function of the lungs had only just ceased, encourages us to hope that, in all cases in which the action of the heart is still going on, we may, by an improved method of performing artificial respiration, restore life; and the want of success (except in rare instances), in those cases where respiration had ceased for some time, and where, probably, the heart was no longer beating, should act as a warning to us not to lose a single instant in endeavouring to promote the respiratory changes, to which alone we must look for a favorable issue to our efforts.

It is a matter of great importance, in connexion with the treatment of asphyxia, to ascertain the period after the cessation of the respiratory changes during which attempts to reanimate are likely to be successful; and this must depend on the time the heart continues to beat. Further, it is also important, considering the differences of opinion which now exist on the subject, to estimate aright the value of the hot bath as a remedial agent in the affection, and to do this it becomes essential to ascertain its effects on an animal when in an asphyxiated condition.

With the view of throwing some light on the points above alluded to, I instituted a series of experiments, the definite object of which was to answer, as far as possible, the following questions:

1. How long does the heart continue to beat in asphyxia?
2. What are the effects of the hot bath on asphyxiated animals? First, after all respiratory movements have ceased, and are not re-excited; secondly, when respiration has been re-excited and is being feebly carried on?

My experiments were made on animals asphyxiated by submersion; but as the morbid changes which take place

in asphyxia are the same by whatever means it may be produced, I think it may be fairly assumed that the remarks I shall have to make and the inferences I shall draw, as far as they may be correct, will be generally applicable to all acute forms of the affection.

With regard to the first of the above questions, it is obviously very difficult to come to anything like a correct conclusion. As far as man is concerned, it is indeed impossible to do so, and even with reference to the lower animals it is very difficult; a large number of experiments becomes necessary in order to obtain an approximation to the truth. The principle generally admitted is that "in asphyxia the movements of the heart cease in a few minutes after the cessation of the functions of animal life;" but the occurrence of certain facts, such as the recovery of individuals who have been under water for several minutes, would lead us to doubt the truth of the assertion. The second question seems more readily answerable, but yet no direct experiments bearing on it appear to have been performed previous to my own, some of which were made four years ago.

The experiments given in the tables below were performed on warm-blooded animals—dogs, cats, and rabbits. Those referred to in table No. 1 were conducted in the following manner:—The animals were plunged into water which varied in temperature from 40° to 50° Fahr., being a few degrees below that of the surrounding atmosphere, in one instance the temperature being reduced to 36° artificially; they were kept completely under water from the time of their immersion, and when removed (after every external symptom of life had disappeared), were, either at once or after the lapse of a stated time, opened by the removal of a portion of the anterior walls of the thorax; the movements of the heart were thus observed without the pericardium being disturbed. Some of the experiments, viz., 9 and 10, 11 and 12, 14 and 15, and 17 and 18, were parallel experiments, i. e. the two animals of each experiment were of the same age and size, were submitted to exactly the same process of drowning, and were opened at, as near as possible, the same time, the difference between the two being that one was put into the

hot bath for the period mentioned, the other was left on the table exposed to the atmosphere during the same time. The Experiments 20 and 21, and 22 and 23, were also parallel experiments; solely directed, however, to show the pathological effects of the hot bath. The Experiments 25 and 26 and 27 and 28 were also parallel experiments, bearing on both the questions we are considering.

TABLE I.

No.	Animal.	Time kept under water.	Put into hot bath at 100°, and how long.	Period after submersion at which thorax was opened.	Period after submersion up to which the ventricular portion of the heart continued to contract.
1	A rabbit	4 minutes	No	5th minute	11th minute, removed whilst contracting.
2	"	6 "	No	7th "	25th minute.
3	"	12 "	No	13th "	35th "
4	"	20 "	No	21st "	26th "
5	"	31 "	No	32nd "	Had ceased to beat when opened.
6	A large dog	14 "	No	17th "	Ditto.
7	A rabbit	11 "	No	12th "	16th minute.
8	A dog	8 "	No	9th "	34th "
9	A rabbit	5 "	Yes; 5 minutes	11th "	20th "
10	"	5 "	No	12th "	Had ceased to beat.
11	"	6 "	Yes; 4 minutes	11th "	30th minute.
12	"	6 "	No	13th "	30th "
13	"	8 "	Yes; 5 minutes	14th "	Had ceased to beat.
14	"	10 "	Yes; 5 minutes	60th "	Ditto.
15	"	10 "	No	60th "	Ditto.
16	A dog	8 "	Yes; 5 minutes	15th "	Ditto.
17	A rabbit	6½ "	Yes; 5 minutes	12th "	18th minute.
18	"	6½ "	No	13th "	Had ceased to beat.
19	A dog	8 "	No	9th "	Ditto.
20	A rabbit	4 "	Yes; 4 minutes	9th "	Heart contracting irregularly when opened.
21	"	4 "	No	10th "	Heart contracting regularly, 23 to the minute.
22	"	4 "	Yes; 4 minutes	9th "	Ditto feebly.
23	"	4 "	No	5th "	Ditto vigorously, 64 to the minute.
24	"	2½ "	Yes; 3 minutes	6th "	No regular action, ceased at 10th min.
25	A cat	4 "	Yes; 4 minutes	13th "	Had ceased to beat.
26	"	4 "	No	13th "	Heart beating regularly, continued up to 15th minute.
27	A rabbit	1½ "	Dipped in	10th "	Heart contracted up to 45th minute.
28	"	1½ "	Yes; 2½ minutes	8th "	Ditto 25th minute.

In analysing the preceding experiments with reference to the first subject of inquiry, viz., the duration of the heart's action, two must be set aside, inasmuch as in them the thorax was not opened till after the lapse of an hour from the period of submersion; these are Nos. 14 and 15. Out of the twenty-six remaining cases, in eighteen the heart was found beating when first observed, in eight its action had ceased.

In taking *an average* of the period during which the heart continued to contract in these cases, Nos. 1, 20, 21, 22, and 23 must be omitted, for in them the organ was either removed whilst in action or the time at which it ceased to beat was not accurately noted; the remaining thirteen give an average of twenty-five minutes *during which the ventricular portion of the heart continued to contract*. If we allow an average of nine minutes to the eight cases in which, on examination, the heart was found not contracting, and, including No. 1, at eleven minutes, take a general average of the twenty-two, we find it, as near as possible, *nineteen minutes*. These results do not coincide with those of Mr. Erichsen, who experimented on dogs by producing asphyxia in the open air; he gives an average of nine minutes and a half.

Setting aside the question of general average, it will be thus seen that in eighteen animals out of twenty-eight the heart was found contracting with more or less vigour and regularity when examined at the following intervals after the commencement of asphyxia, viz., the 5th, 7th, 13th, 21st, 12th, 9th, 11th, 11th, 13th, 12th, 9th, 10th, 9th, 9th, 6th, 13th, 10th, 8th minute, and that it continued in action during periods varying from the 11th up to the 45th minute from submersion.

In considering the second question we have to examine it in two different ways. We have, first, to ascertain what are the pathological effects produced by the hot bath in an animal, in which asphyxia has been so long continued that, on the cause of the asphyxia being removed, no efforts at respiration are made. To do this we proceed to compare

the morbid appearances presented by the various animals referred to in table No. 1, in order to see whether any differences exist between those which were submitted to the action of the hot bath and those which were not so treated.

The chief morbid appearances observed in the animals which were not put into the bath were as follows.

The lungs were but little altered from their normal colour; their substance was less crepitant than natural, and their large, emergent vessels, as seen at their roots, were somewhat distended, but to no great extent. The right cavities of the heart and the pulmonary artery were much distended; the left cavities contained a small quantity of blood; the blood was black and fluid throughout the body, but coagulated when removed from the vessels; the arteries contained a small quantity of blood. On opening a pulmonary vein or one of the large systemic veins, a considerable flow of blood always took place. It was observed during the examination of the animals that, whilst the heart was beating, and even after it had ceased to beat, on dividing a pulmonary vein, blood flowed, and continued to flow for a long time, and that the distension of the cavities of the right side of the heart and of the pulmonary artery became much diminished, the blood flowing freely through the vessels of the lungs.

The general morbid appearances presented by the animals which were put into the hot bath were these. The lungs were much more discoloured than when the bath was not used; their large vessels were more distended; their substance was firmer and heavier. The cavities of the heart were loaded with blood, both those on the left side as well as those on the right. In some instances the blood was coagulated in the vessels of the lungs, in the systemic veins, and in the cavities of the heart, and in all there was more or less of this condition observed. When a vein was opened the flow of blood was sometimes arrested by the presence of coagula, and was rarely free. The blood, when removed from the vessels, coagulated more rapidly and

formed a firmer clot than in the animals not put into the bath. In the animal which was put into the hot bath after being drowned for three and a quarter minutes in water at thirty-six degrees, the morbid appearances were the same as in the other animals, except that there was even more congestion of the lungs. (This experiment is not referred to in the tables.) That there was actually, and not only apparently, increased congestion of the lungs, and an increased quantity of blood in them, is proved by the results of experiments Nos. 22 and 23 and 25 and 26, in which the weight of the lungs in both animals of each experiment was taken. The lungs of No. 23, the larger rabbit and the one not put into the hot bath, weighed *considerably less* than those of No. 22, the smaller rabbit and the one which was put into the hot bath; and, again, the lungs of No. 26, the larger cat, not put into the hot bath, weighed *less* than those of No. 25, the smaller cat, which was put into the hot bath.

The following are the respective weights of the lungs of the four animals :

	Ozs.	drs.	grs.
No. 22.—The smaller rabbit (put into hot bath)	. 0	4	49
„ 23.—The larger „ (not ditto)	. 0	3	2
„ 25.—The smaller cat (put into hot bath)	. . 2	6	36
„ 26.—The larger „ (not ditto)	. . 2	5	37

The following notes are made with reference to the effects of the hot bath on the animals referred to in table No. 1.

In no single instance did the hot bath produce a respiratory effort, or any movement whatever, on the part of the animal. This was not only noticed in animals which had been drowned four, five, or six minutes, but in others which were under water only a minute or a minute and a quarter, and which, on being taken out, did not at once begin to breathe; in no instance of this kind did the bath produce any satisfactory result. The contractions of the heart seemed, generally speaking, to be less vigorous and to last

for a shorter time in those animals which were put into the hot bath than in the others.

In order to ascertain the second point referred to, viz., the effects produced by the hot bath in asphyxiated animals in which respiration has been re-excited, but is being only imperfectly carried on, a series of experiments was performed which are referred to in the table No. 2.

These experiments were designed, as far as possible, to imitate, in the animals experimented on, the condition of an individual, who, after having been drowned, is recovered from the water, and on being exposed to the air, first of all gasps and then begins feebly to respire; they were also designed to test the value of the hot bath as a remedial agent in such cases.

The animals which were the subjects of these experiments were all rabbits, with the exception of one, which was a cat. The rabbits were all of nearly the same age and size. All the animals were drowned in water at the ordinary temperature, which varied from 45° to 50° Fahr.; they were kept under water some for *one minute*, some for *one minute and a quarter*, and one, the cat, for *two minutes*. When removed from the water they were placed on a table exposed to the air, they were laid on their side, their mouth was opened, the tongue drawn forwards, and they were blown upon a few times by the mouth. In all the cases referred to the animals began to gasp almost immediately they were laid on the table, and respiration soon became feebly re-established. In order to compare the effects produced by the hot bath with those where all treatment was omitted, except that of exposing the body to the open air, some of the animals were left to themselves, whilst others, as soon as respiration was feebly re-established, were put into the hot bath.

Altogether, thirteen experiments bearing on this part of the subject were performed, twelve being on rabbits and one on a cat.

Of the thirteen, seven were treated by the hot bath, in which they were kept for periods varying from three and

a half to fifteen minutes. Of these, six died and one recovered.

TABLE II.

No.	Animal.	Time kept under water.	Put into hot bath at 100°, and how long.	Result.
29	A rabbit	1 minute	No	Recovered.
30	"	1 "	Yes; 3½ minutes	Died 5½ hours after submersion.
31	"	1 "	Yes; 15 minutes	Died 4 hours after submersion.
32	"	1 "	No	Died within 20 hours after submersion.
33	"	1 "	No	Died within 20 hours after submersion.
34	"	1 "	Yes; 7½ minutes	Recovered.
35	"	1 "	Yes; 12 minutes	Died 2 hours after submersion.
36	"	1 "	No	Recovered.
37	"	1 "	Yes; 10 minutes	Died 2 hours after submersion.
38	"	1½ "	Yes; 5 minutes	Died within 20 hours after submersion.
39	"	1½ "	No	Recovered.
40	"	1½ "	Yes; 10 minutes	Died within 20 hours after submersion.
41	A cat	2 "	No	Recovered.

Six animals, after being removed from the water, were simply left to themselves, exposed to the atmosphere. Of these, four recovered and two died.

The following are the morbid appearances presented by the animals which died after having been put into the hot bath :

The lungs were generally small, as if collapsed ; they were dark in colour, full of blood, quite firm, and almost liver-like in appearance ; they resembled somewhat foetal lung-tissue, or the collapsed lung-substance met with in adults. In some cases the condensed portions of the lungs sank in water. The trachea and bronchial tubes were free from frothy fluid ; blood was found in all the cavities of the heart, the two ventricles being generally about equally distended ; the blood was never very fluid, and in one

instance it was found coagulated in the cavities of the heart.

The post-mortem appearances of the two animals which were not put into the hot bath, but which died from the after-effects of the drowning, were as follows:—The lungs were somewhat congested, firm, and collapsed, but by no means to so great an extent as in the animals put into the bath. The blood was fluid, but less so than in acute asphyxia.

Without referring in detail to all the experiments, it appears to me that some of them show in a marked manner the different results of the two kinds of treatment resorted to; I am induced to quote the following:

In Experiments 36, 39, and 40, the same animal, a young rabbit, was used. On the first occasion it was drowned for *one minute* and then left to itself on the table. It recovered well. Three days were allowed to elapse, during which the animal was quite lively, took food, and appeared in no respects to have suffered from the effects of the experiment. It was again drowned, this time for *one minute and a quarter*, and when removed from the water was again left to itself. It soon recovered, and next day was apparently quite well. Three days were allowed to elapse again, during which time the animal was quite lively and ate as usual; in fact, no difference whatever was observable in its state as compared with that it was in before the first experiment. The animal was drowned for the third time, and for *one minute and a quarter*, as on the second occasion. When removed from the water it soon began to breathe. After lying on the table for about two minutes it was put into the hot bath; the breathing continued whilst in the bath, and the animal seemed to improve. It was kept in for ten minutes, and when taken out was able to walk. It seemed to go on tolerably well at first, but five hours after submersion it appeared very sickly and the respiration was hurried. Seven hours after the experiment the animal was alive; before the next morning, viz., within twenty hours of submersion, it was dead.

Although the experiments alluded to in the tables are not very numerous, yet, from the marked results obtained, it appears to me that they are sufficient to establish the principle of the injurious effects of the hot bath, at any rate on the class of animals which were the subjects of experiment; and I think we are justified in extending the principle to man. Many physiologists have deprecated the employment of the hot bath in asphyxia, but I am not aware that any experiments have ever been performed previous to my own which show its pathological effects on the lungs, and the manner in which, if had recourse to when respiration is feeble, it tends to destroy life some hours after its use. The recognition of these pathological facts must surely influence our practice, and tend to place our treatment of asphyxia on a more rational and scientific basis.

The following appears to me to be the way in which the hot bath acts :

By its stimulating influence it produces for a time an increased action of the heart, whereby more blood is sent to the lungs. Respiration being *nil*, the blood does not pass freely through the lungs, and hence their vessels become loaded. Some blood, however, finds its way to the left ventricle, which, from its imperfect action, is unable to get rid of its contents; the ventricle thus becomes distended, and subsequently arrested in its contractions. The circulation, although momentarily excited, ceases at an earlier period than when the bath is not used. Again, when respiration is being imperfectly carried on, the bath produces pathological results similar in their nature to those which it causes when respiration is suspended, viz., “engorgement” of the lungs and subsequent arrest of the heart’s action. In one instance I have seen the hot bath produce convulsions, probably from causing an increased formation of carbonic acid and its circulation in larger quantities to the nervous centres.

From the foregoing experiments and observations the following conclusions are drawn :

1. In dogs, rabbits, and cats, when asphyxiated by submersion, the ventricles of the heart do not, as a rule, cease to contract "in a few minutes after the cessation of the functions of animal life," but in many instances their action continues for a very considerable period; in all probability the same remark applies to man, and serves to explain how recovery has taken place after lengthened submersion, a circumstance which has been by many attributed to the fact of syncope having occurred at the period of immersion.

2. In cases of asphyxia where respiration has altogether stopped, the effects of the hot bath are to produce an accumulation of blood in the lungs and on the left side of the heart, together with a tendency to coagulate on the part of the blood. It does not tend to prolong the action of the heart, but rather to paralyse its movements and diminish the duration of its contractions. It does not excite respiratory efforts, and prevents artificial respiration from being properly carried out.

3. In cases of asphyxia where respiration has been re-excited, and is being feebly carried on, the hot bath, although in some instances it seems to have no immediate bad result, yet has a tendency to produce a fatal issue, some hours after its use, by causing extreme congestion of the lungs, together with consolidation and collapse of the pulmonary tissue.

The practical inferences to be drawn from the above conclusions with reference to the treatment of asphyxia seem to me to be the following:

1. That efforts should be made to restore suspended animation in all cases where asphyxia has not been of a *very* prolonged duration.

2. That, considering the effects of the hot bath, its prolonged use, whether respiration has ceased or is feebly going on, is not only inefficacious, but dangerous; and even to its temporary use—as, for instance, when the body is plunged into the bath and immediately withdrawn—there are serious

objections, as it causes a loss of valuable time, and produces no direct benefit.

The object of the hot bath can only be to excite respiratory movements; these will probably be better brought about, so far as an influence of this kind can have any result, by alternately dashing hot and cold water over the body, or by the application of hot and cold cloths, &c.

3. That, judging from the increased mortality of the animals experimented on, which were put into the hot bath, as compared with those not so treated, it is safer practice, and more likely to lead to a favorable issue, to omit all artificial aid in cases where respiration is feebly going on, than to make use of the hot bath.

4. That in the treatment of asphyxia all our efforts should be primarily directed to restoring, or continuing, as the case may be, the respiratory movements, and that all measures which have a tendency to load the lungs or embarrass the respiration should be avoided.

From my own observations in a case in which I succeeded in restoring suspended animation, from experiments I have performed on the dead body, and from the numerous instances of recovery that have taken place from its use, I am induced to believe that the best method we are yet acquainted with, of producing artificial respiration, is that recommended by Dr. Marshall Hall.

Although not directly bearing on either of the questions to which my experiments more particularly refer, there is one point in connection with the morbid condition of the animals to which I wish to direct attention, viz., that whenever a pulmonary vein was cut, especially in those animals which were not put into the hot bath, the blood flowed freely and relieved the distension of the right side of the heart and of the pulmonary artery. This fact seems to me to prove that, whatever may be the proximate cause of the arrest of the circulation in asphyxia, no condition, either of blood-vessels or blood, is produced such as to cause a

mechanical impediment to the passage of the latter fluid through the various vessels of the lungs ; and the fact appears to me to oppose a strong argument against any theory which would account for the cessation of the circulation, on the supposition that, either in the pulmonary capillaries or in the radicles of the pulmonary veins, such actual obstruction exists.