

lead to the rupture of healthy vessels. In respect of the results therefore the views of the different authors agree exactly and differ only as to whether the results are to be referred to granular kidney or not. These differences in theory would remain a matter of opinion still if there were not some fresh facts by which to elucidate them and these have been obtained by the more exact and careful study of the early eye-changes met with in granular kidney. As I shall show shortly, our knowledge of the early stages of albuminuric retinitis has been greatly extended of recent years. If in many of these doubtful cases of high pulse tension and thickened artery albuminuric retinitis or the early changes which lead to it are found, even in the cases in which albumin may not be present in the urine, the diagnosis of granular kidney will be surely justified. Considering that albuminuric retinitis is not of course invariably found even in advanced granular kidney, that it can be discovered in these earlier doubtful cases is a significant fact which throws a startling light upon many of those other cases which must still remain more or less doubtful. Some of these doubtful cases, therefore, at any rate must be referred to the group of granular kidney and the possibility that a much larger number of them can be fairly so referred is therefore increased. It appears to me, therefore, that the presumption is very strong indeed in favour of these cases of high pulse tension as well as those of thickened arteries in the young being the initial stages of granular kidney which it is so important to recognise.

A Clinical Lecture

ON

CAISSON DISEASE OR COMPRESSED AIR ILLNESS.

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GENTLEMEN,—Caisson disease or compressed air illness may justly be regarded as a product of modern civilisation. At the Redheugh Bridge which spans the Tyne not far from here operations are being carried on which have for their object practically the rebuilding of the bridge. Men are excavating the bed of the river so as to obtain a suitable foundation for the piers and in order to do this they are obliged to work in closed iron cylinders called caissons. On leaving work a few of the men have been ill and as two of them have come under my care their illness has given me the opportunity of drawing attention to this interesting malady. I will read first a few notes of one of the cases taken by Miss Alström, clinical clerk, and after that we will discuss the subject generally and at greater length.

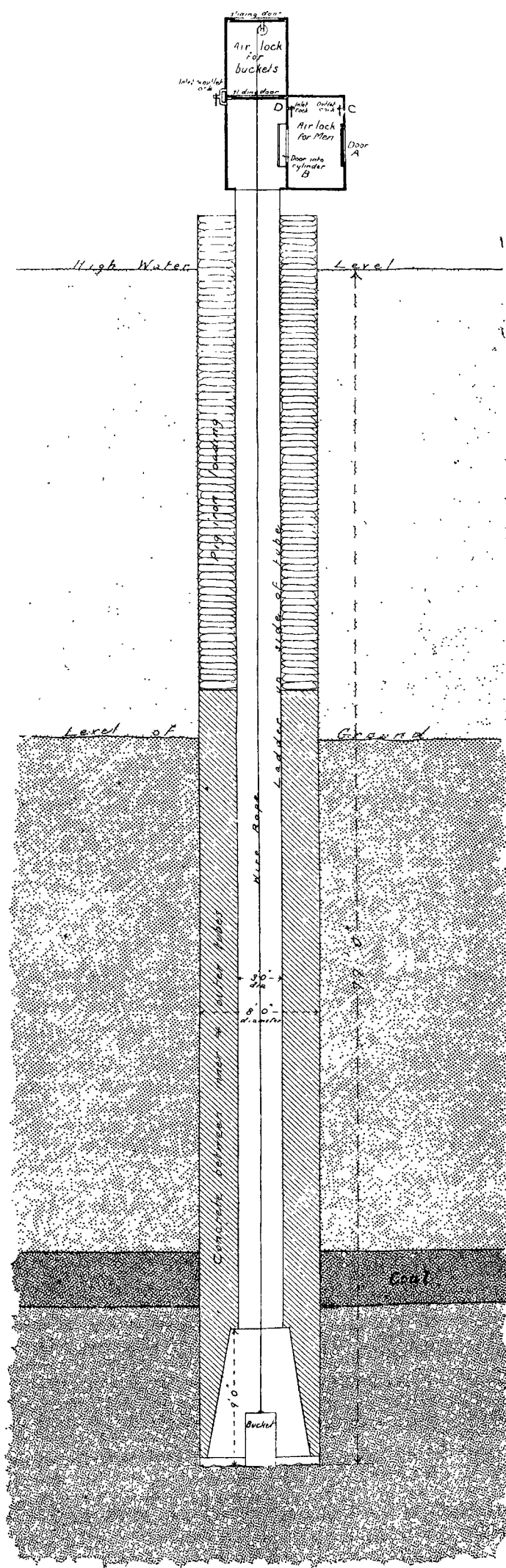
A married man, aged 45 years, a sinker, was admitted on Sept. 29th complaining of loss of power in the legs and arms and of pains all over his body. Until two days ago the patient was working in one of the cylinders at the Redheugh Bridge, 77 ft. below high-water level mark and under an atmospheric pressure of from 31 to 35 pounds to the square inch. On Sept. 27th as he was returning from work he experienced a peculiar numbness and tingling sensation all at once in his legs, felt sick and vomited, became giddy, and shortly afterwards fell to the ground unconscious. His comrades carried him home. 12 hours later consciousness returned and he complained of being in pain all over his body; his muscles were so sore and stiff that he could not turn over in bed; his limbs felt powerless. There was considerable headache and a buzzing in his ears. There was rather profuse perspiration. Next morning he got up and dressed intending to return to his work; his nose began to bleed, but this did not prevent him leaving home. He had not gone far,

however, when he again lost consciousness. It was in this condition that the patient was brought to the infirmary. On coming to himself he complained of the same agonising muscular pain as on the previous day; his breathing was difficult; there was a feeling of sickness and his skin was perspiring freely. With regard to his previous history the patient had followed the occupation of a sinker for 20 years, sometimes in connexion with coal mining in the north and latterly in connexion with the Tower Bridge in London. Until now he had never suffered from the effects of his employment. He had been a steady man, seldom averaging more than a pint of beer daily. In his family history there was nothing of importance. On admission the patient was found to be cold, collapsed, and perspiring. His pupils were normal; the pulse was slow and full; there was marked muscular rigidity; pain seemed to be felt on making passive movement; and there was dyspnoea but no cyanosis of any moment. On regaining consciousness he complained of loss of power in his extremities, throbbing in the head, pains in his muscles, and a feeling of oppression in the chest. He was rather deaf. Subsequently he had a rigor, not followed by a rise of temperature. That night he had rather broken sleep. Next morning we found that the muscular rigidity had passed off, the knee-jerks were exaggerated, sensation was unimpaired, and the dyspnoea was less. There was no bladder implication. The urine was free from albumin and sugar. In the course of the day he vomited and wandered, the delirium assuming rather a noisy character. He was given stimulants and a hypodermic injection of liquor strychniæ. These relieved him. That evening he slept better. On Oct. 1st his pulse which had never been higher than 60 was 56; it was small and firm. The skin was observed to be covered with discrete coffee-coloured spots varying in size from a pin's head to a small bean not elevated. Pain was felt on firmly compressing the muscles. The apex beat of the heart was well defined; the first sound was feeble over the mitral area and the second aortic sound was well marked. The lungs presented nothing abnormal; the respirations were 18. Liver dulness normal; splenic dulness perhaps a little more pronounced than usual. In walking it was noticed that the feet were kept widely apart and there was slight staggering from side to side with a tendency to fall forwards. The patient had barely gone a few yards before he became extremely pale and would have fainted had he not been caught and lifted on to bed. It was several minutes before he rallied and it was an hour or two before the feeling of exhaustion passed away. Under the microscope the red blood corpuscles seemed paler than usual. They did not form rouleaux; the cells seemed to be of unequal size; the white corpuscles were not increased in number. The urine was acid, had a specific gravity of 1020, and was free from albumin and sugar. There were 10.25 grains of urea per ounce of urine. For several days we did not try him walking; he complained of feeling giddy, of buzzing in his ears, and of pains in his limbs. By degrees these symptoms gradually got less and as he felt better he left the infirmary rather against my wishes. He returned on Nov. 8th, 11 days afterwards. He told me that he had been in bed all the time and he certainly looked very feeble and could only crawl. There was still muscular pains in his shoulders and limbs and lower part of the back with a sense of numbness. His breathing was short. There was a constant feeling of giddiness and occasionally a ringing in his ears. He had had a few days previously a slight hæmoptysis. The knee-jerks were not exaggerated.

It was in the sixteenth century that the diving bell was introduced by Sturmius. Into it as no air was kept circulating the workmen took bottles of air and from time to time broke them. Subsequently a tube from an air-pump was connected through the diving bell with a cowl placed over the head of the men so that they could leave the bell and work under the water. It is a long leap from the sixteenth century to the end of the nineteenth and from the simple diving bell to the caisson of to-day, but the same idea runs through all the methods employed. When we speak of a caisson we mean a cylinder composed of iron plates riveted together, and which when of the required length is sunk on to the bed of a river, so as to form a shaft down which when it is properly closed at the top by a perfect fitting diaphragm men descend, air previously having been driven in under pressure so as to force water out of the shaft at the bottom and to keep it out. In order to allow

of men entering and leaving the cylinder there is attached to the shaft close to the diaphragm a chamber or lock with an inner and outer air-tight door, both of which open towards the interior of the shaft that contains the compressed air, mechanical arrangements existing inside the lock in the shape of cocks whereby pressure can be gradually increased or diminished, so that men before passing into the compressed air in the shaft or after having emerged from it are brought by degrees under the influence of an increasing or diminishing air pressure. Caissons were first employed by a French engineer, M. Triger, who used them for boring wells and fixing piles for bridges. From the earliest period that men have worked in the cylinders under compressed air they have complained of pains in the ears and pains in the joints. Dr. Snell, who acted as medical officer to the Blackwall Tunnel and who has embodied his experience of this illness in a monograph on Caisson disease which has supplied me with many of the facts stated in his lecture, informs us that the first medical memoir written on this subject was by MM. Pol and Watelle. The physiological effects stated were pains in the tympanum, lessened frequency of respiration and of pulse, and increased urinary secretion. Of 64 workmen exposed to the influence of compressed air 47 stood the work well, 25 gave up the employment, and two died. Men who work at this particular occupation are exposed to two sets of conditions, both of which are attended by danger: (1) in going into the compressed air and (2) in coming out of it, and the question which first suggests itself is which is the more dangerous, "compression" or "decompression." The patient whose notes I have detailed says that he felt compression the more unpleasant of the two. There is little doubt, however, that decompression, that is, the coming out of the compressed air and returning to that of normal atmospheric pressure, is the more likely to be attended by symptoms. On the ordinary level of the earth's surface each of us is bearing an atmospheric pressure of 15 lb. to the square inch, but because this is pressing equally all around and upon us we are unconscious of the weight and this remark holds true *ceteris paribus* whether we dive under the water or descend into a coal-pit. Knowing these facts engineers thought that if men were subjected to compressed air they could be brought to bear the increased weight with impunity, since the pressure would be equal on all sides and that little or no risk would therefore be incurred by exposure to two, three, or four atmospheres, or, in other words, to 30, 45, or 60 lb. to the square inch. The need for using caissons is apparent when, as in the case of the Redheugh Bridge, it is necessary, in order that new piers shall be built capable of supporting enormous weights, for a substantial foundation to be got by penetrating to the depths of the river-bed. At this bridge the men are working in the caissons at a depth of 77 ft. below high-water level mark, the length of the cylinders themselves being 90 ft. Mr. Huntley, the resident engineer, tells me that the bottom 30 ft. of each cylinder were first riveted together and then lowered on to the river-bed in its correct position. Outside of this is another cylinder. The two are united at the bottom. The space between the two tubes is filled with cement. Other 20 ft. of iron plates were riveted on to these and concrete again added. The air-lock was then bolted on to the top of the inner tube and air pumped in until the water was driven out by pressure. Men were now sent down to excavate the soil at the bed of the river. Two men work in each cylinder. They shovel the soil into large buckets which when filled are raised by a small engine fixed outside the lock. As the cylinder keeps sinking by its own weight new lengths of iron shafting have to be added to it and into the space between the two tubes which has been filled with concrete bars of pig iron are thrown so as to help the sinking of the caisson. In order to enter the cylinder one has to pass into the workman's lock by the door A (vide illustration), door B which opens into the main shaft being at this time perfectly closed and kept thus by the great pressure within the cylinder. Once in the lock and door A closed tightly, the outlet cock C being closed, the inlet cock D is gradually opened. This allows of the compressed air of the shaft escaping into the lock, so that when the pressure inside the lock becomes equal to that inside the cylinder the door B opens of itself. The workman enters the shaft and descends by means of a ladder to his work at the bed of the river. On leaving the caisson the process is reversed. The time usually occupied in passing through the lock is about one minute for every three pounds of pressure. The buckets when filled with soil are passed through the material lock in

a manner similar to that already mentioned with the exception that the sliding doors and cocks are operated by men outside the locks, air being let in and out of the locks very rapidly. After having made their way through 60 ft. of the



Section of cylinder showing air locks by which entrance is gained.

river bed the excavators came upon a seam of coal three feet in thickness and as seen from the illustration they are now working several feet below this.

It was in 1851 that caissons were first used in this country by Hughes for securing foundations for a bridge at Rochester over the Medway at a depth of 61 feet; subsequently by Brunel for the bridge at Chepstow over the Wye, and later at Saltash where one of the workmen died very shortly after leaving the cylinder in which he had been working at a depth of 87.5 feet and under a maximum pressure of 40 lb. In 1859 during the building of the bridge of Kaffre-Azzyat over the Nile five Arabs died from the effects of the compressed air. Blood is said to have issued from their mouths, noses, and ears. The depth of the working was 85 feet below high water and the pressure was 34 lb. to the square inch. Since then bridges have been built all over the world by means of caissons—e.g., the Brooklyn Bridge at New York, and in our own country the most notable undertakings of this character in which caissons have been employed were the Forth Bridge and the making of the Blackwall Tunnel. Dr. James Hunter has given in his thesis for the Edinburgh M.D. his experience of caisson disease among the workmen at the Forth Bridge and Dr. Andrew Smith in a brochure his opinion of the illness gained by attending workmen at the Brooklyn Bridge. In New York Dr. Smith states that the pressure varied from 18 lb. to 36 lb. to the square inch above that of the atmosphere, that the caissons were lighted by gas, and that from 50 to 150 men were employed during the day and from 15 to 30 at night. The compressed air chambers were said to be well ventilated, but the air contained as much as 0.3 per cent. of carbonic acid, to maintain which 150,000 cubic feet of air were required every hour. The men worked two shifts of four hours separated by a period of rest for two hours, but as the caissons sank deeper and deeper the hours of work were correspondingly diminished. Dr. Smith treated 110 cases of illness due to compressed air; three of the patients died.

At the Forth Bridge Dr. Hunter found that epistaxis frequently occurred in the men shortly after emerging from the compressed air; that while the primary effect of being placed in compressed air was to accelerate the heart's action the pulse gradually became smaller and the arterial tension increased; that the respirations varied from 12 to 14 per minute; and that the temperature was sometimes above and sometimes below the normal. The pressure the men were subjected to ranged from 15 lb. to 34 lb. above the normal. At first the men worked from four to six hours at a stretch but this was found to be too long. It was noticed that they suffered most when the soft silt in the bed of the river which contained decaying organic material was being removed. No fatal cases occurred at the Forth but there was a large amount of illness among the workmen. One of my clinical clerks went into the caisson along with Mr. Huntley the engineer. He informs me that the candles burnt more quickly in the compressed than ordinary atmospheric air and created much more smoke. He experienced a feeling of fitness without any fatigue after ascending the ladder. His respiration was at first quickened; it was 40 in the minute; Mr. Huntley's was 20, but he was accustomed to the caisson, while that of another medical student was 32. The pulse was in each instance quickened; at first 100, it fell in a quarter of an hour in my clinical clerk to 88 and in Mr. Huntley to 65. My clinical clerk experienced very unpleasant sensations in his ears until he swallowed air and for a period kept swallowing it so as to inflate through the Eustachian tube the middle-ear. He could not whistle when in the cylinder but could speak quite easily. He had no difficulty of breathing and no uncomfortable feeling other than that just mentioned. The pressure in the caisson was 41 lb. to the square inch. In passing out through the lock and when undergoing decompression the air was observed to become steam-like, dense, and white for a few seconds, a circumstance attributed by the engineer to the air being no longer able to retain moisture so well. The expansion cooled the air and the cooling caused the condensation. One of the students on emerging from the caisson had epistaxis and rather severe ear-ache and face-ache.

With regard to the symptoms, nearly every person who has gone into a caisson of compressed air for the first time has after coming out complained of extremely unpleasant sensations in the ear amounting at times to severe pain. This is doubtless a mechanical effect and is the result of the tympanum being driven in by the compressed air, for when a workman has acquired the faculty of swallowing air

and passing it up the Eustachian tube this inconvenience is no longer felt. A cold in the head or a sore throat is a counter indication to anyone entering a caisson, experience having demonstrated that under these circumstances excruciating pain may be felt which is referred either to the ears or to the forehead. It is natural to expect where a man in a cylinder is exposed to highly compressed air, where the whole body is being pressed, that some bad effects would follow the heightened arterial tension present. The conditions are so unnatural that men can work with safety only a few hours at a time, from two to four hours being according to the pressure a sufficiently lengthened period of exposure. In my conversations with the Redheugh Bridge contractors and the engineer I am told that when the workmen are in the caisson they experience no ill effects; they feel so buoyed up and are so highly strung that in a given time they do far more and much harder work than when above ground; that they are unconscious of using any undue physical exertion and do not feel fatigued; the men perspire freely and rub themselves, thus producing an eruption on the skin which becomes itchy; also that candles burn with greater rapidity in compressed air. Inside the caisson, therefore, it would appear as if vital processes were hurried on, metabolism more active, and consequently a greater strain thrown upon eliminating organs. It is not when men are in the compressed air but after decompression that symptoms arise and these are, in addition to those already mentioned, a feeling of giddiness with a tendency to fall, loss of power in the legs amounting at times to paralysis, severe pains in the legs, arms, and shoulders called by the workmen "bends," epistaxis, hæmoptysis, and occasionally unconsciousness.

What is the cause of the symptoms? There is the fact of pressure, and that this plays a part in producing them is shown by this circumstance that as the pressure in the caisson is raised so is there an increase in the number of patients. On the Tyne the men always noticed that when the pressure inside the caisson was raised so as to keep pace with the rising tide outside there was a greater tendency to suffer. In other words, working under a pressure of 39 lb. to the square inch was worse than one of 32 lb. The condition of the air inside the cylinder, too, is of some importance. From the fact that candles are known to burn more brilliantly and quickly inside the caissons than in the ordinary atmosphere the air tends to become polluted by the smoke and by the exhalations of the workers. In the caissons at the Brooklyn Bridge each man was supplied with from 1000 to 3000 cubic feet of air per hour. This air is said to have contained 0.3 per cent. of carbonic acid, as against 0.06, which is regarded as the maximum in a well-ventilated space. Under such a condition it cannot be said that the men were breathing a very pure air. 6000 cubic feet of air per hour per man is the amount which some engineers and medical men say ought to be supplied. At the Redheugh Bridge where my patient was working 3000 cubic feet were given, but since that date the contractors have been allowing 5000 cubic feet per hour. Hersent, a French engineer, experimented at Bordeaux in 1893 and 1894 with the view of ascertaining what pressures could be borne with safety. Dogs first, and subsequently men, were placed in chambers capable of withstanding high pressures. Several of the dogs became paralysed the day after decompression, others very shortly after emerging from the caisson. The paralysis varied in its duration. In some of the animals the blood-vessels of the spinal cord contained globules of air. In the case of the men similarly exposed to high aerial pressure he found that when they were subjected to a pressure of from 28 lb. to 76 lb. to the square inch for an hour at a time many of them subsequently suffered from severe pains in the limbs and itchiness of the skin.

The morbid anatomy of compressed air illness has yet to be written. Congestion of the membranes of the brain and spinal cord, extravasation of blood within the dura mater, softening of limited areas in the spinal cord and fissures therein caused by escape of gas, congestion of the lungs and dilated right heart, and the presence in the blood-vessels of bubbles of air have all been noted. The physiology and pathology of the action of compressed air are not well known. Personally I own to having a difficulty in coming to a definite opinion upon this subject. An individual in a caisson is exposed to an enormous atmospheric pressure, his whole body is squeezed thereby, his superficial arteries are contracted, the most compressible part of his body—viz., the abdomen—is squeezed, and the interior of his lungs is

brought under the influence of an abnormal distending force. How does the body behave under these circumstances? The oxygen of the atmosphere is being forced in through the pulmonary capillaries under tremendous pressure. Can the carbonic acid correspondingly as quickly escape? Some writers maintain that at first the carbonic acid is increased and subsequently that its elimination is checked—the former being purely a chemical effect, the latter the result of some mechanical hindrance. The hæmoglobin of the blood takes up oxygen quite irrespectively of pressure, but under the enormous pressure workmen are exposed to in the caissons it is thought that a larger amount of oxygen is absorbed, not so much taken up by the corpuscles as simply dissolved in the blood. The part played by the nitrogen of the air need not be discussed, for it is a passive gas. When people ascend to great altitudes they inhale a rarefied air and their breathing becomes quickened, so in descending to great depths and breathing compressed air respiration, owing to the air being under pressure, should become less frequent and that this occurs is admitted, although in my clinical clerk it was increased. If gas is taken up by the blood and dissolved in it under the influence of great pressure then when decompression is too quickly effected there may be an escape of gas into the tissues, hence the fissures found in the spinal cord, or it remains as globules in the blood and is capable of blocking some of the smaller vessels. Under ordinary circumstances it is easier to take oxygen into our blood than it is to get rid of carbonic acid from our lungs. After a brisk run we experience a difficulty of breathing: we pant. The distress is due not so much to the difficulty of obtaining oxygen as to getting rid of the carbonic acid from the system. The quickened respiratory movements have for their object the ventilation of the lungs. When, therefore, men inside the caissons are working hard and this they do largely aided by the supply of oxygen under pressure an excess of carbonic acid must be correspondingly formed. Under ordinary circumstances the escape of this gas through the walls of the pulmonary capillaries is due to the fact that the tension of the carbonic acid in the blood is greater than that in the air in the alveoli of the lungs. Possibly it may escape just as readily under the increased as under ordinary atmospheric pressure, for as the whole body is under pressure the carbonic acid formed in the tissues must be passed into the blood under a correspondingly increased pressure and will thus be carried to the pulmonary capillaries. In compressed air it is easier to inspire than to expire. The pulmonary capacity is increased, for the chest then measures during inspiration more than it does in ordinary atmospheric air, but it requires a stronger muscular effort to make an expiration, hence its duration has to be longer. Without being able to prove or disprove the statement it is just possible that carbonic acid tends to accumulate in the blood of a caisson worker.

Three theories have been brought forward to explain compressed air illness—(1) carbonic acid poisoning; (2) mechanical congestion of internal organs; and (3) increased solution by the blood of the gases met with in the compressed air and the liberation of these gases during decompression. We have no proof that there is carbonic acid poisoning. Although the men in the caisson carry on their work with great vigour and apparently with less sense of fatigue than on the surface there is no evidence of increased metabolism. In none of my cases was the daily discharge of urea increased above the normal. It is impossible to say whether more oxygen is absorbed; if so, the extent to which it is utilised will depend upon the needs of the system. The air which the workman breathes in the caisson is still atmospheric air. It is not modified in its chemical composition and although the individual so far as respiration is concerned is placed under abnormal conditions vital operations are regulated by the same physical laws as if he were on the surface. If compressed air illness is due to carbonic acid poisoning it ought to occur when the men are in the caisson and not after they emerge from it. That the illness is the result of mechanical congestion especially of the brain is the opinion entertained by Dr. Andrew Smith of New York. In several of the workmen who have died the membranes of the brain have been found deeply congested—a circumstance which may have contributed to the fatal termination. The third theory—viz., that of increased solution of gases in the blood—is that which has met with the greatest acceptance. Dalton's law that the weight of a gas dissolved by a liquid is directly

proportionate to the pressure applies to the person of the caisson worker. If in such an individual more gas is dissolved in the blood under compression the excess will be given off after his emergence into the open air. It is the presence of air sucked into the blood that is considered a danger when a large vein at the root of the neck is wounded. There can be little doubt that the escape of bubbles of gas as the blood courses through the capillaries of brain and spinal cord in the decompressed caisson worker is equally dangerous. Paul Bert in his experiments has shown that when animals were exposed to compressed air and were rapidly decompressed several of them died suddenly and at the post-mortem examination free gas was found in the blood and in the right side of the heart. In those animals that were paralysed bubbles of free gas were observed in the spinal blood-vessels and there was in addition subcutaneous emphysema. As to the nature of the gas found in the blood and tissues I am unable to speak with certainty. We are told that carbonic acid is 45 times more soluble than oxygen, but we have no positive proof that it is this gas. It might be nitrogen. The theory that the illness is due to blood first dissolving an excess of gas when the workmen is in the caisson, and that it liberates it when he leaves the cylinder is a possible explanation of why the symptoms come on during or shortly after decompression and of the relief that is obtained by recompression.

As to treatment, preventive and curative, it is absolutely necessary that a sufficient length of time should be passed in the lock, both in compression and decompression, so that the individual is not subjected to the influence of sudden increment or decrement of pressure; one minute for every three pounds of pressure is considered an average period but the length of time might with advantage be increased, for diffusion is slow. The atmosphere in the caisson should be kept as pure as possible and men should not work in the cylinders longer than from two to four hours at a stretch. Only healthy men should be employed. Men who are intemperate in the use of spirits or who are suffering from cold in the head or are weak-chested should not be allowed to enter the caisson. The curative part of the treatment consists in relieving pains in the muscles when severe by means of morphia and when there is collapse by the application of heat to the extremities, stimulants carefully administered, and a hypodermic injection of strychnine when the breathing is impaired. Ergot is recommended with the view of relieving internal congestion and where the symptoms develop quickly and are severe good effects have been obtained by gradually recompressing the patient.

A RETROSPECT OF THE RINDERPEST CAMPAIGN IN SOUTH AFRICA.

By ALEXANDER EDINGTON, M.B. EDIN., F.R.S.E.,
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ON April 16th, 1896, I arrived at Mafeking and on the 17th a conference of delegates from the various States was held, Sir Peter Faure, K.C.M.G. (then the Honourable Mr. Faure), Mr. Newton (Resident Commissioner of the British Protectorate), and others being present. At this time, owing to the prompt action of Mr. Hutcheon (the colonial veterinary surgeon) and his staff the rinderpest was being held in check and no fresh centres of disease were then forming. At the conference I proposed: "That rinderpest is a virulent disease and can only be efficiently dealt with by stamping out; that all animals infected with the disease and all animals which have come in contact with such animals should be immediately destroyed, compensation being paid to the owners for all healthy cattle which may have thus been destroyed; and that the respective Governments should be requested to agree to a mutual action in the matter of stamping out and compensation and to contribute a *pro rata* share of the expenses incurred." These propositions were seconded by Mr. Van der Plank, M.R.C.V.S. At this time every effort was being made to stamp out the disease and hence experimental work was held in abeyance until later in the year when, Bechuanaland having become widely infected, I formed a camp in the veldt in the Taungs native reserve and began experimentation under difficulties