VI. Original Communications

1. QUESTIONS REGARDING THE STERILISATION OF DRESSINGS BY STEAM

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THE recent literature of the sterilisation of the skin and of ligatures is very large. This is not to be wondered at, since most surgeons agree, and rightly agree, that these sources of infection transcend all others in importance. On the other hand, not so much has been written of late years regarding the sterilisation of dressings, though much has been written on the subject in the past. I do not propose in these remarks on the sterilisation of dressings to refer to the simple and reliable methods of sterilisation by boiling or by immersion in antiseptic solutions, often the only methods available. I pass at once to consider some questions with reference to the more convenient but, it must be admitted, rather more complex, plan of sterilisation by steam.

Three difficulties present themselves to the surgeon desirous of making use of this method. The first concerns the steam itself, the second the steriliser, and the third the drums or caskets for the dressings. Of these, to my mind, the first is the greatest. For surgical purposes, steam can be made use of in motion, in equilibrium, under simple atmospheric pressure, and under pressures greater than that of the atmosphere. Further, we have to do with saturated and with superheated steam. Now the subject of steam, I am informed, is not one of the easiest in physics. Its thermo-dynamics are, in fact, extremely complex. Unfortunately, also, the sterilising action of steam is intimately associated with such questions as the latent heat of steam, the hygroscopic properties of dressings, the factors influencing condensation, and similar problems. One cannot, therefore, avoid touching on some of these points, but, being without special knowledge on such purely technical subjects, I shall endeavour to refer to them as little as possible.

Saturated and Superheated Steam. — A good deal of ambiguity exists, I think, among surgeons as to the difference between these two steams, or, at any rate, as to what superheated steam really is. An idea commonly obtains that all steam under pressure, is necessarily superheated. This is, of course, not the case, although very frequently steam under pressure *is* superheated. On consulting the authorities with regard to these two steams, I find that saturated steam may occur under any pressure, provided its temperature has what may be called the "correct value." Saturated steam is steam which carries a certain amount of water in suspension or otherwise mixed with it, the temperature at which it is produced depending, of course, on the pressure. So long as this steam remains in contact with the water which produces it, its temperature is the same as that of the water; if the temperature be raised, the pressure will also be raised. Once away from the water, however, the temperature of the steam may be raised without altering its pressure. Steam which has obtained additional heat in this way is called superheated steam. Its temperature is above the temperature of saturation. If saturated steam be mixed with water (at the same temperature), none of the water will be evaporated; if the same thing be done with superheated steam, some of the water will be evaporated. When steam is saturated, a slight cooling or a slight compression is accompanied with liquefaction, and latent heat is disengaged. When steam is superheated, a slight cooling or compression is unaccompanied by condensation. Superheated steam is deficient or wanting in latent heat, upon the presence of which the value of steam sterilisation so largely depends.

There appear, however, to be different degrees of superheated steam, depending on how far the temperature of the steam is above that of saturation. In this way it is possible that, with a low "grade" of superheated steam, some condensation may occur, and also that a small amount of cooling may be sufficient to bring it again into a state of saturation. The more superheated the steam becomes, the more does it approach the condition of a gas. A high grade of superheated steam probably differs very little from hot air. The simplest example of superheated steam is seen when the water in an autoclave or a steriliser having been all turned into steam, the heating process is continued. But superheating occurs in much less simple ways than this, and, indeed, is intentionally employed in certain sterilisers and in many disinfectors. These chiefly belong to the class of apparatus where steam in equilibrium is employed, and where there is an outer jacket in which steam is retained under a higher pressure and temperature than the steam in the interior. Braatz of Königsberg has also shown that in certain badly constructed patterns of the well-known Schimmelbusch-Lautenschläger steriliser, superheating takes place. The same observer, and also Borchardt and Rubner, have brought out the interesting fact that, if preliminary warming of the dressings to be sterilised be carried beyond a certain temperature before admitting the steam, superheating occurs, even although the steam admitted is only 100°C., and not under pressure. Borchardt, experimenting with cotton wool, found that after 70°C., superheating occurred, the temperature in the wool reaching 105.4°C., and remaining above 100°C. for over an hour. After forewarming to 80°C., 90°C., and 95°C., the temperature reached 108.8°C., 113°C., and 118°C. respectively. Experiments with wide-meshed gauze gave similar results, but a narrow-meshed gauze gave a higher temperature, viz., 116°C. after forewarming to 90°C. These differences depend probably on hygroscopic differences in the gauzes. I have found even engineers differing in their opinion as to what the nature of the steam entering a steriliser was, and, from what has been said, it will be evident that in the complicated system of piping unavoidable in many large institutions, it is not impossible for steam to receive additional heating on its way to a steriliser, and so to become superheated. Superheated steam may also be obtained by adding calcium chloride to water, which slightly raises the boiling point of water at the ordinary pressure, and the steam therefore comes off at the ordinary pressure, but at a slightly higher temperature than 100°C.

The importance to surgeons of a knowledge of what superheated steam exactly is, and how ordinary steam may become superheated, lies in the fact that since 1888 a number of observers have drawn contrasts between the sterilising action of saturated and superheated steam to the great disadvantage of the latter. Thus Esmarch found that anthrax spores, killed in five minutes by saturated steam of 100°C., were not killed in thirty minutes of superheated steam at 110°C., nor in twenty minutes of the latter steam at 120°C. Rubner's results are even more startling, since he found that anthrax spores in superheated steam of 110°C. remained alive twice as long, in superheated steam of 120°C. thrice as long, and in superheated steam of 127°C. ten times as long as in saturated steam of 100°C. No doubt these results were obtained with superheated steam of a high "grade."

With regard to the value of steam under pressure, but not superheated, the researches of Christen, working under Tavel of Berne, are of special interest. He experimented with the most resistant earth spores known, and found that these spores withstood the action of ordinary saturated steam of 100°C. to an extraordinary degree. Globig had found he could destroy them in five to six hours, but Christen could not do so in sixteen hours. With steam under pressure, however, and slightly circulating, he was able to destroy the spores in five minutes at a temperature of 120°C. to 135°C., while only one minute's exposure to a temperature of 140°C. was sufficient to kill all the spores. He found that after 120°C. there is a sudden increase in the bactericidal power of the steam. In employing bacteriological tests to sterilisers, I have found the results of experiments, carried out under apparently exactly similar conditions, to vary a little. I suppose, however, that bacteria of the same species may differ in resistance, just as individuals do, apart from age, the material they have been grown on, etc. Considerable variations occur, apparently, in their resistance to chemicals. Thus, while Gärtner killed colonies of staphylococcus aureus in eight seconds by means of a 1-1000 solution of corrosive sublimate, Abbott found five minutes necessary, and a few colonies survived even thirty minutes. The thermal death-point of the common non-sporing pathogenic bacteria would appear, however, on the whole to be pretty uniform. According to Sternberg, ten minutes of moist heat at 62°C. appear to be sufficient, though the staphylococcus aureus, when in a desiccated condition, requires a much higher temperature, viz., 90° to 100°C., or 80°C. for half an hour (Lübbert).

A recent writer has raised a further point, viz., whether bacteria (not spores) from a laboratory constitute a sufficiently stringent test material or not. This writer applies the term "effeminate" to such cultures, and apparently would accept with reservation any conclusions unless bacteria fresh from a wound were employed. On asking the opinion of two bacteriological friends on this point, I put the question in this way. If you had to be inoculated with bacteria from a wound or a tube, which would you choose? The answers are instructive. The first desired the bacteria from the wound, the second the cultivated organisms.

Air and Sterilisation.—Air, as is well known, is a most feeble germ destroyer. It is a bad conductor of heat. Its penetration is poor. Exposure to 170°C. for an hour is necessary to kill all organisms and spores, though non-sporing bacteria are killed after an hour and a half's exposure to 128°C. Pure air, luckily, seldom remains very long in a steriliser. It gets mixed up with the steam. The danger of such mixtures, however, are considerable. Thus, Rubner found that anthrax spores, killed after an exposure of three minutes to saturated steam, were still alive after ten minutes' exposure to a mixture in which the proportion of air to steam was 20 per cent. Further, spores were still alive after thirty minutes' exposure to a mixture in which the proportion of air to steam was 37 per cent.

The expulsion of air from sterilisers may be done by means of a vacuum, as in the sterilisers of the Kny-Scherer type, or it may be done by the entry of the steam. The removal of the air from the meshes of the dressings themselves also enormously favours the penetration of the steam. For this, steam in motion, whether under pressure or not, must be infinitely more efficacious than steam in equilibrium, even if under pressure. It is a good plan, therefore, with sterilisers using the latter kind of steam, not only to open the exit pipe (referred to later), but also to keep it open for two or three minutes at the commencement of sterilisation.

The presence of air in sterilisers which work under pressure upsets, to a certain extent, the ratio between steam temperature and steam pressure. This should be remembered where the temperature is calculated from the amount of pressure indicated on the gauge.

I have lately carried out a number of experiments with a view to ascertaining the temperature obtained in the centre of various drums under different circumstances of time, pressure and packing. In the course of these, I learnt several pieces of information. My experiments were mostly conducted with those modifications of the original Schimmelbusch-Lautenschläger apparatus which act under pressure. Among other things, the fact was brought home to me that air is frequently either not let out at all, or insufficiently let out. For example, I found that in the self-heating low-pressure variety, so commonly made use of in "Homes," a difference of temperature exists, in some cases of as much as 30°C., between the top and bottom after five or six minutes, *i.e.* where air has not first been let out. This result was obtained by suspending maximum thermometers by a thread in the inside of these sterilisers. This difference in temperature was also observed, to a less extent, in experiments made with thermometers placed inside drums. As the sterilisation was continued, this difference tended to diminish, and after a long period of sterilisation the results were nearly the same in the top and bottom of the steriliser. When the air was let out at the beginning, on the other hand, there was much less difference between the top and bottom, showing that the upper part of the steriliser was generally fairly free of air, the lighter steam occupying the upper part of the steriliser from the first, the heavier air being displaced to the bottom. The air being a bad conductor of heat, took a much longer time to raise the temperature of the thermometer at the bottom than the steam did to heat the thermometer at the top. If anyone wishes to satisfy himself of the presence of air at the bottom of such sterilisers, he has only to neglect to open the lower air escape pipe, and allow steam to accumulate for five minutes. If, now, he opens the escape at the top, only steam will rush out, whereas, if he opens the escape tap at the *bottom*, a rush of air will occur, followed, after a variable period of time, by steam. I have emphasised this point, as it is within my knowledge that this important point of letting out the air from the bottom of sterilisers is constantly neglected by nurses. Nor can we wonder that this is the case, since even instrument-makers, while supplying copious information on other points, entirely omit this one, which is most important if successful sterilisation is to be ensured. It is an interesting fact that in the old form of the Schimmelbusch steriliser, now so much discarded in favour of its pressure derivatives, this serious mistake was impossible of occurrence. In it the exit tube was open from the start, and steam at a pressure of only one-thirtieth of an atmosphere swept out all the air in the steriliser in the course of a few minutes, and afterwards ensured a continuous current of freshly generated steam during the whole period of sterilisation. In another of its derivatives, where the steam is supplied by branch pipes from the main pipes of hospital boilers, the steam only really circulates in the outer jacket, the interior of the steriliser merely gets the overflow, and the steam there circulates very much in the same imperfect way that blood circulates in a sacculated aneurism. In these sterilisers, too, it is easy for a new nurse to make mistakes with regard to the mechanism controlling the outlet and inlet pipes. I have known of drums placed in a steriliser in which no steam got into it!

In all the modern forms of Schimmelbusch's steriliser, there is a distinct difference of a few degrees between the temperature of the steriliser at the top and the temperature at the bottom, even after all air has been let out. The top part is the hotter, being nearest the more freshly generated steam. The lower part is, however, commonly supposed to be the hotter. Another point that cannot be too often insisted upon is, that drums must not be too tightly packed. Nurses are inclined to believe that steam can do anything. I have found that a difference of twenty or thirty degrees can be produced by stuffing a drum with too dense and too tightly rolled up material.

The Preliminary Heating, *the Wetting*, *and the After-drying of Dressings.*—These questions are so bound up with one another that they may be taken together. Under certain circumstances dressings undoubtedly may become very wet during sterilisation. If saturated steam under high pressure be admitted into a chamber of lower pressure and lower temperature, considerable soaking of the dressings will take place. In some varieties of sterilisers without an outer jacket, employing circulating saturated steam, the dressings may be moist to a degree approaching actual wetness, and, for reasons not always easy to discover, they may be wetter at certain times than at others. In drums where the steam is admitted at the top and bottom and not at the sides, the water of condensation upon the cold metal lid of the drum or steriliser may wet the dressings to a considerable degree. Again, pools of water may form at the bottom of the steriliser. Much *indirect* wetting of this kind can be avoided by fixing a bit of lint immediately below the lid of the steriliser, and by inserting a low wire frame beneath the materials to be sterilised and the bottom of the steriliser. In some cases, through faulty construction of the exit pipe, distinct flooding may occur. On the other hand, where superheated steam is used, and especially where it is of high grade and where, therefore, little or no condensation takes place, the dressings may be absolutely dry at the end of the process. Whether this condition of absolute dryness has been obtained at too great a price depends, of course, on the view taken of the sterilising value of superheated steam. Most people will, I think, agree that if a satisfactory sterilisation has taken place the dressings should be distinctly moist at the end of the process. Personally I can see no real objection to slightly moist dressings provided they are sterile. Complaints regarding the wetness of dressings would probably occur less often if too large and too tightly packed drums were not employed, and if the drums were taken out of the sterilisers at once at the end of sterilisation, and rapid evaporation thus favoured. Instead of this, in some cases, they are left lying for a considerable time in the clammy interiors of sterilisers. I am not speaking, of course, of sterilisers where special means are taken for after-drying. Further, there is no necessity in a clean sterilising room, under the care of a trustworthy person, for the holes in the drums to be closed at once on removal. [In one very ingeniously constructed steriliser the mere opening of the steriliser closes the drums.] The holes in the drums can be left open for some minutes. Even if a stray pathogenic organism should happen to be in the neighbourhood, ready to be drawn in by the vacuum taking place inside the drum, it would probably not penetrate the outer towel in which the dressings should be enclosed. Moreover, this suction occurs, I think, at once, when the drums are being taken out of the steriliser and very little afterwards. In experimenting with current saturated steam in a steriliser of the simple potato steamer type, in which the steam enters from below, and also with the old pattern of Schimmelbusch, with the object of investigating the relative dampness, after sterilisation, of various materials (not inside drums), I have been struck with the great rapidity with which evaporation takes place, provided the dressings were taken out at once while hot. The moisture seems to vanish into the air. A roll of gauze, apparently very wet, becomes perfectly dry in a few seconds. Ordinary wool and wood wool wadding dry almost as quickly. Rolled up cotton operation towels take longer, and sometimes remain slightly damp in the centre. If unrolled, however, they too dry at once. Brown holland operating coats take a still longer time, lint longer still, while flannel bandages never really part with all their moisture.

On the other hand, when these materials are not taken out of the steriliser for some time, even the gauze remains distinctly moist, and flannel is really quite wet. Space does not permit me to discuss the actual methods by which after-warming may be carried out, viz., by steam jackets, steam piping, the admission of hot air (not always filtered), and the like. I believe that in many cases such after-warming is not really necessary, though in certain cases it is.

With regard to forewarming, it will be seen from what has been already said that a danger exists if the forewarming be carried beyond about 60°C. Forewarming below that temperature, on the other hand, according to Braatz does not materially lessen the amount of condensation nor render the dressings less damp. Borchardt, however, who is a strong supporter of the old Schimmelbusch steriliser, believes that slight forewarming of the dressings is of service. Working with a most useful steriliser for private work, designed by Mr Cathcart in 1890, which permits of forewarming to a slight extent if desired, I did not find that forewarming of the dressings themselves made much difference. It appears to me, however, that the forewarming of the *walls* of sterilisers is useful in preventing the indirect wetting of dressings which I have referred to above.

Drums or Kettles.—A large number of different patterns of drums exist. Of all these, the ones originally devised by Schimmelbusch have been the most popular. There are signs, however, that their popularity is on the wane. They have, undoubtedly, certain drawbacks. They lack simplicity, being provided with such things as hinges, shutters and bolts. These are apt to go out of order and require repairing. The lid very soon ceases to fit tightly, and in many cases a distinct interval exists between it and the drum. This interval is increased when the drum is lifted, especially in those patterns where the handle is attached to the lid in the wrong axis. Where two such drums are attached together, as in many hospital patterns, this defect is still further increased. Again, the shutter mechanism may be so tight that there may be incomplete exposure of the holes during sterilisation or incomplete closure after sterilisation is finished. In some cases the shutter is so loose that dust may easily get in. I have placed such a drum closed in a steriliser, and found the contents nearly as moist as when the holes were open. Moreover, the bolts connected with the shutter often fall out at unexpected times, even in new drums, and the holes they leave communicate directly with the interior of the drum and may escape notice for some time. In no way, therefore, can this drum be regarded as a perfect apparatus for storing sterilised dressings or for conveying them to an operation at a distance. If used immediately after sterilisation, these defects are, of course, of no importance. As regards the rapidity with which dressings can be sterilised, it may be said that if sufficient holes are present, if they are not too tightly packed, and if a specially rapid sterilisation is not required, these drums do well enough.

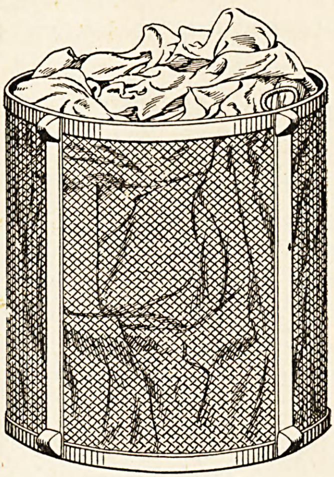

FIG. 1.—INNER WIRE CAGE.

The drum figured here seems to me an improvement on that of Schimmelbusch and on many other patterns.[1] It gives a more rapid sterilisation than the Schimmelbusch drum, and much greater safety as regards storage of the sterilised dressings, since it is practically hermetically sealed after sterilisation. This is, of course, a very great convenience in private work. It consists of an inner frame of wire-net—not a new idea it appears—but new to me. An interval of $\frac{1}{4}$ inch exists between this and the drum, allowing the steam to be in direct contact with the dressings everywhere. There is only one set of holes. These are exposed during sterilisation by raising the lid on three clips (which are so arranged as to grip the lid margin anywhere). The holes are completely covered up after sterilisation by simply pushing home the tightly fitting lid, which has a specially deep rim. From its construction, it is almost impossible for a nurse to neglect to open it before sterilisa-

[1] This drum has been made according to my directions by Mr Gardner, Forrest Road, Edinburgh.

tion, or forget to close it after sterilisation. The small hole at one end with screw cap I have now much enlarged. It was added as an additional safeguard, and also to permit any water of condensation to escape. The interesting point, however, about this drum, is the position in which it is placed during sterilisation. At first, I used to work with it in the ordinary position, the holes being at the top. In this position I found that sterilisation of the dressings at the bottom took a

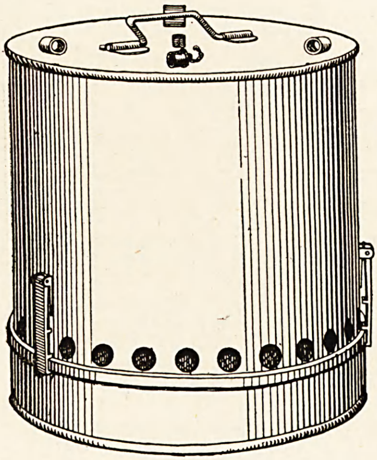

FIG. 2.—DRUM OPEN

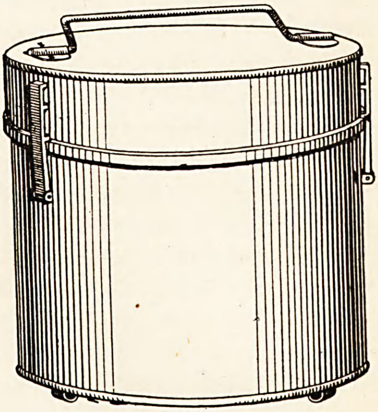

FIG. 3.—DRUM CLOSED.

much longer time than with Schimmelbusch's drum. One day I turned the drum upside down, so that the steam now entered at the bottom. At once I found the whole character of the sterilisation had changed. I found that, working with simple circulating steam of 100°C. not under pressure, and with the drum fairly tightly packed with gauze, a maximum thermometer placed in the centre of the gauze and near the bottom (now the top), recorded over 90°C. in five minutes.[1] Further, the dressings were quite moist. A second thermometer, similarly placed near the holes, gave only 80°C. When the position of the drum was reversed, only in the vicinity of the holes

[1] I have found that the temperature is more quickly raised in the interior of a packed drum with simple circulating steam, not under pressure, than it is when low pressure steam in equilibrium is used. Of course, if the sterilisation is continued, a higher temperature is eventually obtained with the latter.

did the marker show 80°C. In the end remote from the holes, the mercury had not reached 70°C. (the lowest scale on the thermometers). A thermometer in Schimmelbusch's drum, under precisely similar conditions, also showed that the temperature had not risen as high as 70°C. Experiments with steam under pressure in various sterilisers and disinfectors confirmed these results. Dr Knott, Lecturer on Physics in Edinburgh University, kindly supplied me with the explanation of this rather curious phenomenon in steam sterilisation, which, so far as I am aware, has not been noticed in this particular connection before. When the steam enters below, convection occurs; when above, it does not. Convection, it will be remembered, is the physical principle which comes into play in bringing water to a uniform boiling point, the hot water rising to the top, and the colder water falling to the bottom, to be again heated in its turn. In the upright position, the dressings get their heat only by diffusion and conduction. When upside down, convection is added. Sterilisation is therefore performed with this drum *upside down*. Possibly convection might be considered in the vexed question of whether steam is best admitted into sterilisers from above or from below. With this drum, with simple circulating steam not under pressure and with moderate packing, the boiling point is reached all over in fifteen minutes at the bottom of a Schimmelbusch steriliser. When placed in a large disinfector, side by side with a Schimmelbusch drum, I found a difference of at least 20 degrees in favour of the new drum, after fifteen minutes' exposure to a steam gradually rising to 15 lbs. pressure.

Braatz, in one of his papers, briefly refers to a drum he employs which this one seems to resemble. Braatz's drum, however, has apparently two sets of holes, above and below, and possesses even more rapid powers of sterilisation. I am, however, contented with the amount of sterilisation which convection enables this drum to perform, and do not wish to have another set of holes to guard. To favour evaporation, the drum should be placed in its proper position (not upside down), for a minute or two after sterilisation before closing the holes.

Concluding Remarks.—These investigations have strongly impressed me with the necessity of surgeons having a little more than a general acquaintance with the mechanism and working of sterilisers and surgical drums. When a steriliser is first installed, instructions should be obtained from original sources when possible, and not through intermediary persons. If one of the smaller sterilisers is used, the surgeon should satisfy himself that the person in charge really understands its proper working. In hospitals where a central sterilising room exists, a specially trained person is responsible for the sterility of the dressings, a strong argument in itself in favour of such an arrangement. Where a number of small sterilisers are employed, served by branch pipes from a main, there is a considerable risk of their supply of steam being interfered with through their reducing valves getting out of order, or the steam may be unexpectedly tapped or lessened from other causes. When, therefore, an independent supply of steam for sterilisation cannot be obtained, it is very necessary that gauges should be provided for all sterilisers working under pressure, and thermometers for those not working under pressure. The same remarks, of course, apply to sterilisers which manufacture their own steam. Both gauges and thermometers should themselves be tested from time to time. Bacteriological tests should also be performed occasionally. In conclusion, for reasons which have, I think, appeared in the course of this paper, I would express a preference for the employment of saturated steam freely moving through the interior of a steriliser. If this steam cannot be obtained under pressure as well, which seems to be the most powerful combination, I am content with it under atmospheric pressure, provided sterilisation is not hurried nor the drums too tightly packed. The exact length of time in sterilisation depends so much on the variety of the steam, the steriliser, the drum, the packing, and the density of the fabrics to be sterilised, that each surgeon should determine this for himself, preferably by bacteriological experiment, and not by thermometric tests alone.

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2. SYPHILITIC SYNOVITIS IN CHILDREN

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(WITH 2 PLATES.)

THE subject of syphilitic synovitis in children has not received the attention it deserves from medical and surgical writers, and the importance of the condition entitles it to a much wider recognition than has hitherto been accorded to it. It is generally regarded as an affection of great rarity, and in the text-books on diseases of children it is either completely ignored, or the subject is summarily disposed of, with the statement that such a condition is occasionally, but very rarely met with. In a recently published monograph on the syphilitic manifestations of early life, only half a dozen lines are devoted to a consideration of syphilitic synovitis.

In 1853, Richet first drew attention to the occurrence of inflammation of the joints in syphilitic patients, and since that time articles on the subject have been contributed by Virchow, Lancereaux, Voisin, Clutton, Bowlby, Howard Marsh, and Jonathan Hutchinson, senior and junior, and accounts of cases are to be found scattered through the medical journals. Morgan, who in 1895 wrote a paper on this subject, stated that he had only been able to discover one pathological specimen of syphilitic arthritis in London, in the museum of St Bartholomew's Hospital. The specimen referred to was the knee-joint from a young man whose case is recorded by Bowlby in the "Medico-Chirurgical Transactions" for 1894. The museum of the Royal College of Surgeons of Edinburgh is to-day in a still worse condition, as it does not contain