After-Treatment.

Where the case progresses favourably—that is, where the temperature and pulse are descending, pain is slight or absent, and the patient is eating and sleeping well—the wound is not examined until the patient's general and local conditions suggest that the wound may be closed; in wounds of the soft parts this usually occurs on the third to the fifth day. It is impossible to give any rule as to the time for suture. Smear counts have generally been taken, and average reports of 0.2 to 2 organisms per field have been received. On the other hand, wounds with a greater number per field, even up to 9, have been intentionally and successfully sutured. It is really unnecessary to wait until the evening temperature is normal, but it is safer, and it is our usual practice. The clinical aspect of the wound and the patient's general condition are the best guides; in a patient possessing a sense of general well-being and local comfort, a normal pulse and temperature, a good appetite, and a good sleeping capacity, the wound, although glazed and green with the paste, but otherwise of good appearance and with no swelling, may be safely sutured; and experience shows that all of these requirements are not necessary. In a dubious wound or a fracture, smear counts are always made, and with cocci over four, or *Bacillus perfringens* anywhere, the case is left. If for any reason suturing is inadvisable and the paste originally put in has disappeared, the wound is repasted.

Where the case progresses unfavourably, the excision or the pasting has been incomplete, and repasting or further operative measures are required. Nitrous oxide anaesthesia is occasionally used for deep repastings in the ward. Re-filling with paste and hot fomentations are frequently sufficient, as the temperature and pulse may be slow in coming down although there is no sepsis.

The Suture of the Wound.

Under an anaesthetic the wound is gently wiped out, dried with spirit, and the skin edges freshened or further excised. A very thin film of paste is then everywhere rubbed in and the excess removed. Silkworm-gut sutures are used for the skin. Closure of the cavity, preferably by under-running gut or occasionally buried catgut sutures, is of great importance. There should be no tension on the skin; undermining followed by pasting can be safely done. Deeply running sutures have fine rubber tubes threaded on them. No drain is used with the exception of a minute one in a few fractures.

Primary Suture.

This is always done after pasting, where the wound has been completely excised without the blade of the knife entering the original wound cavity. It is frequently done in other cases and even in some minor bone injuries, but only experience with this paste can indicate the suitable ones; here the wound is filled with paste and only lightly sutured or else a very temporary drain is inserted. Primary suture will always be less safe than secondary suture, and the gain of two or three days and the avoidance of a short anaesthesia is not commensurate with the risks run in a case of the slightest doubt.

Abdominal incisions, head wounds, excisions of joints and other relatively clean wounds are pasted lightly in the absence of, and heavily packed in the presence of, a remaining cavity, followed by partial or complete primary suture as the case indicates.

All amputations in which flaps have been fashioned are filled with paste, particular attention being directed to the bone, and the flaps are apposed by two or three sutures; the closure is completed after wiping and slight repasting two or three days later when the pulse and temperature are normal. Flapless amputations are performed only in certain cases of gas gangrene or of extreme collapse.

RESULTS.

I shall not give any records; the staining and the paste are matters for trial by the individual surgeon. A strong, firm scar rapidly results; the skin unites well over a cavity such as is left by a pulped tibia. Extensive wounds of the buttock, and wounds complicated by division of large arteries or by fracture of any of the long bones, have been quickly closed. Fractures have been successfully sutured in three to five days, and wounds dividing muscle have been closed by partial primary suture with safety, which must be the outstanding feature of any method.

After the Carrel-Dakin treatment of any wound secondary suture can be safely and successfully performed at an earlier date and in the presence of a higher average field count if this paste is used.

It has also been packed into acutely inflamed cavities, such as in acute suppurative arthritis of the knee, with excellent results, but this has not been sufficiently tested to warrant a definite expression of opinion.

Where the foreign body has not been removed, I believe that pastes ought not to be used.

In conclusion, the case for complete excision must be again pleaded; it should begin and end all discussions on the wounds of war; without it, good antiseptics and this medley of pastes are almost useless in quickly healing the broken skin. Many good methods of sterilization have been doomed for want of it; a good paste will cover a multitude of sins, but ultimately the omissions will surely be found out. The pathologist has provided and is providing us with the means of sterilization, and now it rests solely with the surgeon as to whether the compound fracture shall become sterile in a few days or pass through months of continued suppuration.

My thanks go out to our consulting surgeons for their help and stimulation, to our pathologists and medical officers for innumerable suggestions in this and other work, and to the sisters for assistance in many practical details.

THE SPREAD OF INFECTION IN OPEN BONE, AND ITS BEARING ON THE TREATMENT OF PROJECTILE FRACTURE.

(Preliminary Communication.)

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This paper gives a brief review of certain features in the spread of infection through fractured bones, which we have observed when studying this problem at a base hospital in France.

Our methods of laboratory work and the precise details of our observations will be fully described elsewhere. Here it will be enough to say that the material used was chiefly obtained from freshly amputated limbs. The injury to the bone was accurately mapped out up to the furthestmost fissuring, and the spread of bacterial infection along the bone was ascertained by cutting the latter into series of sections, and taking cultures from samples gouged out at each level in succession. Blood cultures were made from the patient at the same time so as to control the possibility of any general septicaemia that might be present, because the latter would have confused our attempt to analyse the local spread of the sepsis through the bone from the original wound.

When pathogenic organisms are implanted into normal bone from the blood stream pus is produced at the site of implantation, and so long as the bone remains closed they spread along lines determined by its anatomical conformation, produce further pus, and ultimately lead to necrosis. Before the war the description of these processes and of the subsequent course of repair made up the bulk of the accessible information about the interaction of bacteria and bone.

It has long been a surgical platitude that if a bone in a condition of early acute osteomyelitis is opened up until normal looking bleeding marrow is reached, it will recover without incident beyond the separation of sequestra. In projectile fracture of the shaft of a long bone the wound itself establishes some drainage simultaneously with the introduction of the infective agent—that is, organisms are implanted on to the surface of a widely open marrow, and although the complexity of the cavity and rigidity of its walls renders perfect drainage of the bone wound an unrealizable ideal, yet the conditions on any given surface of exposed marrow are adequate to prevent that spread of the inflammatory process which leads to pus formation in a closed bone.

It is a rare experience to meet with acute spreading osteomyelitis in the early stages of projectile fracture. Pus is seldom found in the medullary cavity of a long bone, nor is it seen issuing from the end of a bone unless a fissure is present. In the latter case the pus comes from the walls of the fissure, and the assumption that the marrow is infected to any appreciable depth must, in the absence of deliberate investigation, remain a hypothesis.

On the other hand, wounded cancellous bone is, to superficial inspection, more liable to osteomyelitis than the shaft, but this appearance requires analysis before a valid comparison can be instituted.

In the first place, owing to the greater strength and elasticity of compact bone and to the tubular character of the shaft, portions of the latter broken off by a missile usually retain their vascular attachments through the periosteum and comparatively few fragments become entirely detached. The solid articular end composed of inelastic cancellous tissue is more liable to be broken up in such a way that fragments are left entirely without blood supply. Such isolated portions are readily attacked by organisms and, if not removed, become foul and necrotic.

In the second place, on account of the physical properties of cancellous bone, the surface of the fracture is always covered with a layer of debris consisting of pulverized trabeculae, dead marrow and blood clot, a culture medium highly favourable to the growth of organisms. The elasticity of compact bone, on the other hand, causes comminution of the shaft to take the form of multiple fissuring rather than of pulverization. By reason of this contrast infection of cancellous bone can best be understood through the study of the results of treatment of the fractured surface, while the process of infection of the shaft can be followed most easily in the evolution of an untreated fissure.

Fissures.

Fissures fall naturally into two categories, the open and the closed, each of which has a distinctive clinical history.

A *closed fissure* is one whose walls spring back into apposition as soon as the force of the blow is exhausted. On this account no dead space exists in which organisms can develop, and such a fissure unites without incident. Closed fissures occur only in compact bone. Two kinds are met with in association with projectile fracture—one due to the direct effect of the missile itself, in which case the fissure commences in the main fracture and ends blindly in the bone; and the other to the indirect effect of the fall or muscle twitch which follows the mechanical stimulus. In the latter case the fissure does not communicate at any point with the original bone wound, and it is apt to assume the spiral form associated with simple fracture. It is in fact a minor degree of the indirect complete fracture which not uncommonly accompanies incomplete direct fracture of a distant part of the bone, or occasionally may even be associated with a simple flesh wound of the limb.

Open fissures occur in both compact and cancellous bone. They start at the main fracture and at the other end open on the surface of the bone into either muscle or joint. They form, in fact, an integral part of the fracture and differ only slightly from it in their reaction to infection.

All fissures in cancellous bone behave as open fissures.

EXTENSION OF INFECTION ALONG OPEN FISSURES.

A fissure whose walls are not in contact with each other affords ample opportunity for the growth of any organisms which may be present in the wound, as it provides a cavity with rigid walls, full of blood clot and defiant of drainage. Its behaviour can be studied clinically in an infected fracture accompanied by fissuring, where the incisions for drainage have been confined to the region of complete solution of continuity. The fissure full of blood clot is, then, in communication at one end with the wound flora, and at the other end opens into either muscle or joint cavity.

Organisms grow along it from the point of primary infection, and, since lateral penetration of the bone by organisms and toxic absorption from the walls of the fissure are comparatively slight, the process of extension is not reflected to a noticeable extent in the temperature chart, pulse-rate, or general condition of the patient. As soon, however, as bacteria escape from the fissure into

adjacent muscle or joint cavity, the clinical picture changes to that associated with pocketing or the development of septic arthritis.

Spread along a Fissure.

The absolute rate of travel of organisms along a fissure can only be determined by the bacteriological examination of serial sections of bones removed by operation. From a clinical point of view estimates of the apparent rate of travel have also been founded on the appearance of infection in a joint at the far end of a fissure. This use of a joint as an indicator is probably fallacious, since it implies the assumption that no delay occurs at the breach in the synovial surface. Delay is known to occur in the case of anaerobes and the staphylococcus, and probably happens to a less degree in the case of the streptococcus, although the material available does not allow of precise statement with regard to this organism.

The process may be illustrated by three cases showing different stages in the life-history of a fissure.

In the first a fissure led into the shoulder-joint from an infected fracture of the surgical neck of the humerus. Serial sections at intervals of 0.5 cm. examined bacteriologically showed that after three days no organisms had grown along the fissure from the main fracture.

In the second case a shell splinter with its attached fragment of cloth was embedded in the lower end of the femur, and from its site a fissure ran up to open on the surface of the shaft 10 cm. above. When examined three days after infliction of the wound, pus had spread to a distance of 0.5 cm. from the edge of the shell fragment. Beyond this the fissure contained blood clot, which, to the naked eye, was fresh and normal in appearance. Bacteriological examination showed that streptococcus, staphylococcus, and anaerobes were present at a distance of 4 cm. from the edge of the purulent area.

In the third case a fissure 9 cm. long led down to the knee-joint from an infected fracture of the lower third of the femur. Between fifteen and seventeen days from infliction of the wound a streptococcus reached the joint, and when the limb was removed on the seventeenth day the fissure contained pus throughout its whole length from fracture to joint.

Fissures, then, offer an easy path by which infection can reach distant parts of a bone, and the organisms concerned may be regarded as growing in orderly progression parallel to and on the surface of the exposed bone from one end of the fissure to the other, or from the original site of implantation throughout all the ramifications of a comminuted fracture. In the latter their progress is often accelerated by an imperfectly drained muscle wound with its opportunities for multiplication and accumulation of a "head" of organisms.

Lateral Penetration.

Pari passu with this spread of infection parallel to the surface a second mechanism comes into play—namely, the direct growth of organisms into bone at right angles to the fractured surface. This mechanism we have named *penetration*, and have studied it by the bacteriological examination of serial sections of bone away from a fracture.

Since penetration depends primarily on the number of organisms presented to an open bony surface, it is best seen in fractures of the cancellous end of a long bone in which the original debris of crushed trabeculae, dead marrow and blood clot has been left undisturbed by surgical interference. Organisms are constantly found in such a bone, and may extend to a depth of 10 cm. or more beneath the surface. This penetration of open bone by bacteria does not appear to be influenced by the particular bone affected nor by its structural variety (cancellous or medullary), nor again by the extent to which it is bruised. Open fissures, like any other part of a fracture, allow penetration to occur at right angles to their walls, and through their agency the degree of mechanical injury of a bone is reflected in the extent of the infection of its substance.

Penetration is influenced by the following factors:

1. Surgical treatment of bone and flesh wound.
2. Diminution of blood supply to the bone.
3. Types of bacteria.
4. Time.

Surgical Treatment of Bone and Flesh Wound.

However freely the flesh wound is opened up, penetration goes on unchecked so long as the original layer of necrotic debris remains on the surface of the fracture. If

this débris is removed by gouge or curette, and firm though bruised bone left at the bottom of a freely-excised flesh wound, penetration either does not occur at all or is limited to the surface layers of the bone.

The simplest conditions under which penetration can be studied are those obtaining in a flapless amputation stump, where bone injury and sepsis of soft parts are alike minimal. If such a bone be examined by the method of serial section organisms are found limited to the terminal 1 or 2 cm. The infected bone is softened, and probably represents the area of terminal necrosis which is so frequently found at a later date. Such an amputation stump affords direct drainage of both bone and flesh wound, and may be taken as a type, departure from which is initiated by deficiency of drainage of either bone or soft parts.

Direct drainage of bone with indirect drainage of the flesh wound are the conditions present after resection of a joint for suppurative arthritis, and these may be illustrated by four cases of resection of the knee-joint following projectile wound.

In two cases the failure of the operation to control septic absorption rendered amputation necessary. In these two cases organisms penetrated 9.5 cm. and 0.8 cm. into the tibia from the cut end in six and fourteen days respectively. In the other two cases the progress of septic absorption was at once arrested by resection and the patients were transferred to England with their wounds reduced to sinuses. Eight months later Captain Everidge, R.A.M.C.T., reported that the wounds had healed rapidly and that no recrudescence of sepsis had taken place, but that the ends of the bones were in a condition of rarefying osteitis and had not united. A tentative suggestion may, therefore, be put forward that penetration by organisms represents one phase in the development of rarefying osteitis.

That direct drainage of bone plays a part in the substitution of the latter process for that of suppurative osteomyelitis is suggested by a case in which a comminution of the upper end of the ulna and a minor fracture of the articular surface of the humerus were associated with a staphylococcus infection of the elbow-joint.

At the first operation, two days after infliction of the wound, the upper ends of both forearm bones were resected and the small gutter fracture of the humerus curetted. This was followed clinically by cessation of sepsis in the forearm, with extension in the upper arm. At amputation, sixteen days later, suppurative osteomyelitis was present throughout the lower third of the humerus, while the forearm bones were normal to naked-eye inspection, though serial sections demonstrated the presence of organisms to a depth of 3 cm. from the open ends. The staphylococcus was the only organism present in all cultures.

In this case, then, three open bones communicated with a common septic cavity, and although too much stress cannot be laid on an isolated instance, the penetration by organisms of all three associated with osteomyelitis only in that bone which was imperfectly drained is a suggestive comment on the different course taken by infection in open and closed bone.

Reinforcement of bone infection from an imperfectly drained flesh wound leads to an increase of penetration. This is seen in a fracture of the articular end of the femur, where the infected knee-joint lies across the track leading from bone to surface. In one such case examined a similar fracture of the upper end of the tibia was present in the same limb. The tibial fracture was exposed in the wound—that is, the element of soft part sepsis was negligible, and in association with this, organisms were confined to the surface of the bone. In the femoral wound, on the other hand, where reinforcement of sepsis from the infected joint took place, penetration occurred to a depth of at least 2.8 cm., the organism in each case being a streptococcus.

Diminution of Blood Supply to the Bone.

The importance of this factor can scarcely be overstated, for penetration seems to be directly proportional to the degree of diminution. It frequently determines amputation, and, while its effects are seen chiefly in an increased growth of anaërobes (as in the soft parts), it also accelerates the progress of the streptococcus.

From the clinical point of view, the significance of this factor can best be illustrated by examples of interruption of the chief artery to the bone and of the medullary artery. Of two cases of projectile fracture of the os

calcis, comparable as regards degree of injury, duration of sepsis, and types of bacteria (anaërobes) present, the posterior tibial artery was intact in one, divided in the other. In the former, penetration reached only 0.5 cm. from the surface of the fracture, in the latter, organisms were present throughout the whole bone. Again, from a fracture of the tibia below the entry of the medullary artery penetration extended to 1.5 cm. in the upper fragment, the blood supply of which was intact, and to 5.5 cm. in the lower fragment, from which the medullary artery was cut off.

Other examples could be quoted, but these are sufficient to indicate the paramount importance of an intact blood supply in enabling bone to resist infection, and the value of conservatism in the treatment of vessels during operative interference with infected fractures.

Types of Bacteria.

The chief groups of bacteria isolated from the bones examined were, in order of frequency:

Streptococcus	...	...	34 per cent.
Staphylococcus	...	...	23 "
Anaërobes	...	...	23 "
B. coli	...	...	20 "

The average depth of penetration from the surface of bones with intact blood supply was:

Streptococcus	...	2.0 cm. in 10 cases.
Staphylococcus	...	1.5 cm. in 6 "
Anaërobes	...	0.8 cm. in 6 "
B. coli	...	0.7 cm. in 3 "

Bones with heavy mixed infection are excluded from the above table.

Time.

While the influence on penetration of the duration of sepsis between infliction of the wound and examination of the bone is not easy to dissociate from other factors, the following two generalizations can be made from the cases examined:

First, within the first four weeks from infliction of a wound the continued presence of organisms on the surface of a fracture does not necessarily lead to infection of the deeper layers of the bone.

Secondly, the rate of penetration is at its maximum during the first few days, to the extent that the average depth of penetration during the first week is equal to the average additional penetration during the succeeding four weeks.

CONCLUSIONS.

The following conclusions can be drawn with reference to the operative treatment of projectile fracture. Some are already well recognized, none are universally practised.

1. Soft parts killed by the direct effect of the missile require removal.
2. An infected fracture of the shaft of a long bone requires opening to the full extent of solution of continuity.
3. In infected fracture of cancellous bone the superficial débris of smashed trabeculae, etc., requires removal. Solid bruised bone is able to resist infection and may be left.
4. As penetration is at its maximum in the first few days early operation is essential, especially in fractures of cancellous bone involving joints.
5. Every artery directly or indirectly supplying a fractured bone is of importance in the defence against infection.
6. In the presence of vascular injury proximal to the fracture, radical measures, such as amputation or resection of a joint, may be adopted with less hesitation.

THE Manor House Military Orthopaedic Hospital, Golders Green, was opened by Sir William Robertson, Chief of the Imperial General Staff, on September 29th. It has been founded by the Allies Hospital Benevolent Society, with the approval of the War Office and the assistance of the Joint Committee of the British Red Cross Society and the Order of St. John. The house, surrounded by nine acres of well-wooded ground and meadow land, is used as the administrative block, with which the wards, each containing forty beds, are connected by covered ways. Electrotherapeutic and hydrotherapeutic departments have been established as well as curative workshops. The accommodation at present provided is for 120 men, but it can be extended if necessary so as to provide 1,000 beds.