A STUDY FROM A CLINICAL STANDPOINT OF THE CHANGES PRODUCED IN THE BLOOD AND TISSUES OF THE HUMAN BODY, BY THE PROLONGED ACTION OF AN EXCESS OF CARBONIC ACID.

Being Thesis submitted to Glasgow University for M.D. Degree.

BY

DAVID CURLE, M.B., C.M.

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A STUDY FROM A CLINICAL STANDPOINT OF THE CHANGES PRODUCED IN THE BLOOD AND TISSUES OF THE HUMAN BODY, BY THE PROLONGED ACTION OF AN EXCESS OF CARBONIC ACID.[1]

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In the early history of the disease known as rickets, before the deformities have become manifest which in the lay mind stamp the sufferer as rickety, it has been observed that the veins of the head and neck become overfilled whenever the child falls asleep. It is a constant symptom wherever there is the profuse perspiration and tendency to lie uncovered, which characterises the onset of sleep in the early rachitic condition. It is also a symptom more or less prominent when the subject is indoors, and any of those conditions arise which in a healthy subject demand an increased elimination of CO_2.

As it is when the child begins to sleep, however, that the symptom has most importance for us, let us consider its significance. In anticipation of sleep all the voluntary muscular system has been at rest for some time. The venous plethora, then, cannot be the result of exertion. Nor can it be the result of cerebral excitement or nervous emotion, as it is when these functions subside in sleep that the symptom is most pronounced. It cannot be the result of an instantaneous rise in temperature of the air or the body, as the symptom soon diminishes in prominence when the child awakes. It cannot be explained as a venous hyperæmia, consequent alone on the withdrawal of a portion of blood from the brain and determination of blood to the skin, as the proportion of blood so added to the body in sleep is so small in comparison with the

[1] For brevity, in the following pages carbonic acid is designated by the symbol of carbon dioxide, CO_2.

capacity of the vascular system to accommodate a large increase of blood, and it does not occur in health.

The conditions under which it originates indicate that it is due to some abnormal cause. The blood is becoming venous quicker than the lungs and skin can excrete CO_2. There is excessive production of CO_2 in the body, imperfect elimination, or both agencies are at work.

In everyday life, when the blood in the capillaries becomes charged with CO_2, more arterial blood is supplied to the part, and the blood is driven into the veins. It is well known that CO_2 will lead to contraction of arteries, even when all the connections with the central nervous system have been severed.

Now in sleep we have diminished excretion of CO_2 to the extent of 25 per cent.

But it must be remembered that whilst we have diminished excretion in health, we have also diminished production within the body. This to some extent can be estimated from the work done by the heart in sleep. It only gives about three-fourths the number of beats per minute which it does when the subject is awake. In accordance with this, the number of respirations per minute in sleep is only three-fourths of that when awake. But in sleep the respirations are not so deep, and to make up for this the skin acts as an auxiliary, and in health acts sufficiently, but not so in the condition we are studying.

Before proceeding further, it will be advisable to consider how the body of the child differs from that of the adult in its power of eliminating CO_2.

According to Dr. M'Kendrick in his *Manual of Physiology*, "In the child there appears to be a different distribution of blood from what obtains in the adult. The heart of a child is relatively small up to puberty, while the vessels are relatively large; after puberty the reverse is the case. Arterial pressure is less in the child than in the adult, whilst the *pressure in the pulmonary circulation is larger in the child than in the adult.*"

As regards the kidneys in the child, Dr. M'Kendrick states (*op. cit.*, vol. ii, p. 401), "For each kilogramme of body weight the following quantities of urea, CH_4N_2O, are formed in the urine:—

3 to 6 years, ...	1 gramme.
8 to 11 years, ...	·8 ,,
13 to 16 years, ...	·04 to ·6 ,,

It will thus be observed that whilst the power of the heart and lungs to eliminate CO_2 is relatively small, compared with that in the adult, that of the kidneys to eliminate carbon in the form of urea is relatively large.

This, then, explains why in the case of the child there is such a difficulty in getting rid of an abnormal quantity of CO_2, and it is in keeping with the late development of function in the lungs and skin.

Our next duty must be to account for this accumlation of CO_2 in the veins of the child suffering from rickets.

It is now generally admitted that where rachitism develops, one or more of the three following factors have been in existence. I will name them after the observers who have laid special but not exclusive stress on each:—

1. *Dr. Alfred Vogel's factor*—"The want of fresh air."
2. *Dr. William Macewen's factor*—"A febrile disease."
3. *Dr. W. B. Cheadle's factor*—"Improper diet." In other words, a diet in which proteids, fats, minerals, and carbohydrates are not represented in suitable proportions, but more particularly where proteids, or fats, or both proteids and fats are deficient, and carbohydrates in excess.

Dr. Baxter, Mr. Clement Lucas, and others have also pointed out the importance of this factor.

Let us now consider how each factor will act:—

1. Want of fresh air, or rather the presence of impure air, it is apparent will lead to defective elimination of CO_2, owing to the presence of CO_2 in the atmosphere. Dr. Angus Smith has shown that apart from the presence of organic matter in the air the presence of CO_2, even in small quantities, is injurious.

The presence of CO_2 to the extent of 1 part in 1000 of air produced in fifteen minutes an increase in the number of respirations from 18 to 19 per minute, which increase remained for thirty minutes. The pulse was lowered in twenty-five minutes from 73 to 71 beats, while at forty-five minutes it was 72 per minute. With $2\frac{1}{2}$ volumes of CO_2 per 1000 of air the pulse rose from 70 to 73 beats per minute at the end of ten minutes, and at the end of thirty minutes was lowered to 69, whilst the respirations increased from 17 to 21 per minute.

With 5 volumes of CO_2 per 1000 of air the pulse fell from from 76 beats per minute to 71 at the end of forty minutes, and the respirations increased from 17 to 24 per minute. It is apparent that where the body is unable to cope with this extra work and depression, CO_2 must accumulate in the blood.

In considering Dr. Macewen's factor, the febrile diseases which chiefly give rise to rickets are measles, whooping-cough, and those which directly damage or impair the respiratory organs as bronchitis, pneunonia, &c., or those which by weakening the heart indirectly affect the elimination of CO_2. It is apparent that the factor operates by allowing CO_2 to accumulate through defective elimination,

The food factor is so important that I must quote Dr. Cheadle's own words from his work on *Artificial Feeding* (third edition), pp. 175, 176:—

"The only constant factor, always present, is the food factor. Sometimes it is the only factor. The chief cause, this fault of diet, is the commonest, the most potent and dominant of all. This much is, I think, well established; the vast majority of cases of rickets arise directly in connection with food." . . . "I think it may also be affirmed broadly that children fed almost entirely on farinaceous food, even if taking it will, without any apparent drawback, as certainly become rickety. We see these experiments made daily before our eyes with uniform results."

To explain how the food factor operates, it will be necessary to take into consideration the following facts ascertained by physiological research. The first five I have taken from

Dr. M'Kendrick's *Manual of Physiology*, the sixth from the work on physiology by Dr. Cleland:—

1. That when proteids, fats, and an excess of carbohydrates are taken into the body, the first which the stomach selects is the carbohydrates, and that it will sometimes select the carbohydrates when in excess to the exclusion of the others.

2. That carbohydrates are more readily oxidised than either proteids or fats.

3. That the amount of CO_2 excreted by the body is increased by a diet rich in carbohydrates.

4. That in a diet rich in carbohydrates the amount of urea eliminated by the kidneys is diminished.

5. That the amount of urea excreted is always increased in amount by a diet rich in proteids.

6. In respiration "the proportion of oxygen absorbed is greater in feeding on animal than on vegetable food, for the carbohydrates, it will be recollected, already contain as much oxygen as would combine with their hydrogen to form water, whereas oils and nitrogenous substances are comparatively deficient in oxygen."

To arrive at some definite conclusion as to the relative value of each element in the food, let us examine the Munich table (Landois and Stirling's *Human Physiology*, vol. i, p. 481), which shows the smallest amount of food compatible with health at different ages:—

Age.	Nitrogenous Elements.	Fats.	Carbo-hydrates.
	Grammes.	Grammes.	Grammes.
Child under 1½ year, . . .	20 to 36	30 to 45	60 to 90
Child 6 to 15 years, . . .	70 to 80	37 to 50	250 to 400
Man (moderate work), . . .	118	56	500
Woman (moderate work), . .	92	44	400
Old man, ...	100	68	350
Old woman, ...	80	50	200

A reference to the table will show that most carbohydrates and most nitrogenous elements are required where most voluntary muscular energy is being developed. As the nitrogenous elements are chiefly used, in health and under

proper diet, for structural purposes, and to nourish the protoplasm in the cells of the body, but are excreted as urea by the kidneys, we may for the present put them out of our calculations. It is, however, to be understood that nitrogenous elements and fats act together. As the quantity of carbohydrates required is increased by muscular energy given out, the table indicates that directly or indirectly the carbohydrates are associated with the production of energy, whilst the fat supplied in the food is largely devoted to keeping up the temperature of the body, and perhaps also in giving out some energy as the co-relative of heat. Fat also enters into the structures of the body. It is worthy of note in the table that most fat is required where least voluntary muscular energy is given out. It is apparent, then, that the child will require very few carbohydrates, but a considerable amount of fat, and more especially as a large proportion is required for structural purposes. Whether, as Dr. F. W. Pavy has asserted, carbohydrates are converted into fats, and also in part into proteids, by the action of the protoplasm of the cells within the body, or whether fats are merely saved by the substitution of carbohydrates, and stored—it seems apparent that stored fats are not available for the production of heat or energy, whilst the body is being fed on carbohydrates, and the voluntary muscular system is at rest; and it is a remarkable thing that an infant, overloaded with stored fat, will allow CO_2 to accumulate in its system, and become markedly rachitic when deprived of fat in its food, whilst a lean child, supplied with and assimilating a proper amount of fat, will escape even when living in a very impure atmosphere.[1] As the increased elimination of CO_2 from the body during active muscular exercise—60 per cent, according to Pettenkofer—is more than the increased consumption within the body, it is apparent that muscular exercise must mechanically assist to remove CO_2 lingering

[1] Dr. Cheadle relates that the baby which received the prize for size and weight at a Greenwich baby show, came before him as a well marked case of rickets.

in the tissues, as well as by causing an increase of temperature of ·5° to 1° C. The likelihood, then, is that CO_2, by preventing the oxidation of stored fat, prevents it from being used as fuel for the body. Now, imbibed fat, according to physiological fact 6, causes an increased absorption of oxygen by the blood. It carries in oxygen with it to consume it, and therefore is used as fuel. As CO_2 is less soluble in warm fluids than cold ones, imbibed fat then will tend to drive it out of the body. For practical purposes, then, CO_2 and cold may be looked upon as two agencies which require the introduction of fats in the food to neutralise their effects, and when both operate at one time the amount of fats must be increased. Reverting now to the physiological facts which I have noted, it will be observed that the *carbohydrates* are the most quickly absorbed of the food elements and the most readily oxidised. They increase the amount of CO_2 to be eliminated, and with it the amount of venous blood, thus causing accumulation of CO_2 in the blood through overproduction when they are given in excess.

Munk has pointed out that whilst carnivorous animals eliminate 70 per cent of the water excreted from body as urine and 30 per cent by lungs and skin, herbivorous animals excrete 30 per cent as urine and 70 per cent by lungs and skin. Now when a child is being nourished solely by carbohydrates, in addition to the excess of CO_2 which the lungs and skin have to eliminate, they have to eliminate more water than on a mixed diet. It may be asked, why, then, use carbohydrates in the diet at all?

It will now be apparent that it is to aid the body to regulate the temperature under the varying conditions of muscular exertion and rest, summer and winter, or it may be tropical heat and arctic cold; for whilst the carbohydrates give off heat and CO_2 in proportion to the carbon which they contain, fats give off heat in proportion to their hydrogen, as well as the carbon they contain, but CO_2 only in proportion to the corbon they contain. The fats then give off more heat, and a smaller proportion of CO_2 for each unit of heat produced, than the carbohydrates do, but the carbohydrates, by damping down

the combustion and causing increased elimination of water from the lungs, keep down the temperature of the body.

It will be further apparent that the carbohydrates, used in excess, by increasing the amount of CO_2 to be eliminated, will detain the blood in the venous system, causing venous plethora and arterial anæmia, a condition of matters compensated in health, and in a pure atmosphere, by a few more respirations per minute, but not so readily where there is pulmonary obstruction or an impure atmosphere. It is worthy of observation here that, whilst blood passes from the arterial system to the venous, a reverse current is prevented not only by the valves in the veins, but also by the contraction of the systemic capillaries, which Dalton has pointed out takes place when the blood gets overloaded with CO_2.

Returning now to our observations on the engorged veins on the head and neck of the child, it is apparent that the obstruction to the flow of venous blood being in the pulmonary vessels, the engorgement referred to is only a part of a general venous hyperæmia.

It is more prominent in the veins of the head and neck, as these parts in the child are in advance of the rest of the body in development, and also because these vessels having no valves the blood gravitates to its lowest level, bringing them into prominence. It is apparent that, sooner or later, in the body, as the result of defective elimination of CO_2, the different organs will work less energetically, metabolism being interfered with. In Dr. Angus Smith's observations, the effect of 5 volumes of CO_2 in 1000 of air was to reduce the pulse at the end of forty minutes from 76 to 71 beats per minute. As the result of defective nutrition and elimination of CO_2, it is apparent that, after a time, the vasomotor centres in the medulla and cord will work less efficiently, and the whole blood throughout the body become more venous, the body thus to some extent reverting to the condition in prenatal life with its mixed circulation.

Let us now consider the state of matters in the sytemic capillaries. On the one side we have a venous hyperæmia, on

the other we have the arteries contracting and exerting what pressure they can upon the blood. The blood, then, in the capillaries being jammed between two pressures, we will have increased transudation. The arterial blood pressure, however, being low we will only have little if any œdema.

In the skin the increased capillary tension excites the sweat glands, but the arterial tension being low, little sweat is poured out whilst the child is awake. In sleep, however, as we have seen, the diminished excretion of CO_2 by the lungs leads to greater venous engorgement, and the capillary blood pressure rising we have the sweat glands excited and profuse perspiration. If we compare with this condition the state of the capillaries in the mucous membranes of the respiratory and gastro-intestinal tracts, we will be in a position to understand why there is such a marked predisposition to catarrh in the early course of rickets.

If we now apply Kraus's figures as to the distribution of the pores, we will observe that where the pores are most thickly placed we will have the greatest volume of perspiration poured out :—

Forehead and neck, . .	1,250	per square inch	of skin.
Breast, belly, and arms, .	1,100	,,	,,
Cheeks and thighs, .	500 to 600	,,	,,
Back, ...	400	,,	,,

Now these figures are also interesting in explaining the conduct and decubitus of a rickety child when it seeks relief in sleep. Like a drowning person, it will endeavour to remove its body from the medium in which it is being stifled. It will endeavour to take advantage to the full extent of its auxiliary organs of respiration. It will rest on its back, where there are fewest pores, and as sleep supervenes, uncover arms, breast, belly, and legs. If the bedclothes are replaced it will partially awake, when deeper respirations will assist the pores till the old state of matters is restored in sleep. In a more advanced stage of the rachitic condition, however, we shall see that extreme tenderness of the body also favours this decubitus.

The anæmic state of the arteries now causes thirst. It is to be noted, however, that imbibed fluids for the most part join the circulation in the venous system.

In health the deficiency of flow in the urine, when caused by carbohydrate feeding, would be compensated by increased excretion by the lungs and skin, but as one of the conditions under which rachitism develops is obstruction in the pulmonary vessels, either as the result in the young child of imperfect development, or of disease in older ones, there will be defective elimination of water. Referring to this difficulty in the flow of blood through the pulmonary vessels, it is worthy of note that except in the case of late rickets it is comparatively rare that rachitism develops after the third year.

Coming now to the state of the blood in rickets, it is apparent that the increase of water will alter the proportion of the corpuscles in each cubic millimetre, and also interfere with their nutrition and growth and affect their colouring matter.

Again, the volume and supercarbonated state of the blood will enable it to hold more carbonate and phosphate of lime in solution than normal, and will even enable it to dissolve out those salts where they have been already deposited. In this connection my experience of urine from rickety patients is that I have found few earthy phosphates in the urine of those affected with early rickets, whilst in those affected with late rickets I have found a superabundance.

Looking now at the effect of the altered blood on the tissues of the body, it is reasonable to suppose that those tissues will thrive best which flourished in the prenatal state, such as cartilage, fibrous tissues, and rudimentary blood-vessels. If we judge from analogy in the varicose ulcer of the leg, those blood-vessels will be faulty in structure. From the venous hyperæmia and increased transudation we may also expect to find hypertrophy of the connective tissues, as stated by Dr. Coats (*Manual of Pathology*, first edition, p. 24), under Passive Hyperæmia—"When œdema does not occur there is frequently developed some swelling of the connective tissues of the parts concerned. This is a true hypertrophy, and not to be confounded with

inflammatory increase of connective tissue. The increased transudation, by providing an increase of nutritious material, causes hypertrophy of the connective tissue, which is swelled and also denser." Again, in extreme cases, from the arterial anæmia we may expect to find degenerations in the tissues of organs, such as amyloid degeneration, albuminoid infiltration, or even necrosis. The zonular cataract found in children is probably due to this cause.

As the result of the altered condition of the blood, we have the cartilages throughout the body most noticeably affected; the blue zone at the ossifying borders being considerably increased in size; the matrix between the rows of corpuscles being considerably softened and swollen. This is in accordance with the extreme tenderness which accompanies or even precedes beading of the ribs, and which is very forcibly brought out when we press gently the ribs on each side of the body between our two hands. Note the effect of this softening of a cartilage when it takes an acute form. If the cartilage acts as a suture, it is converted into a hinge; hence the quadrilateral thorax of rickets or the pigeon-breast should the child happen to have imperfect union of the pairs of ossific nuclei in the lower part of the body of the sternum (the perforated sternum of the anatomist).

Beading of the ribs seems to be the result of hypertrophy, and seems to take place when the transudation is not so profuse as in the latter conditions; but judging from its early advent (sometimes as early as three weeks after birth) and the tenderness with which it is frequently associated, it is not improbable that it is sometimes partly dropsical in its nature. This is in keeping with Dr. Hilton Fagge's observation that "the cartilage cells themselves have an abnormal appearance, which is aptly indicated by the epithet 'dropsical' applied to them by Klebs" (*Lancet*, 1880, vol. ii, p. 809).

Let us now consider the phenomenon known as craniotabes, which, Elsässer has pointed out, frequently precedes beading of the ribs. The bones affected—the occipital, with parts of the parietal—are bones laid down in membrane. In the case of

the occipital, ossification commences about the seventh week of fœtal life, from four centres which at birth have become united, with fissures, however, between them. As the part most affected is the part on which the child's head rests, it is apparent that in the soft condition which the bone presents at birth it will suffer to some extent obliteration of its arteries from pressure. The fissures will assist the supercarbonated blood to dissolve out its lime salts, and the bone will return to its prenatal membranous condition.

The direct cause of the phenomenon laryngismus stridulus, which, most authorities are agreed, is an early and often fatal manifestation of rickets, has not yet been demonstrated. Whether produced by spasm of the laryngeal muscles, brought about by compression of the recurrent laryngeal nerve between swollen thyroid and cricoid cartilages, by swelling of some of the soft tissues, or by central nervous irritation, direct or reflex, has yet to be determined.

Coming now to another early accompaniment of rickets, hydrocephalus, it is apparent that with the large venous trunks obstructed we have not far to seek for a cause, and one which identifies hydrocephalus as being frequently a manifestation of rickets. We can also account for serous effusion found round the brain and spinal cord along with rickets. It has been observed by Dr. Clement Lucas—and the observation has been borne out by my own investigations —that in a number of children who recover from rickets the anterior fontanelle is depressed after ossification, indicating a reabsorption of fluid. Another complication which has been observed in association with rickets by Dr. Hilton Fagge, chronic cerebritis, finds an explanation in the increased transudation (*Lancet*, 1880, vol. ii, p. 808).

As regards the convulsions and tetany in rachitic children, it is impossible to state whether they are always due to the same cause or whether the cause varies. It is conceivable that venous hyperæmia alone or pressure by transuded fluids might account for them, but in practice I have found them chiefly associated with the presence of irritating material in

the stomach and bowels, so that the rachitic condition seemed to have been merely a predisposing cause; and in two cases which were fatal before medical aid could be got, I found this was the condition. As Trousseau has shown that a convulsion may be brought on in a child by external irritation, such as a pin penetrating the anterior fontanelle or the liver, it is rational to believe that a great many cases of convulsions are not associated with the rachitic condition. However, it is apparent that in the rachitic condition less irritation will suffice to set up a convulsion, and at least two-thirds of the infants I have seen in practice who have have taken convulsions have either had other manifestations of rickets or a history which would lead to the suspicion that such a condition was present.

The pain in the osseous system and joints we can understand from the affection of the cartilages and periosteum, but the pain in the muscular system in the early stage of rickets has not as yet received a satisfactory explanation. Sir William Jenner studied it during life, but found no distinct or specific *post-mortem* changes after the death of the patients. It is, therefore, probably due to the hyperæmia. From the swelling of the viscera observed clinically being often absent *post-mortem*, it is likely due to the same cause, unless in those cases where as the result of prolonged transudation the connective tissues are increased. In this connection the organ I have found most frequently enlarged in the early stage of rickets is the spleen, and next to it the liver. The enlargement of the spleen and protrusion into the abdominal cavity is sometimes enormous, but seems in many cases to yield too quickly to treatment to lead to the conclusion that it is always due to hyperplasia. I have even noticed it perceptibly smaller in seven days, but on account of the diurnal variations in health, and the difficulty of examining it under similar conditions of ingestion of food, do not attach much importance to any decrease in such a short period. Let us now consider the changes which take place in the growing bones in rickets when the excessive transudation

is not curtailed by altered conditions of living. It will be apparent that an altered blood pressure will seriously affect the bones, as their veins have no valves. Let us look at the blue zone at the ossifying point of one of the long bones which has been laid down in cartilage. As the result of the increased transudation it will be found considerably increased in depth, and its matrix thinner in consistence than in health. The increased depth of the zone means increased length of the perpendicular rows of corpuscles. Normally the corpuscles increase in size in regular order as they approach the already ossified border. Here they are of four or five different sizes, bearing a close analogy to the red blood corpuscles as described by Dr. Goodhart (*Diseases of Children*, p. 604). Then they are falling out of line as the result of the changes we have been considering, and will do so in an increased degree if the child uses legs and arms to assist it in locomotion. Is there hyperplasia of corpuscles? At first sight under the microscope there would seem to be. Normally there is great proliferation of the corpuscles going on. Does this exceed it, or is it only because more cartilage is in operation at once? From the shortening of the bones, at the same time that they are knobbed and thickened, it is not unlikely that, in so far as cartilage corpuscles are concerned, there is as compared with health no numerical increase. Following the blue zone into the yellow zone, where in health the even and regular deposit of calcareous matter takes place in the cartilaginous matrix around the prolonged rows of corpuscles, it, too, is disordered. The opaque crystals are deposited less regularly. This, too, is in accordance with a thinned consistence in the matrix. Along with the thinned matrix, the increase in the transparent blue zone allowing a more diffuse light to fall on the solution, the crystals we should expect to be less perfectly formed and in deeper relays. Coming to the ossifying zone the disorder is maintained. The parts where the groups of cartilage cells give place to cavities filled with round cells, blood-vessels, and osteoblasts are also confused. The blood-vessels are faulty, and the osteoblasts suffering from malnutrition discharge their

functions badly are imperfectly surrounded by bone, and where the blood-vessels are most faulty and broken down, as the result of an altered blood, we cannot be surprised to find unaltered cartilage forming islets in the bone.

The changes which take place in the periosteum and sub-periosteal layer, as also in those flat bones which are at first laid down in fibrous tissue, it will be observed are governed by hyperplasia of connective tissue, ill-formed blood-vessels, and also by the supercarbonated and watery condition of the blood The result is, in the words of Dr. Coats, "calcification rather than ossification, leading to trabeculæ which are osteid rather than osseous, resulting in a thickened but weakened bone." It will now be apparent that different effects will be produced by the rachitic condition according to the development to which the body has attained when it arises. If growth is going on we will have defective development. If ossification is advanced or completed we will have decalcification of bone.

It will also be apparent that, apart from obstruction in the blood-vessels of the lungs, the rachitic condition may arise when a set of veins is obstructed. Such seems to be the case in fœtal rickets, and I have observed all the naked-eye appearances of rickets in a child born dead with a knot upon the umbilical cord, which slowly compromised the transmission of the CO_2 to the mother and the return of arterial blood to the fœtus. We can also conceive of only a part of the body being involved in such a process, and giving rise to a partial mollities ossium. Two such cases are referred to in Druitt's *Vade Mecum* (twelfth edition), p. 267. Late rickets, such as may set in after fourth year, seem to be cases caused by Dr. Macewen's factor. I have observed one such case follow broncho-pneumonia, and one followed an attack of bronchitis.

If we consider the condition of the body in pregnancy, it will be observed that the condition is closely allied to the rachitic one. It has been demonstrated physiologically that in pregnancy the body gives off more CO_2 than in the ordinary state. The lungs and skin of a pregnant woman have to eliminate CO_2 for her own body and that of the fœtus, and

even in health there seems to be an accumulation of CO_2 in the body in pregnancy. It is Nature's method of softening the synchondroses in view of parturition. The condition is usually associated with a highly hydræmic habit of body and all the appearances of anæmia. It is a condition, however, which sometimes develops to a pathological extent, causing osteomalacia. In puerperal eclampsia and puerperal insanity I think it probable that we have a close analogy to the early convulsions and cerebritis of the rachitic condition.

Before leaving this part of the subject let us consider the disorder known as anæmia or chlorosis, a disorder in every respect resembling the anæmic condition seen in the greatest number of pregnancies, as also in the early stage of rickets. It attacks mostly young women between the ages of 15 and 25—the age at which they are sent out to work for a living in workrooms and shops, where the air is polluted by overcrowding and CO_2 derived from the combustion of coal gas. I have not yet come across a single case of it in which one or more of the factors inducing the rachitic condition could not be traced, but notably the absence of proteids and fats from the diet and the excessive use of carbohydrates. It usually affects persons who loathe animal food, and fats especially. In the early stages it is usually associated with a plumpness of body out of harmony with the pale appearance. On examination, the blood bears a close analogy to that in rickets. There is a diminution in the number of red corpuscles found in each cubic millimetre of blood, because the blood is greatly diluted, and in this connection it is to be noted that even œdema is not uncommon in severe cases. The amount of hæmoglobin in the blood corpuscles is also diminished, so that they have the appearance sometimes found in rickets. The alteration in the bone marrow in anæmia, (which is just a vascular connective tissue loaded with adipose cells,) points to an altered blood pressure, as in rickets. Again, improvement in anæmia is sometimes preceded by a marked increase in the flow of urine, such, as we shall see, is sometimes observed in rickets.

If we compare rheumatism, gout, and tuberculosis with the rachitic condition, it will be found that in many respects they bear a close analogy. They are all associated with a habit of of body to which the term "diathesis" has been applied. They have all a tendency to variations in the temperature of the body, and also to profuse perspirations with evening exacerbations and morning remissions, indicating an altered blood pressure. They have in common a tendency to affect the bones and articulations. In all of them the presence of CO_2 or urea or both causes arterial contraction. They are all attended by venous engorgement and arterial anæmia. They are all associated with defective elimination of CO_2, urea, or both.

In the case of gout an excess of proteids in the diet seems to cause an excess of urea, and excess of alcohol seems to cause an excess of CO_2, so that we have the arterio-venous equilibrium disturbed in the highest degree, and the greatest strain thrown upon the capillaries. Hence the excessive pain which frequently, for the reasons which we found obtained in rickets, begins at night, and sometimes returns at night where improvement has taken place. Wine, by producing more CO_2 in the body than alcohol, owing to the vegetable acids producing it in addition to that produced by the alcohol, should be worse than alcohol for causing gout if my theory be correct, and this is borne out by clinical experience. Again, gout is most severe in the feet, because there the force of gravity is superadded to the pressure caused by the hyperæmia. I think it highly probable that rheumatism is just a modified gout, in which impure air plays a most important part, as also the ingestion into the blood of some of the products of decomposition from the alimentary canal.

Coming now to the consideration of rickets and fibroid disease, and also tuberculosis, some writers have stated that rickets and tuberculosis are mutually exclusive of each other.[1] This shows that they have not been often found together

[1] Dr. Hilton Fagge mentions a case in which both rachitic and tubercular diseases were present in one child (*Lancet*, 1880, vol. ii, p. 813.)

in one subject. But the older writers did not consider the rachitic condition rickets unless they found marked deformity in the bones, nor did they consider the changes found in the spleen, liver, and lymphatic glands in association with osseous deformity rickets if they stood alone.

Dr. Dickinson (*Lancet*, 1880, vol. ii, p. 933) has stated—"I think there can be no reasonable doubt that the swelling of the viscera is as much a part of the rickety condition and as essentially belongs to it as that in the bones. It is, however, to be remarked that when the visceral change is most marked, that in the bone is seldom extreme, as if its disease exhausted its force in one direction or the other." Dr. Dickinson's remarks here referred to the increase of the interstitial substance, the interstitial splenitis, as he called it, in the case of the spleen, the growth in the mesenteric glands which rendered them shotty to the touch; fibrosis, as Dr. Goodhart calls it on p. 48, vol. ii, 1881. Now, from the application of our theory and the quotation from Dr. Coats, it will be apparent that where the transudation is very great the increase of interstitial substance will not take place, but the osseous deformity will. The amount of capillary blood pressure which will suit the one will not suit the other, and we can conceive of a number of children escaping the osseous deformity altogether and developing the fibrosis; whilst in others, the change being more acute, osseous deformity and fibrosis will be found in different degrees of severity in the same body, or, in early stage, osseous deformity only. Now, it has been my clinical experience, and it is my conviction, that a great number of cases of rickets would have turned out cases of fibroid disease had they not been looked after in time. The osseous deformity drew attention to them. In a parish in Ayrshire, with which I am well acquainted, amongst nearly 2,000 inhabitants, there has been only one marked outbreak of rickets for about thirty years, and it was confined to a single family. All the children of the village got farinaceous foods in infancy, they occupied very small sleeping apartments, two or three frequently occupying a sleeping closet of about 450 cubic feet capacity,

till they approached adult life. Their food was often the poorest—potatoes, vegetables, and milk from which the cream had been separated, with porridge and wheaten bread. They escaped rickets, but as they reached puberty succumbed in great numbers to phthisis, chiefly of the fibroid form. In one family 3 out of 6 died thus; in another, 6 out of 12; in another, 3 out of 4, and the fourth succumbed at the age of 37 to the same after several years' ill-health with occasional hæmoptysis. In some cases whole families were cut off, whilst the parents survived. Now, my belief is that had these people lived in the atmosphere of a town they would have developed osseous deformity. A number would have died no doubt from convulsions, meningitis, and early catarrhal affections, or probably tabes mesenterica. I have had many such experiences, and Dr. Crisp has cited one such case (*Lancet*, 1880, vol. ii, p. 814), that of a family in which one child died of tubercular meningitis, another of chronic hydrocephalus, and a third suffered from severe rickets which caused permanent deformity.

Lately I had under my care a child, aged 3 years, whom I first saw in connection with an eruption of urticaria in 1893, the result, to all appearance, of an indiscriminate administration of sweets on the part of some friends. In the following January she had an attack of bronchitis, from which she made a quick recovery. During the summer of 1895 she was peevish and out of sorts, but with no pulmonary symptoms. I advised a change to the country. In September, whilst in Ayr, she took croup suddenly during the night. The house was blamed by a local physician, and she was sent home after a stay of only a few days. I saw her after she came home. The tonsils and fauces had no appearance of any organic change, nor were any symptoms or signs of rickets manifest beyond restlessness at night, but accompanied by neither sweating nor rise in temperature. (At my suggestion the attendant was supplied with a clinical thermometer, and a careful record of the temperature kept.) I examined her at intervals during the winter and following January, but no

change was apparent. In the beginning of February an evening rise of temperature to 100°, and one or two nights 101°, was recorded, and it was attended with marked emaciation. I saw her daily, and on several occasions found a few râles in proximity to and under the right scapula. They, however, came and went, but without pronounced signs of change in the lungs. At the end of February I had a consultation with Dr. Tennant and Dr. R. B. Ness. When they examined the râles were absent, and the conditions just such as I have described. However, a grave prognosis was given, and Dr. Tennant recorded similar experiences where râles had gone only to return. This was Dr. Ness's experience in my absence. The child died a fortnight later. Had the case anything to do with rachitism? I am convinced it had. The child had lost its mother at birth, and had been brought up on one of the foods to which I shall refer later on. When I first saw her she looked well nourished and the picture of health, but yet I believe the damage had been done, as subsequent events showed. From the first I advocated the avoidance of sugary food, and the the liberal use of cream and soups. Notwithstanding my advice she was supplied with an overabundance of sweets to the last. She did not manifest the changes in the bones, because she lived in the best of hygienic surroundings in a large self-contained house. When the weather was fine she got full advantage of the open air. The history, the early bronchial catarrh, and the croup, all point to the subtle development of the rachitic condition, and I have no doubt that a fibroid state predisposed to the apparently tuberculous termination.

Whether the advent of tubercle in the organs altered by increase of connective tissue and weakened by an altered blood is merely another stage in degeneration, a disintegration of certain elements to a life independent of the body, or the arrival of a new destructive agent in a prepared soil, I do not yet consider established beyond all doubt. I do not doubt the virulence of the tubercular bacillus when once formed or specialised, but think its origin not sufficiently established, and

in this connection would point out that our present theory by no means accounts for cases which arise *de novo*. If we refer to the work of Sir Andrew Clark and his colleagues, Drs. Hadley and Chaplin, on *Fibroid Phthisis*, it is apparent that all the cases, tubercular and non-tubercular, in which their origin could be traced began under conditions such as we have found caused the rachitic condition in children—viz., something which led in the first place to obstruction of the flow of venous blood in the lungs; and when *post-mortem* examinations were held in the purely fibroid cases there was found increase of connective tissue in other organs as well as the lungs, just such as have been mentioned as having been found in connection with rickets. It seems impossible to dissociate some of these cases which occurred in early life from what we have seen to be the rachitic condition. Take Case 41 (page 68), where the disease commenced with an attack of bronchitis in a child 7 months old; Case 33 (page 70), which commenced with whooping-cough in a child 7 years old; Case 12 (page 72), which commenced with measles when 8 years' old. A glance down the personal history column of table of purely fibroid cases on page 139 reveals the fact that 43 out of the 45 cases investigated had their origin in infancy or childhood in Dr. Wm. Macewen's factor, and of the 13 cases where the fibroid form of disease was associated with tubercle, 2 had a similar origin.

Guerin wrote in 1840—"It is necessary to avoid the notion that rachitism only commences with the osseous deformity." Pathologists hitherto have been very much divided as to the lesions found after death which strictly belong to the rachitic condition. Much confusion seems to have arisen from some considering that rachitism only commenced with the osseous deformity. Again much confusion seems to have been caused by different *post-mortem* examinations having been made at different stages of the disease.

My belief is that whenever we have over-production of CO_2 or defective elimination, we have the rachitic condition.

It is apparent that with so many factors at work causing rickets, the phenomena will be modified according to the part

which each plays in a given case. Again, a great many cases out-grow the early changes, and early clinical observations are in many cases impossible, as the aid of the physician is not generally sought till something alarming attracts the parents' attention. Undoubtedly a great many cases of rickets do pass unnoticed.

As regards the symptoms of rickets and the manifestations of disease associated with it, owing to no cause being discoverable which would explain every case, authorities have been divided as to what were strictly rachitic manifestations and what were concurrent diseases.

From the cause I have assigned it is apparent that profuse perspirations when the child sleeps, the tendency to lie uncovered, obvious tenderness when touched, beading of the ribs, craniotabes, convulsions, with tetany and carpopedal spasm, laryngismus stridulus, hydrocephalus, cerebritis, meningitis, bronchial and intestinal catarrh, swelling and tenderness of muscles, enlargement of liver and spleen with in some cases a small amount of ascites, anæmia, swollen glands, are all likely as early manifestations, but any or nearly all of these may be absent, or may have been present at one time and unnoticed.

Sometimes in a doubtful case we are assisted by its history, and in this connection my clinical experience convinces me that where we have had an excessive quantity of carbohydrates or deficient amount of fats administered for some length of time to a child under 3 years of age, especially if living in a polluted atmosphere, we have to do with rachitism, and will soon have osseous deformity. But if not, unless means are taken to avert it, we shall find later on some of the manifestations to which I have alluded.

What constitutes an excess, then, is an important question for us. Analyses of human milk appear to vary in results as to the amount of carbohydrates present. From 3·7 to 6·7 per cent appears to be the quantity. The quantity of milk which an infant receives from the breast has been estimated at about 1 pint for the first few weeks, gradually increasing, till in later months it reaches 3 pints per day.

Taking 6·7 as the percentage, 1 pint would yield 1·3 oz. avoirdupois as the amount of carbohydrate supplied to an infant at the beginning of lactation, and about 4 oz. at the end of lactation.

One of the popular foods contains in its dry state about 81 per cent of carbohydrates. The directions advise three to six tablespoonfuls of powder to be used for 1 pint of prepared food. Taking the tablespoonful at 180 grains, three tablespoonfuls give, when made with water, 1 oz. avoirdupois per pint of carbohydrates; six tablespoonfuls give 2 oz. avoirdupois per pint.

To imitate human milk in proteids and fats, 2 parts cow's milk and 1 part water must be used; this adds ·6 oz. carbohydrates to each pint of milk. The total carbohydrates, then, for a young child, if the directions are followed—viz., 1·6 oz.—is not greatly in excess of the natural amount. But in the natural human milk the carbohydrates do not increase in percentage with the age of the child. It is, however, as the child progresses, and the percentage reaches 2·6 oz. avoirdupois per pint, that the excess arises. Thus, a child at the end of 4 or 6 months getting 3 pints, with 2·6 oz. carbohydrates in each, is getting 7·8 oz. instead of 4 oz. of carbohydrates per day. As children, however, usually get as much artificial food as they can swallow, it is not unusual for them largely to exceed the above quantities, as the carbohydrates increase the thirst; and this is the direction in which the error mostly lies with some foods. Another source of error I have found in mothers adding too much cane sugar to diluted cow's milk. A few days ago I came across a child which was 11 months old, and had been for some length of time in receipt of a daily allowance of nearly 8 oz. between the sugar in the milk and cane sugar added. It seemed to suffer excruciating pain from the pressure of its clothes, had beaded ribs, a very much enlarged abdomen, with spleen and liver enlarged and highly resistant to the touch, a widely open anterior fontanelle bulging outwards. It had just commenced to take convulsions.

Another method of giving an excess of carbohydrates is by

giving skimmed milk, a diet on which children are never satisfied until it is accompanied with farinaceous foods and sugar.

There is still another way in which children get too many carbohydrates, and that is when diarrhœa setting in sweeps away the less digestible proteids and fats, whilst one instalment after another of carbohydrates is absorbed. It will be observed that most injury will be done when, as the result of preparation, the carbohydrates are taken into the body as sugars. To these errors must be added the evils of the excessive use of sweetmeats by children, and also the occasional addition of potatoes and such foods when used in the family.

The strain thrown on the lungs by such excesses as we have been considering must frequently be considerable, and I believe that in many cases the rapid breathing of rachitic children is due to this cause, although latterly it is increased by the difficulty of abdominal respiration, and pain in the respiratory muscles and ribs.

It will be apparent from these remarks that the history of the amount of carbohydrates used will often help in a difficult diagnosis. If we take the broad view of the rachitic condition which I have been advocating, it will be apparent that a great many other diseases may fall to be added to those associated with it—such as aneurysm—and those changes in the blood-vessels associated with hyperplasia of the connective tissue of the sheaths. Bronchiectasis, for a similar reason, may have a similar predisposing cause. Again, a number of diseases associated with a defective arterial supply, consequent on a large portion of the blood being kept in the veins, may have a similar association; and in this direction I think that the narrowed aorta often found after death during anæmia is not without its significance as indicating that arterial anæmia is the counterpart of venous plethora, especially when CO_2 excites the arteries to contraction. The premature decay of the teeth, I think, finds the best explanation in a defective blood-supply.

Further, if we consider the rachitic condition in its most chronic form as a return in some measure to prenatal life, I think we have an indication of that altered condition of nutrition which allows certain tissues in the body to grow and flourish independently of the wants of the body at the expense of others.

I have already alluded to the pseudo-rachitic condition in pregnancy. In 1890 I had to deal with an epulis growing from the alveolar process of the inferior maxilla in a woman 21 years of age, and pregnant about six months. It was removed by the late Sir George Macleod, and on examination by a competent pathologist pronounced an epithelioma. It has not recurred, and the patient has never since manifested any other symptoms of such disease. The only alteration in her condition which could predispose to it was pregnancy, which was accompanied with considerable anæmia. The dilated veins in this case were commented upon at the time by Sir George Macleod.

If we argue from analogy, it is not inconceivable that the nerves and nerve centres may often be involved in the general hyperplasia which so often takes place in prolonged rachitism, and in this direction also the nourishment of the different parts of the body may be seriously affected by alterations in the trophic centres.

Coming now to the question of prevention and treatment, it is remarkable how children to all appearance unaided outgrow the rachitic condition, not, however, without shortening, deformity, and damage to the structures in the body. In the younger children, if they once get the length of walking on their own legs, it seems in many cases all that is needed to arrest the disorder; and this points to the importance of pure air, not only in helping those who have contracted the rachitic habit of body, but also in preventing it. Vogel was so convinced of its importance that he says nothing of the influence of diet.

Dr. Arch. E. Garrod (*British Medical Journal*, 21st Sept., 1895) states that rickets is more common in colder than

warmer climates, and this is in accordance with the result of my own enquiries. He also states that it is most prevalent in earlier summer months, and at a minimum in December. These statements indicate that it is most prevalent where and when children are most kept indoors. Then it is by universal assent a disease of the towns, and most prevalent where the population is densest. In this connection a paper published by Mr. James Thomson, F.G.S., in 1884, on "The Prevalence of Rickets in Glasgow and the West of Scotland," gives very interesting details. Mr. Thomson made about forty visits to localities where children were at play, and counted the number of children who showed marked rachitic deformity. The statistics derive value from the fact that, owing to street dangers in Glasgow and the large size of the tenements of houses, young children usually play near the entrance to their own homes. Mr. Thomson's observations bring out prominently two things—(1) That the fewer the number of apartments in the houses of a district, or, in other words, the denser the population, the more rickets; (2) that where most sugar was used rickets was most prevalent.

They also show that even in villages or small towns rickets will develop if the houses are small and carbohydrates are injudicially used; for in the villages to which Mr. Thomson has referred not only are the houses chiefly one and two apartment ones, but they have very small apartments, the roofs being very low.

From the census returns of Glasgow in 1891, it appears that taking the aggregate of those districts where Mr. Thomson found rickets most prominent, but has not specified the size of houses, the proportion of one apartment houses is 29·9 per cent, and two apartment houses 44·8 per cent.

The density of the population of Glasgow as a whole, is brought out by Dr. Russell in the following figures:—

	Population.	Acreage.
Old Glasgow (before 1891), .	565,710	6,111
Greater Glasgow, . . .	658,073	11,861
Leeds, ...	367,500	21,572

The average number of persons to the acre in old Glasgow is 93, and in greater Glasgow 56.

The average number in those districts visited by Mr. Thomson, varied from 106 to 350. The latter number was found in St. Rollox, where Mr. Thomson found rickets at its worst.

The following are some of Mr. Thomson's statistics :—

"In Abbotsford Place, below Cumberland Street, S.S., the proportion of deformed limbs was 1 in 14 children.

"In Upper Abbotsford Place, or above Cumberland Street, the proportion of deformities was 1 in 9.

"In Mackinlay Street, a continuation of the latter, the proportion of deformed children was 4 in 15, or 1 in 3¾. In this street the houses consist of two apartments. In Upper Abbotsford Place the houses consist of two, three, and a few with four apartments. In Lower Abbotsford Place the houses consist of four, five, and six apartments.

"In Bedford Street, S.S., there was 1 child deformed in 7. The houses are varied, and consist of two, three, and four apartments.

"In Main Street, S.S., the proportion of deformities was 1 in 6.

"In Thistle Street, S.S., near the foot of the street, there was 1 child deformed in 5; ages, from 3 to 7 years.

"In Govan Street, S.S., the proportion of deformities was 1 in 6. The houses in those streets consist of one, two, and three apartments.

"In Nithsdale Road, S.S., the proportion of deformities was 1 in 9 children. The houses consist of two, three, and four apartments.

"In Main Street, Bridgeton, the proportion was 1 in 4 children from 3 to 7 years, and 1 in 92 from 7 to 14 years. The houses are mostly one and two apartments.

"In Greenhead Street, Bridgeton, there was 1 child in 9

deformed. The houses consist of three, four, and five apartments.

"In John Street, Bridgeton, which extends from Main Street to Greenhead Street, there was 1 child deformed in every 3 from 3 to 7 years. The houses are small, and consist of one and two apartments. Population largely employed in mills.

"In the village of Carfin, Lanarkshire, which consists of one street, there was 1 deformed in every 3½ children. The population is mostly Irish, and all employed in coal mines. There is little oatmeal used in this locality.

"In Dalry, Ayrshire, there was 1 deformed in 150 children. Oatmeal is much used as porridge, and it is also largely used baked into bread.

"In Henrietta Street, Pollokshaws, there was 1 child deformed in 9. There are 8 tons of sugar used for 1 ton of oatmeal, and there is more jelly than oatmeal sold in this locality.

"In the village of Neilston, between the ages of 3 and 7 years, there was 1 child in 15 deformed. These consisted of knock-knees and bow-legs, and in all instances they are but slightly deformed. Nearly all the cases were amongst incomers to the village. Between the ages of 7 and 14 years there was 1 deformed in 128.

"In the village of Neilston there are fewer children seen upon the streets than in any other town in the central valley of Scotland, which can only be accounted for from the fact that females form the greater portion of the population, and these are mostly employed in the thread and other public works, and many of them are thus employed till they are considerably advanced in life. Tea and sugar are largely used. One merchant informs me that he sells 20 tons of sugar for 1 of oatmeal.

"Hartfield Street, between the east end of Parliamentary Road and Kennedy Street. Ages of children, 3 to 7 years.

"There were 40 children upon the street; 12 of these were deformed in the legs.

"Three of these children were knock-kneed, with large abdomens, and the anterior portion of the heads was unusually large; 4 were curved laterally and outwards, or bow-legged, with full, broad chests; 5 were more or less curved anteriorly. There is 1 child deformed in every 3⅓. The children in this street had a sickly aspect.

"Petershill Street, off Springburn Road, 12·40 P.M. Ages of children, 3 to 7 years.

"There were 13 children upon the street; 4 of these were slightly deformed in the legs.

"There were 2 children having legs curved anteriorly about the middle of the legs; 1 child had the leg curved laterally and outwards, bow-legs; 1 child was knock-kneed.

"In this locality there are six tons of sugar sold for one ton of oatmeal. Few bake oatmeal bread. The oatmeal used is cooked as porridge. Wheaten loaves are principally used. Otherwise, these children are well cared for. There is 1 child deformed in the legs in 3¼.

"Caledonia Road, S.S., opposite the gate of the Southern Necropolis, 6 P.M. Ages of children, from 3 to 7 years.

"There were 9 children upon the street; 5 of these children were deformed.

"One of the children was badly knock-kneed; 1, the centres of the legs were curved anteriorly at an angle of about 25 degrees; this child could not walk, and the head was unusually large; 2, the legs were curved laterally and outwards, or bowlie; 1, the right leg was much curved laterally and outwards about 3 in. below the knee. Five children in 9 deformed.

"Braehead Street, off Rutherglen Road, near east end, 4·15 P.M. Ages of children, from 3 to 7 years.

"There were 8 children upon the street; 4 of these children were deformed in the legs.

"One of these children the legs were curved laterally outwards, or bowlie; 1, the legs were curved slightly laterally outwards; 1, the legs were curved laterally inwards a little above the middle of the leg; 1, the legs were curved anteriorly in the middle of the leg. There is 1 child deformed in the legs in 2.

"There are 6 tons of sugar sold in this locality for 1 ton of oatmeal.

"Rutherglen Road, Polmadie, 4·40 P.M. Ages of children, from 3 to 7 years.

"There were 14 children upon the street; there were 5 of these deformed in the legs.

"One of these children the legs were much curved laterally ontwards, or bowlie; 1, the legs were slightly curved laterally outwards; 1, the legs were curved laterally inwards near the upper end of the fibula; 1, the legs were curved anteriorly in the centre; 1, the legs were slightly nill-kneed. There is 1 child deformed in the legs in $2\frac{4}{5}$.

"Oatmeal is bought in single pounds; there are 6 tons of sugar for every ton of oatmeal sold in this locality."

"Orchard Street, Partick, 3 P.M.

"There were 10 children upon the street; 3 of these were deformed in the legs.

"In one of these children the legs were nil-kneed, abdomen and feet large; 1, the legs were curved anteriorly at the middle; 1, the legs are much curved laterally, or badly bowlie. There is one child deformed in the legs in $3\frac{1}{3}$ children.

"Hosier Street, Partick, 3 P.M. Ages of children, from 3 to 7 years.

"There were 5 children upon the street; there was 1 child curved laterally outwards, or bow-legged.

"Oatmeal is little used.

"Langlands Road, Govan, 4·30 P.M. Ages of children, from 3 to 7 years.

"There were 11 children upon the street; 3 of these were deformed in the legs.

"One of these children the legs are curved laterally outwards in the middle of the fibula; 1, the leg is curved anteriorly above the astragalus; 1, the legs are nill-kneed, and fibula curved inwards near the middle. One child deformed in the legs in $3\frac{3}{4}$.

"Oatmeal is bought in single pounds, and little used; there are about 5 tons of sugar sold for 1 ton of oatmeal.

"Albert Street, off Glebe Street, Townhead, 1·30 P.M. Age of children, from 3 to 7 years.

"There were 26 children upon the street. 8 of these were deformed in the legs.

"1 of these children the legs were much curved laterally inwards below the knee; 1 was nill-kneed; 1, the legs were much curved laterally outwards, or bowlie; 1, the legs were curved anteriorly about the middle; 4 were more or less slightly deformed. There is 1 child deformed in the legs in $4\frac{1}{2}$. These children seemed to be well cared for.

"Graham Street, Airdrie, 4·5 P.M. Ages of children, from 3 to 7 years.

"There were 16 children upon the street; 3 of these were deformed in the legs.

"1 of the children was nill-kneed and weakly in the back; 1, the legs were badly curved laterally outwards; 1, the legs were curved anteriorly about the middle. There is 1 child deformed in the legs in every $5\frac{1}{3}$.

"There are 6 tons of sugar sold for 1 ton of oatmeal.

"Whifflet, 11·30 A.M. Ages of children, from 3 to 7 years.

"There were 16 children upon the street.

"There were 3 of these children much curved laterally and outwardly. The children in this locality are otherwise strong

and healthy looking. There is 1 child deformed in the legs in every 5⅓.

"There are 3 tons of sugar sold for 1 ton of oatmeal.

"Renton, 10·45 A.M. Ages of the children, from 3 to 7 years.

"There were 37 children upon the street; 3 of these children were deformed in the legs.

"1 of the children the legs were slightly curved laterally outwards; 1 was nill-kneed, and weakly in the pelvic region; 1, the legs were curved laterally outwards near the base. There is 1 child deformed in the legs in 12⅓.

"Oatmeal is daily used, unless by the Irish portion of the community.

"Dumbarton, Main Street, 12 noon. Ages of children, from 3 to 7 years.

"There were 12 children upon the street; 2 of these were deformed in the legs.

"In 1 of the children the legs were slightly curved anteriorly and laterally in the middle; 1, the legs were curved anteriorly, and the os calcis is much enlarged. There is 1 child in 6 deformed in the legs.

"There are 2½ tons of sugar sold for 1 ton of oatmeal.

"Bankier Street, off Claythorn Street, Calton, 12·50 P.M. Age of children, from 3 to 7 years.

"There were 9 children upon the street; 3 of these were deformed in the legs.

"1 of these children the right leg was curved laterally outwards, and much curved inwards below the knee in left leg; 1, the legs were curved anteriorly a little above the ankle, and in-kneed and wriggled much in walking; 1, badly nill-kneed, abdomen large, and pelvic region much protruded. There is 1 child deformed in every 3. Oatmeal is little used.

"Lanark, 3·15 P.M. Ages of children, from 3 to 7 years.

"There were 22 children upon the street; 3 of these were deformed in the legs.

"1 of the children was nill-kneed in right leg, and curved laterally outwards in left leg; 1 was nill-kneed; 1, the legs were curved anteriorly. There is one child deformed in every $7\frac{1}{3}$.

"Oatmeal is not so much used as it was a few years ago.

"Kilmarnock, High Street, 12 noon. Ages of children, from 3 to 7 years.

"There were 45 children upon the street; 3 of these were deformed in the legs.

"Bellshill, west end, 2 P.M. Ages of children, from 3 to 7 years.

"There were 27 children upon the street. There was 1 child slightly deformed.

"Oatmeal is largely used. 1 child deformed in 27.

"Bellshill, east end, 3 P.M. Ages of children, from 3 to 7 years.

"There were 12 children upon the street; 3 of the children were slightly deformed in the legs. 1 child deformed in 3.

"Oatmeal is little used. The population principally consists of English and Irish.

"Huntingdon Place, St. Rollox, Glasgow, 1 P.M. Ages of children, from 3 to 7 years.

"In this place every second child is deformed, representing every form of deformity.

"Ages from 7 to 14.

"There were 51 children upon the street, and 1 girl, about 10 years of age, the legs were slightly curved anteriorly.

"Oatmeal is seldom sold in this locality.

"Strathaven, north side of town, 3 P.M. Ages of children, from 3 to 7 years.

"There were 6 children upon the street; 2 of these were deformed in the legs.

"One of the children the legs were badly curved laterally;

1 was nill-kneed and weakly in spine. There is 1 child deformed in 3.

"There are 4 tons of sugar sold for 1 ton of oatmeal.

"Crossford, near Lanark. A gentleman of that village informs me that there has not been a native child deformed in this village for the last 40 years. There was 1 deformed child brought into the village about 4 years ago, whose parents were Irish.

"Oatmeal is used twice daily.

"Stornoway, Outer Hebrides. I have been unable to learn of a single case of deformed legs in that town.

"Oatmeal is much used.

"Islay. Dr. M'Indoer informs me that there has not been a native child deformed in the legs for 30 years. About 28 years ago there was a delicate child, with deformed limbs, brought from Glasgow to Islay. The parents were poor and were obliged to use oatmeal, at least twice daily. Their child not only regained health, but the legs became normal, and he is now as well formed in the legs as any man in Islay."

The latter observations are in accord with my own in the village in Ayrshire to which I have already alluded, where the only marked case of rickets in thirty years occurred in a badly lit and badly ventilated house which was originally a barn.

Now, apart from the question of sugar in Mr. Thomson's observations, it is remarkable how prevalent rachitism is in one and two apartment houses, and how the proportion decreases when five and six apartment houses are reached But the excessive use of sugar and carbohydrates is not confined to the smaller houses. I have frequently found it quite as bad in the larger ones, but not attended with osseous deformity. To all appearance the excessive use of carbohydrates and the influence of an atmosphere over-loaded with

CO_2 are necessary to produce the osseous deformity in most cases of early rickets, whilst less will suffice to produce the changes in the soft tissues, especially if the influence is prolonged.

If we compare Mr. Thomson's observations with those of Dr. J. B. Russell in his address to the Glasgow Philosophical Society (November, 1888), it will be apparent that the kind of houses in which rickets is most prevalent is the very kind in which diseases of the lungs—including consumption—are most prevalent. In the following table, which brings this out, the rates are per 100,000 inhabitants :—

	One and Two-Room Houses.	Three and Four-Room Houses.	Five Rooms and Upwards.
Acute diseases of the lungs (including consumption), . .	985	689	328
Nervous diseases and diseases of nutrition in children, . .	480	235	91

In practice it is exceedingly difficult to find a case which we can ascribe to impure air alone. Dr. Baxter mentions one such case which he met with where deformity developed in a child which had got no starchy food, and the child had been reared in a cellar to which no daylight ever penetrated, and in which gas was continually burning (*Lancet*, 1880, vol. ii, p. 1,018).

The following case is interesting as showing how impure air will turn the scale where another factor is at work :—

James S., 8 months of age, whilst being fed on Nestle's food to which cane sugar was being added, and living at Fort William, showed no signs of impaired health during a stay of five months. From his return home in the beginning of August to a two-apartment house in a narrow *cul-de-sac* in town, however, his appetite began to fail, and he became cross and restless. On the ninth day after his return he took a convulsion.

On examination, his limbs and body appeared well nourished. The abdomen, however, was protruding, with both spleen

and liver prominent and resistant to the touch. There was considerable tenderness when the ribs were touched, and indications of a rachitic rosary. The anterior fontanelle was large and bulging. The mother assured me that there was no change in diet or otherwise, except the change to the air of the town.

Reverting to the prevalance of rickets in one and two apartment houses, 18 per cent of the population of Glasgow occupy one-room houses, and 47·5 per cent two-room houses. The Glasgow Police Amendment Act of 1890 enacted that no dwelling-house be used for the purposes of sleeping in by a greater number of persons than in the proportion of one person of the age of 10 years or upwards for every 400 cubic feet of space, or of one person of an age less than 10 years for every 200 cubic feet of space. It was a charitable measure, calculated so as not to harass the industrial poor (the average rent in Glasgow being about one shilling per week for each individual). It is apparent that the cubic space is too small to prevent the development of osseous deformity in children, not to speak of rachitic changes in the soft tissues which, although invisible, are even more important. In estimating the evils of overcrowding I think we have hitherto placed too high a value on the presence of organic *débris* in crowded districts, and too small a one on the presence of CO_2, which undoubtedly, by interfering with the metabolism in the body, decreases its resisting power. Dr. Angus Smith, in his work on *Air and Rain*, gave the amount of CO_2, as the result of forty-two analyses, in the air in the streets of Glasgow at 5·02 volumes per 10,000, whilst the proportion in Manchester in ordinary weather was 4·03, in London 4·3 to 4·7, and on the mountains and moors of Scotland 3·36. Dr. Smith also found that during fogs the proportion of CO_2 may be increased to 8 volumes per 10,000 of air. Now, this must seriously interfere with the removal of CO_2 from the houses. It must affect mothers as well as the children at their breasts. Good work has been done by the Glasgow Corporation retaining, and in some cases opening up at considerable expense, breath-

ing spaces in the form of parks and playgrounds; but it is to be remembered that these are only available for a few hours daily during spring, summer, and autumn, and hardly at all in winter. If the present latitude in feeding is to be allowed, there seems to be no means of preventing rachitism in Glasgow but either by legislation to drive people into houses larger than they can afford to keep up, or do as suggested by the late Dr. Hugh Thomson—force air into the apartments through pipes, as we do the water, from some untainted source.

With reference to the pollution of the air, good ventilation must be attended to, especially where coal gas is being used for illumination or cooking, and in this direction the substitution of electric light is to be commended. Then, as regards sleeping accommodation, it is most important that too many members of a family do not occupy one bed in a confined corner. This, I believe, is the reason why the younger members of a family suffer from rickets whilst the older ones escape, as in the case of a working man a larger family does not usually mean a larger house. Again, with our knowledge of the density of CO_2 and its tendency to gravitate into hollows, the use of cellars or sunk flats for habitation must be abandoned. On the other hand, our knowledge of spontaneous cure when the child is able to walk points to exercise in the open air and sunlight as an important preventive.

It is worthy of observation that once the catarrhal or sweating stage of rachitism has set in, it is very difficult to persuade parents to take their children out. During August I saw six such cases. In three of them there had been convulsions. In the whole of them I ordered a change in diet, and requested the mothers to take them out for a few hours daily. The scruples of the mothers I overcame by stating that their children were being poisoned by foul gas in their houses. Five of them have made a good recovery. The sixth never was taken out, and died. Of course, this is a treatment not always expedient, but it is remarkable how the overfilled veins diminish, the bulging fontanelles fall in, and the sweating disappears where it can be carried out. As

regards zymotic diseases as a cause of rachitism, it looks as if with schools, in which the members of several hundred families meet, we will have epidemics, but on this point also fresh air would be an advantage.

Coming now to the question of diet, it is apparent that if mother and child enjoy pure air, the safest and the best food for an infant is its mother's milk, with no addition until development indicates that the child is ready for it.

On this point the teeth give us some indication that the digestive tract is sufficiently advanced. The usual excuse for extra feeding is that the mother's milk is not satisfying the child. It is apparent that other causes may be making the child cry. I have often found the pain set up in the early rachitic condition the cause. One of the cases to which I have referred was that of a child, 5 months old, which was constantly crying. As it was relieved when undressed I tried how it stood as regards tenderness, and found it suffered the greatest agony when the ribs were only slightly compressed. An inquiry disclosed the fact that owing to the appearance of a skin eruption on the mother, the maternal milk had been withdrawn for four weeks, and unsuitable artificial food substituted. At my request the mother changed her own diet, took cod-liver oil in addition, put the child back on the breast, sought the open air, and with so far the happiest results. This is a case typical of what I have frequently found, and my experience is that a mother may suffer grave alterations in the state of her own health without affecting her child at the breast.

From the first physiological law which I have quoted from Dr. M'Kendrick's work, it is apparent that the administration of carbohydrates to a child which is being brought up at the breast, if in any great excess, may lead to the rejection of more important elements.

In those cases where it is absolutely necessary to use artificial food, my experience is that we cannot go upon better lines than those advocated by Dr. Cheadle—viz., imitate nature in the proportion of proteids, fats, carbohydrates, minerals,

and water; and also see that the food has the antiscorbutic element present.

It is most important that the quantity given is what the child can digest, as overfeeding means carbohydrate feeding, and the element we should most watch is the carbohydrate, as proteids and fats given in excess are not so likely to be absorbed or so injurious. As the child progresses and is able for the exhibition of muscular energy, we have Moleschott's or the Munich tables to guide us.

Dr. Cheadle states that privation of fat alone seems sufficient to set up rickets (*op. cit.*, p. 182) from the occurrence of rickets in a child brought up on skimmed milk, all other hygienic conditions being unimpeachable, but no mother would dream of adding water to skimmed milk as she would to pure milk, and the child would get more of it than of pure milk before it was satisfied; hence an increased quantity of carbohydrates, and little else than carbohydrates, as the casein by physiological law 1 is not likely to be absorbed in the presence of the excess of carbohydrates, especially with no fat to assist it. But, further, no mother would think of giving a child skimmed milk without bread or farinaceous foods, and reference to p. 190 of Dr. Cheadle's work mentions that the child had farinaceous food as well.

The case of the young lions at the Zoological Gardens appears to be that of rickets caused by an impure atmosphere. Dr. Crisp mentions (*Lancet*, 1880, vol. ii, p. 814) that "all the lions born in the Gardens had soft bones, and nearly all of them had died before reaching maturity, while lions born in travelling menageries often live." Now lions and carnivorous animals generally are used with very little CO_2 in their tissues in their wild state, their food being such that they form very little, giving off according to respiratory quotient calculated by Pflüger (Dr. M'Kendrick's *Physiology*, vol. ii, p. 344), 75 to 77 volumes of CO_2 for every 100 of oxygen inspired.

A very small excess of CO_2 in the air, therefore, will injuriously affect them.

My conclusion is that fats prevent the accumulation of CO_2 in the body by keeping up the body heat. As oatmeal contains a much larger proportion of fats than the fine wheaten preparations, this is perhaps the reason why Mr. James Thomson found the smallest proportion of rickets where most oatmeal was used.

I have so far indicated preventive measures against the rachitic condition being set up, the next most important thing is to recognise the earliest departure from health. If, therefore, we have any or all of the three early symptoms, the tenderness, the profuse perspiration when the child falls asleep, or the tendency to lie uncovered, along with the history of one of the factors I have mentioned at work, I think we have good grounds for believing that the patient is becoming rachitic, or if we have craniotabes or beading of the ribs with the same history, I think we may come to the same conclusion. Convulsions or an attack of laryngismus stridulus should also excite our suspicions.

When we do find the condition present our first duty is to get a pure atmosphere for the patient as quickly as possible, so as to get the blood as quickly as possible transferred from the venous system through the lungs to the arterial system. By such a procedure I have found convulsions frequently stopped or averted. Where a purgative is desirable, castor-oil, for obvious reasons, will be a desirable one, and I have found it the most useful. So frequently is the acute rachitic condition associated with convulsions that I have been in the habit of administering bromide of potassium as a preventive, and with good results. The proper regulation of the diet should receive early attention. The use of cod-liver oil or other fats, as cream, butter, &c., are known in practice to be followed by speedy improvement in the rachitic condition as also in the fibroid, and we can understand their value in altering the ratio between the oxygen absorbed and CO_2 to be eliminated (the respiratory quotient of Pflüger), as well as in keeping up the body heat. I think failure in treatment is often due to too small a quantity of these being administered. In a case of

fibroid disease which I saw in an adult in October, 1891, and which had suddenly developed tubercular symptoms, although no bacilli were found in the sputum, recovery, which still continues, followed a lengthened administration of 5 oz. cod-liver oil and 12 oz. cream daily; and I have seen a child under 12 years of age tolerating and improving in health on half this amount. In this direction, also, the use of iron or arsenic to increase the hæmatin in the blood, and assist in the absorption of oxygen, finds a reasonable explanation, as it does also in chlorosis. Increased diuresis accompanying improvement in chlorosis has been pointed out by Dr. M'Call Anderson (*Clinical Memoranda*, 1893, p. 2). The following case is remarkable as showing the same in rickets:—

It was in connection with an acute attack of pleuro-pneumonia that I first saw Mary C., aged 6 years, in August last. The child, although to all appearance well-nourished, showed signs of former rickets in the long bones. The following was the mother's description of the child's personal history:—She was born in Partick, and brought up on gruel made from oat-flour, milk, and water, with the addition of sugar, and had been to all appearance healthy until she was 9 months of age, when she had an attack of bronchitis. The bronchitis soon disappeared, but from that time until she was 18 months of age she was troubled with diarrhœa, profuse perspiration when asleep, and pain when her chest was touched. A friend, who happened to be a trained nurse, having seen the child, suggested as a remedy bathing with a solution of rock salt. According to the mother, "from the time the rock salt was used the child *began to pass large quantities of water*, the sweating gradually to disappear, and the child to take to its feet." The recovery, however, took place just as the parents had removed to a locality less crowded than the previous one.

The anæmic condition I have always endeavoured to help as much as possible with diet, and in this connection in the case of children have found the meat juice prepared according to Dr. Cheadle's directions valuable. The addition of lime to

the food I have found unnecessary in rickets, and am convinced that good food contains enough and to spare.

Reverting to our observations on gout and rheumatism, it is apparent that carbonated water swallowed and absorbed into the venous system is not likely to give much relief in the acute forms. My experience of it in my last two cases of gout lead me rather to the conclusion that it aggravates it. Nor will the sudden abandonment of proteids and fats for carbohydrate feeding help gout. The arterio-venous equilibrium will be best restored by pure air and a diet in which proteids, fats, and carbohydrates are properly adjusted and in moderate quantity.

The value of purgatives in both rickets and gout finds a partial explanation at least in an increased intestinal respiration eliminating water, urea, and CO_2. Again, the increase in pain which follows the use of wines in gout suggests the avoidance of lemonade, lime-juice, and similar beverages containing free vegetable acids in all those diseases associated with an altered blood pressure, as the acids not only suddenly set free CO_2 from the carbonates in the blood, but decrease its power of retaining CO_2 until it is eliminated by the lungs and skin. The importance of avoiding anything like an excess of carbohydrates in the diet in any acute pulmonary affections will, I think, be manifest from our observations.

I have thus endeavoured to show that the rachitic condition, and the disorders which it leads to, are brought about by the action of CO_2 in excess on the blood, the blood-vessels, and tissues; and, in conclusion, would point out that it appears to be the only agency which would account for the origin of rickets from impure air, acute fevers, and improper diet, whilst also accounting for cases of congenital origin, late rickets, and osteomalacia, and explaining the development of the various rachitic phenomena.

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