A CONTRIBUTION TO THE PATHOLOGY OF PROJECTILE FRACTURE OF LIMB BONES.

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PROJECTILE fractures observed during this war have created new problems, owing partly to the frequent complexity of the lesions, and partly to the co-incident infection, of a type rarely encountered under civil conditions. They have given far greater opportunities than have occurred hitherto for the study of the interaction of bacteria and bone. It is the purpose of this communication to illustrate these reactions as they occur during the first six weeks after infliction of the wound, and to show that they may be modified not merely by morbid changes incidental to the local trauma, but by circumstances remote from and independent of the primary injury to the bone. These conditions, whether local or remote, and whether acting singly or in combination, tend to produce a variety of types of infection, ranging from the unrestrained bacterial invasion of a damaged bone, to the deviations from this type brought about by surgical intervention. In the absence of clear conceptions of the progressive changes within the bone which lead either to healing or to a state necessitating radical surgical interference, the foundations of rational treatment do not exist.

The material on which this paper is based was derived from thirty-two patients at a base hospital in France, and comprises a variety of infected fractures, chiefly of the cancellous tissue, but also of the shaft, of long bones. The cases were taken at random as opportunity offered, and of necessity include a considerable proportion which were not on the road to recovery. In addition to clinical observation of each case, the fracture and adjacent soft parts were dissected, and bacteriological examinations were made from serial sections of the bone. The results have shown that the variables contributing to form each type of infected fracture are such as to make it desirable to accumulate for examination a sufficient number of examples to allow of a grouping of the cases for statistical analysis. The importance of this lies not only in confirming isolated or limited findings, but in tracing the stages through which infection of bone passes, and in attempting to correlate clinical states with the nature and degree of the infection. Although the observations recorded here do not altogether reach this standard, they have indicated certain lines along which the problem may be attacked, and have led to a number of reasonably definite conclusions.

The scope of the inquiry is indicated in the following scheme :—

I. MECHANICAL ACCOMPANIMENTS OF PROJECTILE FRACTURE.

Bruise.

Fissure.

II. METHODS OF INVESTIGATION.

Nature of material.
 Details of technique.
 Recording of results.

III. SPREAD OF INFECTION FROM FRACTURE.

Varieties of bacteria isolated from bone.

Factors influencing penetration of bone by bacteria :—

Structural and anatomical variety of bone.

Extent and degree of injury.

Types of bacteria.

Infection of the surrounding soft parts.

Diminution of blood-supply.

Surgical treatment of wounds.

Time.

IV. EXTENSION OF INFECTION ALONG FISSURES.

V. CONCLUSIONS.

I. MECHANICAL ACCOMPANIMENTS OF PROJECTILE FRACTURE.

The varieties of projectile fracture are so well known that formal description of them is superfluous. Two features, however, stand out so prominently as to repay detailed examination—namely, the bruise which invariably accompanies gunshot injury of bone, and the fissures which commonly do so.

Bruise of Cancellous Bone.—When a missile strikes cancellous bone, a bruise is produced at the point of impact, whether the outer compact layer is broken or remains intact. Bruising is met with under three conditions (1) Direct bruise round the track of a penetrating missile ; (2) Direct bruise without penetration , (3) Indirect or contrecoup bruise in the same or an adjacent bone.

1. *Direct Bruising round a Missile.*—Examples are shown in *Figs.* 203, 204, and 205. In *Fig.* 203, the periosteum has been removed from the back of the tibia to show the bluish appearance of the bruise as seen through compact bone. The articular cartilage is stained by the blood in the joint except at the site of the bruise. In the transverse section of the same tibia, taken immediately below the embedded shrapnel ball, the characteristics of a typical bruise are seen—the dark-red colour of the effused blood filling the cancellous spaces, the outline concentric with the foreign body, and the sharp line of demarcation, broken only by a slight tendency to radiation at the junction with the normal bone. This bruise was sterile on culture, and the whole specimen demonstrates the type colours of a recent aseptic trauma.

Fig. 205 represents a horizontal transverse section of one femoral condyle from a resection of the knee-joint for multiple shell-wounds. The joint contained a sterile blood-effusion. The figure shows clearly the sharp limitation of the bruise concentric with the shell fragment, and the characteristic absence of fissures radiating from the shell site. Several such bruises have been examined under a dissecting microscope, and the absence of even the smallest cracks in the trabeculæ confirmed.

FIG. 203.—Upper end of tibia from behind, showing bluish appearance of bruised cancellous bone as seen on the surface after removal of periosteum. *A*, Entry wound. *B*, Shrapnel ball.

FIG. 204.—Transverse section of same tibia immediately below shrapnel ball, showing appearance of aseptic bruise two days after injury.

Figs. 206 and 207 show the extent of the bruising up the shaft from a penetrating wound of the femoral condyle accompanied by fissuring.

Fig. 208 (Case 12) shows a bruise which was produced by a minimal tangential blow. The articular cartilage was chipped, but the subjacent compact layer of bone was not even cracked.

The colour of a bruise fades rapidly on exposure to the air or immersion in water. During an operation, an underlying bruise is easily recognized by the bluish colour on the surface of the overlying bone or articular cartilage. When exposed, it is a much darker red than normal cancellous tissue.

2. Direct Bruising without Penetration.—Direct bruising of the condyles of the femur without fracture has been found associated with extensive flesh wounds where large shell-fragments of low velocity have opened the knee-joint and necessitated amputation for suppurative arthritis.

3. Indirect or Contrecoup Bruising in the Same or an Adjacent Bone.—

Fig. 209 shows a direct and indirect bruise in the same bone. *Z¹* is the direct bruise round the fracture, separated by a zone of undamaged bone from *Z²*, the indirect bruise produced by impact of the head of the humerus against the scapula.

Fig. 211 shows the extent of an indirect bruise which was produced in an otherwise uninjured tibia as a contrecoup effect from a fracture of the lower end of the femur (*Fig. 210*). This bruise showed on the upper surface of the tibia as a bluish discoloration round the spine, but no crack of the latter or of the articular cartilage existed.

Bruising of the marrow of the shaft similarly accompanies fracture. Owing to the thickness of the surrounding compact layer, it can only be seen on section. Where fissures exist, the bruising always extends up to, and may extend beyond, their limits.

Fissures.—These are found in both the compact bone of the shaft and the cancellous bone of the extremities, though much more commonly in the former. They can, in fact, be considered as a regular accompaniment of comminution, and frequently extend for long distances—10 cm. or more—up and down the shaft from the point of primary injury, or from the site of an embedded foreign body which has not produced a complete fracture.

Fissures are of two kinds—those which remain open, and those whose walls spring back into apposition as soon as the force of the blow is exhausted. The latter are found only in the elastic compact bone of the shaft, and unite

FIG. 205.—Section of femoral condyle with embedded shell-fragment, showing bruise without fissuring; day following injury.

without incident, in contrast with the open fissures, which play an important part in spreading infection. They may be due either to the direct effect of the missile itself, in which case the fissure commences in the fracture and ends blindly in the bone, or 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 is apt to assume the

FIG. 206.—Lower end of femur removed by amputation 48 hours after injury. Embedded shell-fragment, with surrounding fissures.

FIG. 207.—Longitudinal section of femur shown in Fig. 206. Extent of corresponding bruise.

spiral form associated with simple fracture; it is, in fact, a minor degree of the indirect complete fracture which not uncommonly accompanies direct partial fracture of another part of the bone, or occasionally may even be associated with a simple flesh wound of the limb.

All fissures in cancellous bone behave as open fissures. Apart from extreme comminution they do not often occur, unless prolonged from the

shaft, or unless a projecting portion of cancellous tissue is separated from the main bone by a perforating injury.

As a rule, a missile which penetrates the articular end of a bone, and remains embedded, cuts a tunnel but very little larger than itself, and comes to rest in a closely-fitting bed of bruised bone (*Fig. 205*). If a longitudinal section of such a tunnel is examined under a low power of a stereoscopic dissecting microscope after removal of the débris with which it is filled, the wall is seen to be sharply defined, the trabeculae lining it being flattened by the pressure of the missile, while those in the immediate neighbourhood show no disturbance.

II. METHODS OF INVESTIGATION.

Nature of Material.—There are three sources from which material can be obtained (1) Fragments of bone removed at operation; (2) Amputated limbs, (3) Autopsy.

1. FRAGMENTS OF BONE REMOVED AT OPERATION.—(*a*) *Small Fragments* Cultures from bones were never made at operation, on account of the difficulty of carrying out an adequate bacteriological technique, and of the uncertainty of reaching the limits of infection in a living bone. (*b*) *Large Fragments*: The portions of bone removed in the resection of joints were found suitable for studying the spread of infection in cancellous tissue.

2. AMPUTATED LIMBS. — These were chosen as the principal source of material, for two reasons: (*a*) Because they are the most accessible source of fresh material, (*b*) Because it seemed probable that from them the processes at work in bones which ultimately unite might be reconstructed.

In order to obtain trustworthy data from the bacteriological examination of bones, it is essential that they should be examined immediately; or if this is impracticable, that steps should be taken to inhibit the growth of organisms which always follows the removal of any tissue from the body, and which makes it impossible to draw valid conclusions as to the conditions obtaining at the time of amputation. Post-mortem growth is illustrated by *Cases 1, 2, and 3, Appendix I.**

3. BONES REMOVED AT AUTOPSY.—In consequence of the liability to post-

FIG 208.—*Case 12.* Coronal section of astragalus from amputation; 2½ days after injury. Bruise from minimal wound of articular cartilage without fracture of bone.

* In order to avoid undue interruption of the narrative, detailed accounts of some of the cases have been collected in Appendix I, p. 328.

mortem growth, investigation of bone removed at autopsy has been confined to two cases in which no delay occurred in obtaining the material. Even if the material is taken immediately after death, the results do not necessarily correspond to those found in patients who ultimately recover; for where death is preceded by a gradual failure of the circulation, bacteria may grow as saprophytes throughout the bone during the terminal phase of the illness. In such a case the bacterial invasion is in reality a post-mortem phenomenon occurring during life (see *Cases 4 and 5, Appendix I*).

Details of Technique.

Procedure at Operation.—Under the anæsthetic a swab is taken from the wound as close to the fracture as possible; 10 c.c. of blood are withdrawn from a vein for cultural purposes; and if a joint is involved, a sample of the effusion is obtained by puncture away from the wound, after sterilization of the skin. The bone when removed is rapidly cleaned and put into ice, in which it remains until all preparations for investigation are complete.

Technique of Taking Bone Cultures.—After making a smear from the fracture, the whole bone is flamed with a blowpipe, and fixed in a vice which has previously been sterilized in the same way. Transverse sections are then made at measured intervals* with a flamed hack-saw, commencing at the end away from the fracture. The face of the section from which cultures are to be made is lightly seared, and pieces are scooped out with a *dry* sterile gouge. Before each successive transverse section, the bone and vice are lightly heated again with the blowpipe or searing iron.

FIG. 209.—Section of head of humerus removed by resection 5 days after injury. Z¹, Direct bruise extending from fracture. Z², Indirect bruise from shock against scapula.

Each of the fragments removed by the gouge is about the size of a pea. One is inoculated into a serum-broth tube, for aerobic cultivation: the other into a short, stout culture tube containing broth, fitted with a solid glass rod flattened at the lower end for the purpose of grinding up the bone fragment as far as possible; from this suspension anaerobic cultures are prepared, and the tube itself is also incubated as a control upon the aerobic cultures. Anaerobic cultures are made into tubes of broth and milk media covered with a layer of liquid paraffin. The broth tubes contain small pieces of coagulated

* Unless sections are taken at frequent and regular intervals throughout the bone, the limit of infection cannot be determined with accuracy. Experience has shown that an interval of 2 cm. is the most suitable.

white of egg to indicate the presence of proteolytic anaerobes. If marked proteolysis occurs, a subculture is made into the same egg-broth medium grown aerobically, to test whether the digestive action may not be due to facultative anaerobes. The flora of the aerobic and anaerobic cultures are compared by making fresh and stained preparations, and by plating on serum agar and MacConkey agar. The aerobic colonies are picked off and identified. Comparison of the aerobic and anaerobic growths makes it possible to determine the presence of strict anaerobes. Anaerobes, when present in the bone fragment implanted in the primary *aerobic* broth-culture, are frequently found to have grown freely, especially in mixed cultures, their growth being aided

FIG. 210.

FIG. 211.

FIG. 210.—Shell fracture of lower end of femur.

FIG. 211.—Indirect or contrecoup bruise of upper end of tibia without fracture. Produced by blow on femur shown in Fig. 210. Sterile on culture.

by the layer of bone fat which forms on the surface. The complete identification of anaerobes was not undertaken, but the presence of *B. perfringens* was noted when the anaerobic milk-cultures presented the typical appearance of 'stormy fermentation'—that is, a clot of casein torn up by gas—and when, in such a culture, stout Gram-positive, non-motile, non-sporing, anaerobic bacilli were found.

Where necessary, smears of the bone samples are taken for microscopical examination.

There are two possible sources of error in the technique: (1) Overheating of the bone; (2) Contamination by bone dust from the saw.

1. To check overheating, a thermometer was placed in a tibia, and the bone flamed with considerably more vigour than that necessary to ensure

surface sterilization. The thermometer rose from 17.5° C. to 26.5° C. In practice there has been no reason to suspect any error from this source.

2. Contamination is guarded against by making transverse instead of longitudinal sections, by commencing at the end farthest from the wound and therefore the least heavily infected, by searing each surface immediately before taking the scoop, and by flaming bone and vice between successive sawings. In the earlier cases sterile liquid paraffin was allowed to drip on to the saw-blade; this had the effect of greatly diminishing the dust, and causing it to adhere to anything it touched, but was afterwards discarded as superfluous.

In spite of the refractory nature of the material examined, accidental contaminations were met with in only 6 per cent of the aerobic cultures. As a rule these could easily be recognized as such, and in practice did not hamper the deductions which could be drawn from the cultural results.

Controls.—Cultures were taken from the blood, and, where possible, from uninjured bone, for the reason that in an established streptococcal septicæmia the organism present in the blood can be recovered both from uninjured bone and from the damaged bone beyond the limits of local penetration.

The room in which the investigations were carried out was on a medical floor, and had never been used as a surgical ward, aerial contamination of the cultures by pyogenic organisms derived from septic wounds can therefore be excluded.

Recording of Results.—After taking samples for culture, each section of bone is put aside in order, and from these a diagram is reconstructed to scale later. It is important to preserve these sections for future reference, and to clean them thoroughly in order to trace minute fissures concealed by the periosteum and to obtain more precise measurements.

The following method has been found useful for rapidly cleaning sections of bone in order to study points of detail: Remove soft parts, and place in 50 per cent liquor sodæ chlorinatæ (B.P.) for twelve hours. Immerse in water at 80° C. for fifteen minutes. Replace in liquor sodæ chlorinatæ for two periods of half an hour each, with alternate washings in water at 80° C. Bleach in H_2O_2 for twenty-four to forty-eight hours. Immerse in rectified spirit, and dry.

Each transverse section is traced on a glass plate, from which the tracing is transferred to paper, and a note is made of the colour and appearance of the bone at the level of section. Bruising is indicated on the diagram by darker stippling. The levels of section are numbered in sequence away from the fracture for convenience of reference, although they are actually cut in the reverse order (see *TECHNIQUE*).

The direction, up or down, of each bacteriological sample is indicated on the diagram representing the whole bone, its size and position being defined by the tracing.

A centimetre scale is attached to the diagrams, but owing to an obliquity of some of the sections, which has not been reproduced, and to the difficulty of estimating the depth of each scoop, there is an occasional error of a fraction of a centimetre in the distance of a sample from the fracture. For the sake of uniformity this has been neglected, and measurements have been given to a millimetre in all cases.

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The bacteriological findings are represented by the following conventional signs —

Growth resulting from direct penetration of organisms from the fracture.

Growth of septicæmic origin.

Sterile.

Other conventional signs used are · A = Main fracture. A¹ = Fissure extending from main fracture. B = Foreign body

For the permanent recording of colour, the most suitable medium is a good water-colour sketch. This must be made as quickly as possible, on account of the rapidity with which the colours of fresh bone change. The Kaiserling method, in our experience, has the limited advantage of differentiating bruised from normal bone, but has proved inadequate to preserve the natural colours. Klotz and Maclachlan's modification of the Jores method gives better results.*

III. SPREAD OF INFECTION FROM THE FRACTURE.

Within the time limits of this investigation—that is, the first six weeks after infliction of the wound—infection of bone is met with in two forms, penetration by organisms without suppuration, and spreading suppurative osteomyelitis. For this reason the term infection is used in this paper to imply the presence of bacteria in bone as demonstrated by culture, without reference to their fate or to the reactions they excite. Since pathological states intermediate between these two stages of infection have not been observed, we have employed the term penetration to signify a demonstrable progression of bacteria through bone away from a fracture. The term does not imply the co-existence of inflammation.

Penetration has proved to be the chief manifestation of infection in the material examined, to the extent that only one instance (*Case 22*) of spreading suppurative osteomyelitis has been met with out of 37 bones investigated. The rarity of suppurative osteomyelitis is due to the fact that the missile itself establishes some drainage of the bone simultaneously with the implantation of the infective agent—that is, the infection is from the first an open one, in contrast with the closed infection of osteomyelitis as met with in civil experience.

Varieties of Bacteria Isolated from Bone.—With few exceptions, the bacteria isolated from freshly examined material fall into four groups, streptococci, staphylococci, anaerobic bacteria, and coliform bacilli. The frequency of occurrence of these groups is shown in *Table 1*, in which also will be found data relating to the bacterial content of wounds and of joints during a comparable period of their surgical history. The figures for wounds have been reduced from data published by Captain A. Fleming ("On the Bacteriology of Septic Wounds," *Lancet*, September 18, 1915).

* Adam and Judah, *International Association of Medical Museums*, Bull. v, June 1, 1915.

Table 1.—SHOWING THE FREQUENCY OF OCCURRENCE OF BACTERIAL GROUPS IN BONES, WOUNDS, AND JOINTS, EXPRESSED AS PERCENTAGES (ACTUAL NUMBERS IN BRACKETS).

INFECTION	BONES	WOUNDS (<i>Fleming</i>)	JOINTS
Streptococcus..	33.6 (86)	35.4 (177)	55.5 (15)
Staphylococcus	23.3 (25)	15.0 (75)	25.8 (7)
Anaerobes	23.3 (25)	34.6 (173)	7.4 (2)
<i>B. coli</i>	19.6 (21)	14.8 (74)	11.1 (3)
Totals	100 (107)	100 (499)	100 (27)

Table 2.—GIVING DETAILS OF THE SOURCE OF BACTERIA ISOLATED FROM THE MATERIAL ANALYSED IN Table 1.

SOURCE	STREPTOCOCCUS	STAPHYLOCOCCUS	ANAEROBES	B. COLI
Femur .	8 bones gave 15 cultures	4 bones gave 6 cultures	6 bones gave 12 cultures	5 bones gave 13 cultures
Tibia .	5 bones gave 16 cultures	5 bones gave 8 cultures	5 bones gave 7 cultures	3 bones gave 4 cultures
Fibula ..	—	1 bone gave 1 culture	—	1 bone gave 1 culture
Os calcis	—	—	1 bone gave 2 cultures	—
Humerus	1 bone gave 2 cultures	3 bones gave 3 cultures	2 bones gave 2 cultures	1 bone gave 1 culture
Radius	—	2 bones gave 4 cultures	1 bone gave 1 culture	1 bone gave 1 culture
Ulna	1 bone gave 3 cultures	2 bones gave 3 cultures	1 bone gave 1 culture	1 bone gave 1 culture

Note on Tables 1 and 2.—The cultures from bones were derived from 59 samples taken from 29 bones (19 patients) giving a pure or mixed growth. The 29 bones examined were femur, 10; tibia, 7; fibula, 2; os calcis, 1; humerus, 4; radius, 2; ulna, 3. The material was in every case removed at operation and examined fresh, and does not include specimens from cases of streptococcal septicæmia.

The results for joints include only those cases in which not more than two bacterial varieties were isolated, since mixed growths similar to those found in septic wounds are usually obtained from cases of extensive injury where the joint forms part of the primary wound, and where consequently there is no question of selection of the originally implanted bacteria.

Reviewing these results, it would seem that selection of the soil bacteria inoculated at the time of entrance of the missile takes place in the tissues, the process of selection affecting particularly the group of anaerobes. Thus, in wounds providing a nidus for growth of micro-organisms in muscle, anaerobes form a large proportion of the bacterial contribution, the proportion decreasing in bones, and still more so in joints. It may be that in the case of joints the suitability of the effusion as a culture medium is an additional factor determining the selection. These considerations are essential to the study of the sequence of infection in cases of fracture involving joints.

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It has already been noted, and the point deserves emphasis, that in cases of streptococcal septicæmia, the streptococcus can be isolated from fractured bones beyond the limit of local penetration, and even from uninjured bones. A partial examination without a blood-culture control made in ignorance of this fact, might easily lead to erroneous interpretations regarding the spread of infection. It is naturally difficult to decide whether the streptococcus in these cases merely resides in the blood-vessels of the bone marrow, or whether in addition some local multiplication in the perivascular tissue has taken place. The constancy with which positive cultures are obtained renders possible the latter supposition (see *Case 13*, and *Cases 5, 15, 16*, Appendix I). The results obtained in *Case 15* suggest that, in spite of general septicæmic invasion of a bone, a progressive extension of streptococcal infection from the site of injury is demonstrable from the number of positive cultivations in a variety of media, dependent on the number of cocci present in the material implanted in the culture tubes. The culture results in this case are tabulated below.

Table 3.—Case 15 (Fig. 256).

SPECIMEN TAKEN FOR CULTURE	SITUATION RELATIVE TO FRACTURE	GROWTH IN		
		AEROBIC BROTH	ANAEROBIC BROTH	ANAEROBIC MILK
Femur 1	Lower fragment in fissured portion	+	+	+
„ 2	Lower fragment at limit of fissure	+	+	+
„ 3	Lower fragment 2.1 cm. beyond fissure	+	0	+
„ 4	Lower fragment 7.8 cm. beyond fissure	+	0	0
„ 5	Upper fragment 3.4 cm. from fracture	+	0	0

+ = Growth of streptococcus.

The *B. pyocyaneus* and *B. proteus* were not often encountered, the former having been found in only 3 samples out of 112 yielding cultures (2.6 per cent)—see *Case 17*, and the latter in 2 out of 112 samples (1.7 per cent)—see *Case 14*.

From two bones in which necrosed comminuted cancellous tissue was present on the surface of the fracture, a number of aerobic bacteria, probably associated with putrefaction, and giving unfamiliar reactions, were isolated. As this phase of infection is not typical of the series of cases investigated, an account of the bacteriological findings need not be given.*

Examples of Penetration through Normal Bone.—The simplest conditions under which penetration of bone can be studied are those obtaining at the end of an open amputation stump where the patient is in good

* Notes on the cultural reactions of staphylococci and *B. coli* isolated from bone will be found in Appendix II.

condition, the trauma confined to the actual surface of section, the blood-supply intact, and the infection limited to the ordinary pyogenic organisms found in wounds.

FIG. 212.

FIG. 213.

FIG. 214.

FIG. 212.—Case 7. Tibia from flapless amputation exposed to infection about 10 days. Organisms confined to cut surface. Gutter wound of anterior aspect of upper end has allowed penetration of organisms to 2 cm.

FIG. 213.—Case 7. Transverse section of tibia at level of (1), (2), (3). A, Fracture.

FIG. 214.—Case 7. Fibula from flapless amputation exposed to infection for about 10 days. Organisms confined to cut surface.

Table 4.—Case 7.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA*	ANAEROBIC BACTERIA*
Tibia 1 . . .	0.5 cm.	{ Streptococcus Staphylococcus Yeast	+ (including <i>B. perfringens</i>)
" 2 . . .	2.0 "	Streptococcus	0
" 3 . . .	4.5 "	0	0
" 4 . . .	2.5 "	0	0
" 5 . . .	Surface	{ Streptococcus Staphylococcus <i>B. mycoides</i> Yeast	+ (including <i>B. perfringens</i>)
" 6 . . .	1.5 cm.	0	0
" 7 . . .	3.5 "	0	0
Fibula 1 . . .	Surface	Staphylococcus	—
" 2 . . .	2.0 cm.	0	—
" 3 . . .	4.1 "	0	—
" 4 . . .	6.5 "	0	—
Knee-joint at amputation		Streptococcus	0
Blood from vein at amputation		0	—

Exposure of bone to sepsis.—About 10 days.

Amputation.—June 2, 1916, 11.20 p.m.

First culture taken from bone.—June 3, 12.40 a.m.

Last culture taken from bone.—June 3, 2.5 a.m.

Order of cultures.—Fibula 1, 2, 3, 4. Tibia 3, 2, 1, 4, 7, 6, 5.

* In this and the following tables, + = Growth of anaerobes ; 0 = Absence of growth , — = Culture not made.

Case 7—Lieut. A., age 25. [*Ref. No.* 202.]

Lesion.—Gutter of articular border of tibia, involving knee-joint.

Clinical History.—Flapless amputation 12 cm. below knee-joint at casualty clearing station for bomb wounds of leg. Re-amputation above knee at base hospital for streptococcal arthritis of knee (*Figs.* 212, 213, 214).

These bones show that in amputation through normal shaft under the simplest conditions, organisms do not penetrate far below the surface. The invaded bone is, however, softened, and this process of penetration by organisms is possibly associated with the formation of the superficial sequestrum which frequently separates at a later date. (See *Case 6*, Appendix I, for similar conditions in cancellous tissue, and *Case 8*, Appendix I, in which the conditions as regards the bone were identical, but in which drainage of the soft parts was not sufficiently free to allow of saving the limb.)

FACTORS INFLUENCING PENETRATION OF BONE BY BACTERIA.

Analysis of the material examined shows that a number of factors operate to influence the process of penetration, and that they are frequently found in varying combinations. The discussion of the factors which have been kept in view as possibly influencing penetration is arranged as follows —

1. Structural and anatomical variety of bone.
2. Extent and degree of injury.
3. Types of bacteria.
4. Infection of the surrounding soft parts.
5. Diminution of blood-supply
 - a. Local: Interruption of the main artery of the limb, Interruption of the chief artery to the bone, Interruption of the medullary artery at the site of fracture.
 - b. General. Death, Hæmorrhage following operation, and Secondary hæmorrhage.
6. Surgical treatment of wounds.
 - a. Penetration in fracture with untreated bone Early; and Late.
 - b. Penetration with obstruction of drainage: (i) Influence on penetration of inadequate drainage of soft parts, (ii) Influence on penetration of inadequate drainage of bone.
 - c. Penetration in presence of undrained fissure.
 - d. Penetration in well-drained bone with reinforcement of sepsis from the soft parts.
 - e. Absence of penetration with free drainage of bone and soft parts.
7. Time.

1. Influence of the Structural and Anatomical Variety of Bone.—We have found no evidence that the marrow of the shaft differs materially in its reaction to penetration from the cancellous bone of the articular ends, nor has any difference been noted between individual bones.

2. Influence of the Extent and Degree of Injury.—In untreated cases, while the whole surface of the fracture is potentially a source of penetration, the actual track or resting-place of the missile is the most favourable

point of departure, on account of the presence of infected débris on the surface of the bone. If this is removed, there is no evidence that the subjacent bruise facilitates penetration.

3. Estimate of the Power of Penetration possessed by each Bacterial Group.—Since the frequency-data presented in *Table 1* are based on the results of cultivating at various distances from the site of the fracture, they may be presumed to give an indication of the penetrating capacity of the invading bacteria. Direct evidence is obtainable by measurement of the extreme limit of penetration in a series of cases, and by taking an average for each group of organisms. This has been done, with the following results (three bones giving very mixed growths are excluded) (a) The average distance of penetration of the streptococcus in ten cases is 2.0 cm. (b) The average distance of penetration of the staphylococcus in ten cases is 1.5 cm. (c) The average distance of penetration of anaerobes in six cases is 0.8 cm. (d) The average distance of penetration of *B. coli* in three cases is 0.7 cm. The two sets of observations are mutually confirmatory, and justify the conclusion that they are an expression of the penetrating capacities of the bacterial groups concerned. Cases 9 and 10, Appendix I, illustrate the low penetrating power of *B. coli*.

It has not been possible to make an exact study of the anaerobes met with in bone, but it is apparent that the *B. perfringens* has less tendency to penetrate bone than other types of anaerobe. Thus, of 20 bones examined, out of 16 cultures growing anaerobes from the surface of the lesion, 8 yielded *B. perfringens* (50 per cent), while out of 29 cultures growing anaerobes at various levels, *B. perfringens* was present in 7 (24 per cent).

4. Infection of Soft Parts.—It is evident that penetration in fractured bone cannot be dissociated from the conditions as regards infection of the surrounding soft parts, since the primary lesion of the bone is an integral part of the wound, and is therefore liable to receive reinforcement of sepsis from inadequately drained recesses. This question is intimately connected with the influence of surgical treatment of the wound on penetration, and its further discussion here is unnecessary.

5. Effect of Diminution of the Blood-supply.—As in the soft parts, any considerable diminution of the blood-supply to bone is immediately reflected in an increased growth of bacteria, especially anaerobes. There are two conditions under which this occurs, namely (a) Local diminution; (b) General diminution.

a. LOCAL DIMINUTION OF BLOOD-SUPPLY.

1. Interruption of the Main Artery of the Limb.

Case 11.—Major S., age 33. [Ref. No. 206.]

Lesion.—Perforating high-explosive shell wound of elbow, with superficial fracture of under surface of coronoid process of ulna.

Clinical History.—Dec. 25, 1916, severe multiple wounds. Elbow track cleaned out at casualty clearing station, and brachial artery tied. Elbow remained normal till Jan. 16, 1917, when patient complained of severe pain in joint, which showed the physical signs of acute arthritis. Immediate resection of head of ulna and radius. Humerus intact, not interfered with.

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Examination of Parts Removed, Jan. 16.—Under surface of coronoid process bare. No breach of cartilaginous surface of ulna. Capsule soft and infiltrated

FIG. 215.—*Case 11.* Olecranon process removed by operation 22 days after injury. Temporary interference with blood-supply by ligature of brachial artery.

where attached to edge of coronoid process, and infection probably reached joint by this route (*Fig. 215*).

Table 5.—*Case 11.*

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Ulna 1	In fissure	Streptococcus	0
" 2	1.6 cm.	"	0
" 3	2.5 "	"	0
Elbow-joint at operation		"	0
Blood from vein, Jan. 12		0	—
" " Jan. 21		0	—

Exposure of bone to sepsis.—22 days.

Resection.—4.0 p.m.

Bone in ice.—From 4.5 p.m. to 5.45 p.m.

First culture taken from bone.—6.10 p.m.

Last culture taken from bone.—6.21 p.m.

Order of cultures.—3, 2, 1.

Owing to the ligature of the brachial artery in the wound in this case, the blood-supply of this portion of the bone was temporarily interfered with, although at no time was there any serious inadequacy of the circulation through the forearm.

ii. *Interruption of the Chief Artery to the Bone.*—Two cases of wounds of the os calcis illustrate this point, the wounds and general condition of the patients being sufficiently similar to eliminate any other influence adequate to explain the discrepancy. The blood-supply of this bone is derived almost entirely from the posterior tibial artery. Where this artery was intact (*Case 12*), penetration was limited to the immediate neighbourhood of the fracture. Where the artery was divided (*Case 13*), penetration of organisms was found throughout the whole bone.

Case 12.—Lieut. L., age 22.

Lesion.—Perforating shell-wounds of ankle. Compound fracture of tibia, fibula, astragalus, and os calcis. Ankle-joint open. Astragalo-calcanean joint full of blood.

Clinical History.—Wounded Sept. 15, 1916, at night. Wounds packed with gauze at casualty clearing station. On arrival at base hospital, very ill, skin jaundiced, partly conscious. Amputation 15 cm. above malleoli on Sept. 18 at 11.0 a.m., two and a half days after infliction of wound. Death two hours later.

Clinical Picture.—Anaerobic toxæmia.

Examination of Foot, Sept. 18, 5.40 p.m.—Perforating wound at level of inferior tibiofibular joint, involving both bones, opening ankle, and grazing astragalus. This wound contained mud and cloth beneath the gauze pack. Separate perforating

FIG. 216.

FIG. 216.—Case 12. Os calcis with perforating shell-track removed by amputation 2½ days after injury. Posterior tibial artery intact. Penetration to 0.5 cm.

FIG. 217.

FIG. 217.—Case 12. Tibia with gutter fracture, same limb as Fig. 216. Penetration to 1 cm.

wound of os calcis, with entry below posterior end of sustentaculum tali, and exit at peroneal spine. Soft parts of foot swollen, but not gangrenous. No gaseous cellulitis. (Figs. 216, 217, and 208.)

Table 6.—Case 12.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Tibia 1	1.0 cm.	Staphylococcus	+
" 2	4.2 "	0	0
Calcaneum 1	Surface	0	+
" 2	0.5 cm.	0	+
" 3	1.8 "	0	0
Blood from vein at amputation		0	+

Exposure of bone to sepsis before amputation.—2½ days.

Bone in ice.—From 11 a.m. to 5.30 p.m.

First culture taken from bone.—5.40 p.m.

Last culture taken from bone.—6.30 p.m.

Order of cultures.—Tibia 1, 2. Calcaneum 3, 2, 1.

Note.—The bacillus isolated in pure culture from the blood and from Tibia 1 and Calcaneum 2 was a non-proteolytic anaerobe morphologically resembling *B. perfringens*, but differing from it in not producing the 'stormy fermentation' reaction in milk.

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Case 13.—Lieut. R., age 41.

Lesion.—Multiple high-explosive shell wounds. Right foot Anterior half shattered. Right leg Perforating flesh wound 10 cm. above ankle, dividing posterior tibial artery Right knee Small penetrating wound, with shell fragment embedded in internal condyle of femur. Other minor flesh wounds.

Clinical History.—Wounded Oct. 22, 1916. Operation at casualty clearing station, Oct. 23, confined to cleaning all flesh wounds and disarticulation at right tarsometatarsal joint. Right knee not touched. Arrived at base Oct. 27. Temperature 102.4°. pulse 120. Right knee quiet. Amputation in lower third of thigh for streptococcal arthritis, Oct. 29, 11.25 a.m. Death Oct. 30, 5.30 a.m.

Clinical Picture.—Septicæmia.

FIG. 218

FIG. 218.—*Case 13.* Os calcis with shell wound of tuberosity removed by amputation 7 days after injury. Posterior tibial artery divided. Penetration of whole bone by anaerobes. (Cf. Fig. 216.)

FIG. 219.—*Case 13.* Lower end of femur removed by amputation 7 days after injury. Streptococcus in blood recovered from all parts of bone.

FIG. 220.—*Case 13.* Tracing of transverse section of femur shown in Fig. 219. Small shell-fragment with surrounding bruise. Streptococcus in blood recovered from injured and uninjured bone. Z¹, Soft bone probably infected from shell. Z², Hard bruised bone. Growth at (1) may be a local extension from shell.

FIG. 219.

FIG. 220.

Examination of Limb. [Oct. 29.—Foot Surface of amputation covered with brown exudation—superficial necrosis. Foul wound of heel, with fracture of tuberosity of os calcis. No gangrene or gaseous cellulitis. Leg Septic tunnel through deep flexors, dividing posterior tibial artery Knee Skin puncture covered with small dry scab. Small hole in synovial membrane, through which the deeper part of the extra-articular track had become infected. Small shell-fragment embedded in anterior part of internal condyle at reflection of synovial membrane from bone to capsule. Surrounding bruise. Joint effusion, blood-stained. Os calcis and 14 cm. of femur examined for penetration by organisms. (Figs. 218, 219, 220.)

Table 7—Case 13.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Os calcis 1 ..	In fissure	Streptococcus, coliform bacillus	+
„ 2 . . .	0.7 cm.	Streptococcus. coliform bacillus	+
„ 3 . . .	2.1 „	Streptococcus, coliform bacillus	+
Femur 1	0.5 „	Streptococcus	0
„ 2 . . .	2.5 „	„	0
„ 3 . . .	5.5 „	„	0
„ 4 . . .	5.5 „	„	0
„ 5 . . .	8.0 „	„	0
„ 6 . . .	12.0 „	„	0
Tibia (control)	.	„	0
Knee-joint, Oct. 29 ..	.	„	0
Blood from vein 3½ hours after amputation	.	„	0

Exposure of bone to sepsis.—7 days.

Bones in ice.—From 11.45 a.m. to 5.30 p.m.

First culture taken from bone.—5.35 p.m. Last culture.—7.15 p.m.

Order of cultures.—Femur . 3, 2, 1, 4, 5, 6. Tibia. Os calcis 3, 2, 1.

iii. *Interruption of the Medullary Artery at the Site of Fracture.*—The effect of this is seen in a more extensive growth of organisms in the fragment which is cut off from the medullary artery. (See also Cases 15 and 16, Appendix I.)

Table 8.—Case 14.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Upper fragment 1 .	In fissure	Streptococcus	0
„ „ 2 .	1.5 cm.	„	0
„ „ 3 .	3.5 „	0	0
„ „ 4 .	6.3 „	0	0
„ „ 5 .	10.3 „	0	0
„ „ 6 .	0.8 „	Streptococcus	0
Lower „ 1 .	In fissure	Streptococcus, <i>B. proteus</i>	0
„ „ 2 ..	„ „	Streptococcus, <i>B. proteus</i>	0
„ „ 3 .	1.5 cm.	Streptococcus	0
„ „ 4 .	3.5 „	„	0
„ „ 5 .	5.5 „	„	0
„ „ 6 .	7.7 „	0	0
Femur (control)	.	0	0
Blood from vein, Feb. 20	..	0	—

Exposure of bone to sepsis.—81 days.

Amputation.—March 8, 2.30 p.m.

Bone in ice.—From 2.30 p.m. to 3.35 p.m., March 8.

First culture taken from bone.—3.50 p.m. Last culture.—5.0 p.m.

Order of cultures.—Lower fragment . 6, 5, 4, 3, 2, 1. Upper fragment : 6, 5, 4, 3, 2, 1. Femur.

Case 14.—Sec. Lieut. B., age 28. [Ref. No. 207.]

Lesion.—Multiple high-explosive shell wounds. Abdomen Penetrating upper end of left linea semilunaris, no evidence of visceral injury. Sterile secondary effusion into left pleura. Left forearm. Extensor tendons of wrist divided; cellulitis of hand; fracture of olecranon. Right hernia testis. Left leg: Compound fracture of tibia and first metatarsal. Many minor wounds.

Clinical History.—Wounded Feb. 5, 1917 All wounds opened up and drained same day at casualty clearing station. Transferred to base Feb. 21. Still profoundly septic. Pockets of pus opened on two occasions. Amputation of left leg above knee was followed by rapid improvement in general condition and healing of all wounds. Transferred to England March 22.

Examination of Limb, March 8.—Three wounds of tibia. Main fracture exposed in wound of anterior aspect of leg. Bone dry and dead-looking where visible. Soft parts adherent to bone right up to fractured ends. No pocketing of pus. Muscles of leg cedematous, with commencing fibrosis in neighbourhood of fracture. Anterior and posterior tibial vessels intact. Upper and lower tibial wounds are small cracks at bottom of suppurating sinuses. (Fig. 221 and Table 8.)

b. EFFECT OF GENERAL DIMINUTION OF BLOOD-SUPPLY.

1. *Death.*—The gradual failure of circulation which not uncommonly allows the extremities to become cold for many hours before death, is particularly favourable to the growth of anaerobes and other saprophytes. (See Case 4 (Fig. 247), Appendix I, of amputation followed by death, with anaerobic penetration of 24 cm., and contrast it with Case 7 (Fig. 212), of surviving amputation, with anaerobes confined to surface.)

FIG. 221.—Case 14. Fractured tibia removed by amputation 31 days after injury. Penetration greater in lower than in upper fragment, owing to difference of blood-supply. A¹, Fissures. A², Small fracture with no penetration at L⁶. A³, Small fracture with penetration at U⁶. Foramen for medullary artery near U⁴. U, Upper fragment. L, Lower fragment.

2. *Hæmorrhage*.—After severe hæmorrhage the resistance of bone to penetration is reduced in association with the general diminution of the circulation.

1. *Hæmorrhage following Operation.*

Case 17—Lieut. L., age 28. [*Ref. No. 208.*]

Lesion.—Superficial gutter of articular border of internal tuberosity of tibia, with tear of semilunar cartilage. Tangential blow by fragment of high-explosive shell, which remained extracapsular.

Clinical History.—Wounded July 3, 1916, 1 a.m. On July 6 arrived at base, 3 days 7 hours after being wounded. Joint effusion, consisting of blood-stained synovia contained staphylococcus.

First operation, July 6, 6.30 p.m. (3 days 17½ hours after wound).—Local excision of track, shell-fragment, fracture, and portion of semilunar cartilage. Joint closed after irrigation.

Second operation, July 12, 9.30 p.m. (9 days 20 hours after wound).—Resection of knee-joint, including the whole of tibial fracture. Joint effusion consisting of pus—staphylococcus.

July 13, cavity packed with gauze on account of persistent oozing of blood. July 16, pyocyaneus infection of cavity.

Third operation, July 18 (6 days after resection).—Amputation through resection wound.

Aug. 15, transferred to England. April, 1917, garrison duty abroad.

Examination of Limb after Removal, July 18.—(Edema of subcutaneous tissue. Muscles macroscopically normal. No pus outside resection cavity (*Figs. 222, 223, and Table 9*).

FIG. 222.

FIG. 222.—*Case 17*. Tibia—showing portions removed by resection and amputation. A, Original surface-wound from which no penetration occurred in ten days. After severe hæmorrhage which followed resection organisms penetrated to at least 10 cm.

FIG. 223.—*Case 17*. Tracing from lower surface of resected portion of tibia shown in Fig. 222. No penetration in 10 days.

FIG. 223

This case illustrates the different degrees of penetration by organisms before and after a severe hæmorrhage. In the resected portion of the bone there was a fracture infected presumably by the staphylococcus, since that organism was present in the joint. After a period of nearly 4 days, during which penetration was possible, the surface of this fracture was removed entire by the gouge to a depth of 2 to 3 mm. After a further period of 6 days, during which the clinical appearance of a mild infection was present in the

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wound, examination of the resected portion of bone showed that penetration of organisms had not reached a depth of 0·6 cm. (i.e., penetration was less than 1 cm. in 9 days). After the hæmorrhage there was penetration to at least 10 cm. in 6 days. It must, however, be pointed out that we have no knowledge of the penetrating power of *B. pyocyaneus*.

Table 9.—Case 17

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Tibia resection 1	0·6 cm.	0	0
" " 2	2·8 "	0	0
" " 3	5·4 "	0	0
" amputation 4	Surface	Staphylococcus, <i>B. pyocyaneus</i>	0
" " 5	2·0 cm.	Staphylococcus, <i>B. pyocyaneus</i>	0
" " 6	9·5 "	<i>B. pyocyaneus</i>	0
Blood from vein, July 24		0	—
Knee-joint, July 6 and July 12		Staphylococcus	0

Exposure of tibia to sepsis between date of wound and date of resection of knee.—9 days.

Exposure of tibia to sepsis between resection and amputation.—6 days.

Resection.—10.30 p.m.

Bone in ice.—From 10.35 p.m. to 12.15 a.m.

First culture taken from bone.—12.25 a.m.

Last culture taken from bone.—12.35 a.m.

Order of cultures.—8, 2, 1.

Amputation.—5.45 p.m.

Bone in ice.—From 6.40 p.m. to 11.25 p.m.

First culture taken from bone.—11.30 p.m.

Last culture taken from bone.—12 midnight.

Order of cultures.—6, 5, 4.

ii. Secondary Hæmorrhage.

Case 15, examined twenty-four hours after severe *secondary hæmorrhage*, is described in Appendix I. Owing to division of the medullary artery, it is not possible to estimate the effect of the secondary hæmorrhage in the production of the extensive penetration observed.

6. Influence of Surgical Treatment of Wounds on Penetration.—

The results obtained from the study of the material which forms the basis of this communication do not represent the natural history of untreated gunshot fracture. In the majority of cases it must be assumed that this has been modified by the ordinary surgical technique of cleansing and drainage of wounds.*

* By surgical cleansing is meant the removal of all dead tissue and foreign matter (mud, cloth, and missile) from a wound. By drainage is meant the establishment of free communication of all parts of the wound with the surface. The aim of these procedures is to prevent the saprophytic growth of bacteria in wounds which precedes parasitic invasion of the living tissues.

In none of the cases was any attempt made to bring about surgical sterilization of the wound by the continuous or intermittent instillation of antiseptics. The ordinary routine was as follows —

Soft Parts. The wound was excised or opened freely so as to allow of either gravity drainage by tubes, or gauze drainage of a funnel-shaped wound.

Bone. All comminuted cancellous tissue lying on the surface of the bone wound was removed by gouge or curette, on the assumption that such bone was killed by the direct effect of the missile, and consequently formed a suitable nidus for bacteria. The firm bruised portion was not removed. The treatment as a whole constitutes in effect the establishment of drainage for the bone.

a. PENETRATION IN FRACTURE WITH UNTREATED BONE.

The following represent (i) Early, and (ii) Late stages in the evolution of an untreated septic fracture —

i. *Early Stage.*—This is shown in *Case 18*. Appendix I.

FIG. 224.

FIG. 226.

FIG. 227.

FIG. 224.—*Case 19.* Femur removed by amputation. No surgical interference with actual fracture. Growth throughout bone. A, Fracture.

FIG. 225.—*Case 19.* Transverse section of femur shown in *Fig. 224* at level of (2). Growth throughout bruised and uninjured bone.

FIG. 226.—*Case 19.* Transverse section of upper end of tibia, showing penetration from small untreated fracture (indicated by arrow): Specimen 1 taken from indirect bruise beneath superior fibular facet. Specimen 2 in *Table 10* was from opposite tuberosity 2 cm. lower.

FIG. 227.—*Case 19.* Fibula showing fracture of head, and associated penetration.

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ii. *Late Stage*.—In the following case, and in Case 20, Appendix I, the interval which elapsed between wound and amputation is not known with certainty. From the data available it was between 7 and 14 days. In both cases the flesh wound had been partially opened up, but the bone had clearly not been interfered with in any way.

Case 19.—Pte. P.

Clinical History.—Amputation in lower third of thigh for suppurative arthritis of knee. Early tetanus with local spasm.

Examination of Limb after Removal.—Vertical gutter wound on outer side of knee, extending from upper border of patella to level of tibial tubercle. In the upper third of this was the mouth of a sinus leading down to a gutter fracture of the external condyle of the femur (Fig. 224). In the lower third was the mouth of a similar sinus leading to a small wound of the external tuberosity of the tibia. Behind this sinus the comminuted head of the fibula lay bare in the wound. Pus tracks from femur, 4 cm. upwards, deep to vastus externus; from tibia, one-third down leg, in anterior tibial compartment; from fibula, 5 cm. downwards, in subcutaneous tissue.

Knee-joint no tension, free exit of pus through sinuses; articular cartilage—white, intact, synovial membrane—superficial sloughing, effusion—yellow pus; extracapsular extension of pus—nil, popliteal space—intact, no foreign body. (Figs. 224, 225, 226, 227.)

Table 10.—Case 19.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Femur 1	Surface	Streptococcus, coliform bacillus, Gram + diplococcus	+ (including <i>B. perfringens</i> and tetanus-like bacillus)
„ 2	1.4 cm.	Streptococcus, coliform bacillus, minute Gram + diplococcus, minute Gram + staphylococcus	+
„ 3	4.7 „	Streptococcus, coliform bacillus, minute Gram + diplococcus, minute Gram + staphylococcus	+ (including tetanus-like bacillus)
„ 4	2.8 „	Coliform bacillus, minute Gram + staphylococcus	+
„ 5	6.1 „	Coliform bacillus	0
„ 6	11.0 „	Coliform bacillus	0
Tibia 1	3.3 „	Coliform bacillus, Gram + diplococcus, Gram + slender bacillus in chains	+
„ 2	3.5 „ (about)	Coliform bacillus, Gram + diplococcus, Gram + slender bacillus in chains	+ (including <i>B. perfringens</i>)
Fibula 1	3.6 cm.	Coliform bacillus	0
„ 2	10.2 „	0	0
„ 3	15.6 „	0	0
Knee-joint		Streptococcus, coliform bacillus	+ (including <i>B. perfringens</i>)

Amputation.—June 23, 1916, 11.40 a.m.

Limb in ice.—From 12 noon to 3.30 p.m., June 23.

First culture taken from bone.—4.0 p.m.

Last culture taken from bone.—7.0 p.m.

Order of cultures.—Femur 6, 5, 4, 1, 3, 2. Tibia 1, 2. Fibula 1, 2, 3.

This case, and *Case 20*, Appendix I, suggest that the presence of the dead comminuted surface-layer of cancellous bone facilitates the growth of a mixture of organisms, and that, in consequence of the unchecked proliferation on such a surface, extensive penetration occurs.

b. PENETRATION WITH OBSTRUCTION OF DRAINAGE.

As a general principle it may be stated that, in a septic flesh wound infiltration of the walls by organisms is in inverse proportion to freedom of drainage.

FIG. 228.

FIG. 230.

FIG. 229.

FIG. 231.

FIG. 228.—*Case 21*. Size and position of tibial wound (surface gutter).

FIG. 229.—*Case 21*. Tracing of transverse section through tibial wound shown in Fig. 228. Removed by amputation 16 days after injury. No penetration with free drainage. A, Wound.

FIG. 230.—*Case 21*. Size and position of femoral wound. Obstruction of drainage by knee-joint between fracture and surface.

FIG. 231.—*Case 21*. Tracing of section of femoral condyle through wound shown in Fig. 230. Penetration to at least 2·8 cm. from wound with obstructed drainage. Limit not reached.

In bone wounds, apart from untreated fractures, it is difficult to obtain examples of obstruction of drainage, for the reason that only some unusual combination of circumstances can afford the opportunity.

The following have been met with in our experience :—

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1. Influence on Penetration of Inadequate Drainage of Soft Parts.

Infected amputation stump closed by suture of the flaps (Case 4, Appendix I). The primary effect of closure of the stump on penetration was overshadowed by the terminal stages of the disease.

Interruption of the drainage track by an infected joint through which a continuous feed of streptococcus led to increase of penetration (Case 21). This case affords a comparison between two similar wounds with different degrees of drainage in the same patient. The tibial wound was close to the surface, well open, and had had the superficial damaged bone removed by curetting. The femoral wound communicated with the surface by a narrow track, across the course of which lay the infected knee-joint. The drainage of this wound was not only obstructed, but a continuous reinforcement of its surface infection took place from the neighbouring joint. The foreign body and superficial layer of damaged bone had not been removed.

Case 21.—Major G., age 36. [Ref. No. 211.]

Lesion.—Small surface gutter of tibia, not communicating with knee-joint. Small perforating wound of knee-joint, with crack of external condyle of femur near attachment of lateral ligament. Shell fragments in both bones. Numerous other wounds from fragments of high-explosive shell.

Clinical History.—Wounded June 2, 1916. No operation before arrival at base on June 4, when all wounds except that into knee-joint were opened up, cleaned, and foreign bodies removed. Aspiration of knee-joint on account of increased effusion turbid yellow fluid—streptococcus—June 12. Tibial wound excised and bone curetted. Track to knee-joint excised. HClO irrigation. Synovial membrane closed. Wound packed June 14. Amputation above knee June 18, 2.30 p.m. Transferred to England July 4. (Figs. 228, 229—Drainage good. Figs. 230, 231—Drainage obstructed.)

Table 11.—Case 21.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Tibia 1	0.7 cm.	0	0
" 2	2.4 "	0	0
" 3	5.2 "	0	0
Femur 1	0.2 "	Streptococcus	0
" 2	2.8 "	"	0
Knee-joint, June 12		"	0
" June 13		"	0
" June 16		"	0
Blood from vein at amputation		0	0

Exposure of bones to sepsis.—16 days.

Dissection of limb commenced.—3.0 p.m., June 18.

Last culture taken from bone.—5.20 p.m.

Order of cultures.—Tibia. 3, 2, 1. Femur 2, 1.

ii. Influence on Penetration of Inadequate Drainage of Bone (Case 22).

In this case three bones opened into a single septic cavity, but while the drainage of the radius and ulna was as complete as possible, that of the humerus was limited to a small opening in the articular surface.

FIG. 232.

FIG. 232.—Case 22. Lower part of humerus removed by amputation 18 days after injury, showing small fractures. Purulent cancellous osteitis at level of section due to obstructed drainage of bone. Pure staphylococcus infection.

FIG. 233.—Case 22. Forearm bones removed by amputation radius 16 days after resection of uninjured head, ulna 18 days after gunshot fracture. Penetration limited to 4 cm., absence of macroscopic osteitis associated with free drainage of bones.

FIG. 233.

Table 12.—Case 22.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Humerus	At level of section of condyles	Staphylococcus	0
Radius 1	Surface	"	0
" 2	2.0 cm.	"	0
" 3	4.0 "	"	0
Ulna 1	Surface	"	0
" 2	1.2 "	"	0
" 3	3.2 "	0	0
Elbow-joint, May 30		Staphylococcus, <i>B. coli</i>	0
" May 31		" "	0

Exposure of bones to sepsis.—Radius, 16 days, humerus and ulna, 18 days.

Amputation.—5.15 p.m. Humerus culture taken.—5.15 p.m.

First culture taken from radius.—6.30 p.m. Last culture taken from ulna.—7.5 p.m.

Order of cultures.—Humerus. Radius 1, 2, 3. Ulna 1, 2, 3.

Direct smear from sawn humerus showed pus cells and staphylococci.

The original tube of Radius 3 containing the bone-fragment grew, whilst a sample sub-cultured at once from this did not, showing that few organisms were present, and suggesting that this section was near the limit of penetration.

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Case 22.—Lieut. G., age 22. [Ref. No. 212.]

Lesion.—High-explosive shell wound over olecranon process. Comminution of upper extremity of ulna. Chip from edge of trochlea of humerus. Radius uninjured.

Clinical History.—Wounded May 13, 1916, at night.

Operation, May 15.—Resection of comminuted portion of ulna and head of radius. Chipped edges of trochlea curetted. Exposed cancellous bone of humerus bruised. Drainage and irrigation of wound. Second operation, May 31.—Purulent cancellous osteomyelitis of humerus. Pus extended to upper limit of cancellous bone. Lower part of medulla looks infected, but is not purulent. Healthy bleeding marrow reached at middle of shaft. Amputation at this level, 5.15 p.m. Transferred to England June 12. Sequestrectomy, July 27, Sept. 17, and Jan. 6, 1917. Discharged from hospital Jan. 22, with healed wound and useful stump.

Clinical Picture.—Osteomyelitis.

Examination of Limb, May 31, 1916. No pus apart from humerus. Œdema of arm, but not of forearm. (Figs. 232, 233, and Table 12.)

C. PENETRATION IN PRESENCE OF UNDRAINED FISSURE.

Case 23.—Lieut. C., age 40. [Ref. No. 213.]

Lesion.—Fracture of external condyle of humerus, with crack into elbow-joint. Other minor flesh-wounds from high-explosive shell.

Clinical History.—Wounded Dec. 12, 1916. Shell fragments removed at base Dec. 16. Local operation on elbow wound, drainage improved and fracture curetted, elbow-joint not infected Jan. 1, 1917. Resection for arthritis of elbow Jan. 14. Transferred to England Feb. 14.

Although interference with the local blood-supply in the neighbourhood of the external condyle may have facilitated penetration, the chief factor was probably the feed of organisms from the imperfectly drained fissures shown in the diagram (Fig. 234).

FIG. 234.—Case 23. Lower end of humerus removed by operation 33 days after injury.

Anterior and posterior views, and tracing from transverse section. Penetration to 1.6 cm. in presence of undrained fissures. A, Fracture.

Table 13.—Case 23.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Humerus 1 ..	0.3 cm.	Streptococcus	0
" 2	1.6 "	"	0
" 3	3.3 "	0	0
" 4	3.0 "	0	0
Ulna (control)		0	0
Blood from vein at amputation		0	0

Exposure of bone to sepsis.—33 days. Resection.—3.30 p.m., Jan. 14,

Bone in ice.—From 3.30 p.m. to 5.30 p.m., Jan. 14. [1917]

First culture taken from bone.—5.45 p.m. Last culture.—6.20 p.m.

Order of cultures.—Humerus 4, 3, 2, 1. Ulna.

d. PENETRATION IN WELL-DRAINED BONE WITH EXTENSIVE
REINFORCEMENT OF SEPSIS FROM THE SOFT PARTS.

Case 24.—Pte. H. [Ref No. 214.]

Clinical History.—Wounded May 13, 1916. Amputation May 17, 5.30 p.m.

Lesion.—Large foul wound of inner side of knee, opening joint. Comminution of internal condyle of tibia and femur.

Examination of Limb, May 17, 7.30 p.m.—Wound extended from inner border of patella to inner hamstrings. Joint widely open and contained a little brownish pus. Cartilage not eroded. No extracapsular extension of pus apart from wound, and no œdema of leg. Large foul pus-cavity extended up to level of amputation between vastus externus and femur; this was an extension from the original wound. (Fig. 235 and Table 14.)

With this last case may be compared the original tibial wound of Case 7. In both instances pus from the knee-joint flowed over the fracture on its way to the surface, and in

FIG. 235.—Case 24. Tibia removed by amputation 4 days after injury. Shell wound of internal tuberosity. Bruise extends to Section 4 (11.4 cm. from fracture). Penetration less than 3 cm. in well-drained bone with reinforcement of sepsis from soft parts.

Table 14.—Case 24.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Tibia 1 .. .	Surface	Streptococcus, coliform bacilli	+
" 2 .. .	2.9 cm.	0	0
" 3 .. .	5.5 "	0	0
" 4 .. .	11.4 "	0	0
" 5 .. .	21.0 "	0	0
Knee-joint pus		Streptococcus, coliform bacilli, Gram - cocci	+ (including <i>B. perfringens</i>)

Exposure of bone to sepsis.—4 days.

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Case 24 there was a further addition of sepsis from a large cavity in muscle. In spite of this, the freedom of drainage of the bone was adequate to prevent extensive penetration.

e. ABSENCE OF PENETRATION WITH FREE DRAINAGE OF BONE AND SOFT PARTS.

An example of this is given in the tibial wound of *Case 21*.

The series of cases described above shows that the degree of penetration is inversely proportional to the adequacy of drainage established by surgical interference. An estimate of the depth to which uncomminuted, bruised, cancellous bone requires removal by operation should be based upon a consideration of the factors which have been shown to influence penetration, especially the extent and intensity of infection of the soft parts and the length of time during which the wound has remained untreated since infliction. Bruising, *per se*, is not an indication for removal of bone.

7. Influence of Time on Penetration.—In estimating the relationship between the length of time during which a bone is exposed to infection and the degree of penetration by organisms, cases in which growth is clearly enhanced by diminution of blood-supply or by obstruction of drainage must be excluded.

In *Table 15* are grouped 16 observations on bones in which no complications are introduced by these factors.

Table 15.—SHOWING THE RELATION BETWEEN TIME AND PENETRATION.

CASE	BONE	TIME	PENETRATION	STERILE AT	ORGANISMS AT LIMIT
12	Calcaneum	2.5 days	0.5 cm.	1.8 cm.	Anaerobes
12	Tibia ..	2.5 "	1.0 "	4.2 "	Staphylococcus, anaerobes
26	Humerus	3 "	Surface	0.5 "	Staphylococcus, anaerobes
18	Femur	3.5 "	0.8 cm.	1.9 "	Anaerobes
24	Tibia	4 "	Surface	2.9 "	Streptococcus, coliform bacilli
7	Tibia	10 "	2.0 cm.	2.5 "	Streptococcus
7	Tibia (amputatn.)	10 "	Surface	1.5 "	Mixed
7	Fibula "	10 "	Surface	2.0 "	Staphylococcus
9	Tibia	14 "	0.8 cm.	4.7 "	<i>B. coli</i> , anaerobes
6	„ (amputation)	16 "	1.5 "	4.0 "	Streptococcus, staphylococcus
21	„	16 "	Surface	0.7 "	Streptococcus
8	„	23 "	2.0 cm.	11.2 „ (no section made between 2 and 11 cm.)	„
23	Humerus	23 "	1.6 "	3.3 cm.	„
25	Femur	26 "	Surface	1.5 "	„
14	Tibia, upper fragment	31 "	1.5 cm.	3.5 "	„
14	„ head	31 "	0.8 "	3.0 "	„

Although the number is too small to allow of detailed analysis, a general consideration of the table brings out two points: Firstly, cases in which organisms are confined to the surface are equally spaced over the first four weeks. The continued presence of organisms in contact with open bone does not, therefore, necessarily lead to infection of the deeper layers. Secondly, if the average depth of penetration reached in the first week be compared with the average depth reached during the succeeding four weeks, the process does not appear to be one of uncontrolled progression. Thus, the average penetration by organisms in the first week is 0.46 cm. (five observations),

FIG. 236.

FIG. 237.

FIG. 236.—Case 25. Upper surface of lower extremity of femur resected 26 days after injury.

A, Original shell-wound curetted 2 days after infliction. A¹, Fissure through which streptococcus reached knee-joint. Z¹, Granulation tissue resting on a thin layer of bone which contained pus cells and streptococcus. Z², Fibrous tissue filling cancellous spaces; deep to this the bone was softer than normal. Z³, Bone of normal consistence; red colour probably due to inflammatory hyperemia, but may be partly residual from original bruise. Beyond this, normal bone. (See key figure—Fig. 237.)

FIG. 237.—Case 25. Tracing from bone shown in Fig. 236. Z¹, Granulation tissue lining original wound. Z², Zone of sclerosed bone. Z³, Zone of hyperemia. 1, Junction of hard and softened bone. 2, Normal hard bone.

while the average additional penetration during the succeeding four weeks is 0.46 cm. (eleven observations). These figures suggest that, where penetration beneath the surface occurs, the rate is greater during the first few days than during the succeeding weeks.

Although there is no evidence as to the mechanism by which the slowing of the rate of penetration is brought about, it is natural to suppose that it is in the nature of an immunity reaction. At a later date the development of a defensive reaction associated with the process of repair is suggested by the conditions found in Case 25, the only instance met with in the series.

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Case 25.—Sec.-Lieut. B., age 22. [Ref. No. 215.]

Lesion.—High-explosive shell wound of internal condyle of femur. Fissure into knee-joint.

Clinical History.—Wounded Aug. 4, 1916. Two days afterwards the shell fragment was removed and its site curetted at a casualty clearing station. Arrived at base nine days after being wounded, with streptococcal arthritis of knee. Limb immobilized. Resection of knee-joint Aug. 30, twenty-six days after being wounded. Transferred to England. Limb still in plaster, April, 1917

Joint at Resection.—Cartilage eroded at points of pressure. Synovial membrane : surface replaced by soft granulation tissue. Effusion pus. Extracapsular extension nil. Periarticular œdema considerable.

Examination of Bone Removed, Aug. 30 (Figs. 236 and 237)—The surface illustrated in Fig. 236, when examined with a dissecting microscope, showed that the grey zone deep to the layer of granulations consisted of two areas. (1) A narrow superficial strip showing definite osteomyelitis, especially near the fissure—i.e., the cancellous spaces were filled with pus, (2) Deep to this a dense white zone, the cancellous spaces of which looked solid in contrast with the empty cancellous spaces of the adjacent red area. Considerable numbers of streptococci were found in the pus of the superficial area, and although it was difficult to obtain a good smear, none were seen in the sclerosed area. The red cancellous bone deep to the sclerosed zone was softened as far as Specimen 1, which was taken at the junction of hard and soft bone.

Table 16.—Case 25.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Femur 1 (soft bone) ..	1.5 cm.	0	0
" 2 (hard " ..	4.0 "	0	0
Knee-joint, Aug. 13		Streptococcus	0
" Aug. 21		"	0

Exposure of bone to sepsis.—26 days.

Resection.—3.30 p.m.

Bone in ice.—From 3.30 p.m. to 6.30 p.m.

First culture taken from bone.—6.40 p.m.

Last culture taken from bone.—6.45 p.m.

Order of cultures.—2, 1.

IV. EXTENSION OF INFECTION ALONG OPEN FISSURES.

A fissure whose walls are not in contact 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 of the femur, 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 either into a muscle or joint-cavity.

Organisms grow along the fissure 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 degree in the temperature chart, pulse-rate, or general

condition of the patient. As soon, however, as bacteria escape from the fissure into an adjacent muscle or joint-cavity, the clinical picture changes to that associated with pocketing or with the development of a septic arthritis.

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. Estimates of the apparent rate of travel have been founded, from a clinical point of view, 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 (see *Case 27*), and probably happens in 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 two methods are illustrated in *Cases 26* and *27*. *Case 27* also illustrates the persistence of anaerobes in a fissure after they have disappeared from the original wound.

Examination of a Fissure at an Early Stage before Extension has taken place.

Case 26.—Sec.-Lieut. B., age 35. [*Ref.* 216.]

Lesion.—Neck of humerus shattered by rifle bullet. Gas infection of soft parts.

Clinical History.—Wounded Sept. 14, 1916. Limited excision of surface wound, with tube drainage, at casualty clearing station. Rapid swelling of shoulder. X rays showed that the fissure extended to the shoulder-joint. Sepsis rapidly subsided after resection on Sept. 17, 4.15 p.m. Transferred to England Oct. 1. (*Fig. 238*).

FIG. 238.—*Case 26*. Head of humerus removed by operation 3 days after injury. Anterior and external views and section. A, Main fracture of surgical neck. A¹, Fissure, showing no extension of organisms. Whole head bruised.

Table 17.—*Case 26*.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Humerus 1	Surface	Staphylococcus	+
„ 2	0.5 cm.	0	0
„ 3	1.8 „	0	0

Exposure of bone to sepsis.—3 days.

Bone in ice.—From 4.20 p.m. to 6.10 p.m., Sept. 17

First culture taken from bone.—6.20 p.m.

Last culture taken from bone.—6.45 p.m.

Order of cultures.—3, 1, 2.

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Examination of Fissure at a Later Stage after Extension of Infection into Joint.

Case 27—Lieut. H., age 21. [Ref No. 217.]

Lesion.—Comminuted shell fracture of femur 9 cm. from lower end. Fissure into knee-joint.

Clinical History.—Wounded Aug. 18, 1916. Incisions for drainage and removal of shell fragment at casualty clearing station, Aug. 19. Further incisions for drainage at base, Aug. 21. Much laceration of thigh muscles, with severe infection. Bubbles of gas in pus from wound. The knee-joint at first had the usual quiet effusion associated with fracture of the lower third of the femur.

The first complaint of pain in the knee was on the evening of Sept. 3. The following morning it was tender and hot, with increased effusion. Aspiration yielded a turbid fluid containing the streptococcus. Amputation, Sept. 4. Transferred to England, Sept. 17.

Examination of Limb, Sept. 4.—Femur. Periosteum thickened above and around fracture. Continuity of pus along main fissure from fracture to joint. Muscles. Abscess in crureus at level of amputation, communicating with fracture. Knee-joint. Early arthritis. Synovial membrane injected. Articular cartilage unaltered. (Figs. 239, 240, 241, 242.)

Table 18.—Case 27

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Femur 1 (soft bone)	In fissure	Streptococcus, staphylococcus, <i>B. coli</i>	+ (including <i>B. perfringens</i>)
„ 2 ..	0.4 cm.	Streptococcus, staphylococcus, <i>B. coli</i>	0
„ 3 ..	1.5 „	0	0
„ 4 ..	4.1 „	0	0
Pus from wound at amputation	.	Streptococcus, staphylococcus, <i>B. coli</i>	0
Blood from vein at amputation		0	—

Exposure of bone to sepsis.—17 days.

Amputation.—9.30 p.m.

Bone in ice.—From 9.30 p.m. to 10.55 p.m.

First culture taken from bone.—11.30 p.m.

Last culture taken from bone.—12 midnight.

Order of cultures.—4, 3, 2, 1.

Table 19.—Case 27. KNEE-JOINT.

DAYS AFTER INFLECTION OF WOUND	EFFUSION	ORGANISM
7	Blood-stained, synovial	0
9	„ „	0
17	Turbid yellow, very few pus cells, the turbidity due almost entirely to organisms	Streptococcus

Table 20.—Case 27 EXAMINATION OF DIRECT SMEARS.

POINT FROM WHICH TAKEN	CELLS	ORGANISM
Femur 1, in crack at level of section of condyles	Pus	Streptococcus
Marrow, 2.5 cm. above fracture	Excess of reds	0
" 5 " " "	Fewer reds	0
" 7.5 " " "	Normal marrow	0

Description of Figs. 239, 240, 241, 242.

FIG. 239.—Case 27. Lower half of femur removed by amputation for streptococcal arthritis of knee 17 days after injury. Longitudinal section of bone, with fissure opened out to show continuity of pus from fracture to articular cartilage. A, Fracture. A¹, Fissure extending to joint. Same femur as in Figs. 240, 241, 242.

FIG. 240.—Case 27. Lower fragment of fractured femur with fissure (A¹) into knee-joint.

FIG. 241.—Case 27. Femur shown in Fig. 240 from below. A¹, Continuation of fissure through articular cartilage.

FIG. 242.—Case 27. Transverse section through condyles of femur shown in Fig. 240. A¹, Fissure in bruised condyle. Removed by amputation 17 days after injury. Penetration 0.4 cm. from fissure. Shows lateral penetration from fissure at a distance from the main fracture.

V. CONCLUSIONS.

1. From the surface of a divided or fractured bone exposed to infection, bacteria may penetrate to the deeper parts.
2. In an untreated fracture, penetration is apparently unlimited.
3. If the dead bone on the surface of the fracture is removed early, penetration is much reduced, and may not occur at all.
4. Penetration, particularly of anaerobes, is greatly increased by reduction of the circulation through the injured bone.
5. Penetration is increased by obstruction to drainage, either of the bone or of the soft parts.
6. The order of frequency and power of penetration of the bacteria found is: (1) Streptococcus, (2) Staphylococcus; (3) Anaerobes, (4) *B. coli*.
7. The rate of penetration is at its maximum during the first few days.
8. In the material examined, no difference in reaction to penetration has been noted between cancellous bone and the marrow of the shaft.
9. Bruising—an invariable accompaniment of projectile fracture—does not appear to facilitate penetration if the surface layer of debris is removed and drainage established.
10. In a septic fissure, growth of bacteria is progressive, and may lead to infection of a distant part—for example, a joint. Dissemination of infection throughout a bone takes place by penetration from its walls.

We wish to express our appreciation of the valuable help afforded us by Major J. W. West, R.A.M.C., in obtaining some of the material, of the intelligent co-operation of Private W. A. Hume (now Second Lieutenant R.F.A.), and Sergeant A. F. Collett, R.A.M.C., and also of the skilful illustrations in line and colour by Sergeant A. K. Maxwell, R.A.M.C., for whose assistance we are indebted to the Medical Research Committee.

FIG. 239.

FIG. 240.

FIG. 241.

FIG. 242.

APPENDIX I.

SUMMARY OF CONTENTS.

Post-mortem growth in bone.—*Cases 1, 2, 3.*

Effect on penetration of the circulatory conditions preceding death.—*Cases 4, 5.*

Additional examples of penetration through normal bone.—*Cases 6, 8.*

Illustrations of the low penetrating power of *B. coli*.—*Cases 9, 10.*

Additional examples of extensive penetration associated with interruption of the medullary artery.—*Cases 15, 16.*

Additional examples illustrating early and late stages of penetration in untreated septic fracture.—*Cases 18, 20.*

Post-mortem Growth in Bone (*Cases 1, 2, 3*).—The importance of using fresh material is shown by the following observations. Three limbs, amputated in the lower third of the thigh for septic arthritis of the knee, were left for 21, 28, and 28½ hours respectively at room temperature in May, at the end of which time the femurs were examined for the presence of organisms. In all three the cut end of the femur was soiled by pus from the wound, and in *Cases 2* and *3* this was the only opening by which organisms could enter the bone, in *Case 1*, owing to a fracture of the external condyle, the bone was open to infection at both ends. In *Cases 1* and *2* growth was general throughout the bone, while in *Case 3* the limit was fixed at about 11 cm. in 28½ hours.

Case 1.—Pte. R., age 26. Wounded April 24, 1916. Amputation 11.0 a.m. May 1. Examination of bone 2.30 p.m. May 2. Sepsis before amputation, 7 days. Duration of post-mortem growth, 28 hours.

Lesion.—Open septic knee-joint, with fracture and bruise of external condyle of femur (*Fig. 243*).

Table 21.—*Case 1.*

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM SOURCE OF INFECTION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Femur 1	In fissure	Streptococcus, staphylococcus	0
„ 2	1.0 cm.	Streptococcus	0
„ 3	3.7 „	„	0
„ 4	4.0 „	„	0
„ 5	2.0 „	„	0

CONCLUSION.—In 28 hours, growth to at least 5 cm., limit not reached.

Case 2.—Pte. W. Wounded April 27, 1916. Amputation 6.0 p.m. May 2. Examination of bone 2.0 p.m. May 3. Sepsis before amputation, 5 days. Duration of post-mortem growth, 21 hours.

Lesion.—Open septic knee-joint, with bruise of external condyle of femur, but no fracture (*Fig. 244*.)

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Table 22.—Case 2.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM SOURCE OF INFECTION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Femur 1	6.2 cm.	Streptococcus, <i>B. pyocyaneus</i> , <i>B. proteus</i>	0
„ 2	13.3 „	„ „	+ (including <i>B. perfringens</i>)
„ 3	14.0 „	„ „	+
„ 4	13.5 „	„ „	+

CONCLUSION.—In 21 hours, growth to at least 10 cm. , limit not reached.

FIG. 243.

FIG. 243.—Case 1. Lower end of femur with fracture and bruise of external condyle. Cut surface soiled by pus from wound. Post-mortem growth from both ends in 28 hours at room temperature.

FIG. 244.

FIG. 244.—Case 2. Lower end of femur with bruise of external condyle, but no fracture. Cut surface soiled by pus from wound. Post-mortem growth from cut end to 10 cm. in 21 hours at room temperature.

FIG. 245.—Case 3. Lower end of femur with bruise of external condyle but no fracture. Cut end soiled by pus from wound. Post-mortem growth from cut end to 10 cm. in 28½ hours at room temperature.

Case 3.—L.-Cpl. C. Date of wound not known. Amputation 11.0 a.m. May 5, 1916. Examination of bone 6.0 p.m. May 6. Sepsis before amputation duration not known. Duration of post-mortem growth, 28½ hours.

Lesion.—Open septic knee-joint, with bruise of external condyle of femur, but no fracture (*Fig. 245.*)

Table 23.—Case 3.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM SOURCE OF INFECTION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Femur 1	5.3 cm.	Streptococcus	0
" 2	11.0 "	0	0
" 3	11.3 "	Streptococcus	0
Knee-joint		Streptococcus, staphylococcus	—

CONCLUSION.—In 28½ hours, growth to 10 cm., limit reached (*Table 23*). Growth has extended further in the bruised than in the normal condyle, probably because the effused blood is a medium specially suited to the streptococcus.

These three bones show so extensive a penetration by organisms as to arouse suspicion of post-mortem growth. This suspicion has been confirmed by the results of examination of fresh material of corresponding type obtained by operation. Thus, the average distance of penetration of the streptococcus in fresh material has been found to be 2 cm., contrasting with an average distance of 8 cm. (limit not reached in two of the cases) for these three bones.

Effect on Penetration of the Circulatory Conditions Preceding Death (*Cases 4, 5*).

Case 4.—Lieut. B., age 21. Extensive saprophytic invasion of bone, associated with terminal circulatory failure.

Table 24.—Case 4.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Femur 1	2.2 cm.	Streptococcus, <i>B. coli</i>	+
" 2	4.4 "	Streptococcus, mixed growth	+
" 3	6.7 "	Streptococcus, mixed growth	+
" 4	9.0 "	Mixed growth	+
" 5	14.0 "	" "	+
" 6	18.8 "	Streptococcus, mixed growth	+
" 7	24.3 "	Streptococcus, staphylococcus, coliform bacilli	+
Blood culture 31 hours before death		0	0

Ante-mortem exposure of bone to sepsis.—10 days.

First culture taken from bone.—35 minutes after death.

Last culture taken from bone.—1 hour 25 minutes after death.

Order of cultures.—7, 6, 5, 4, 3, 2, 1.

Clinical History.—Wounded Sept. 19, 1916. Compound fracture of fibula. Amputation in lower third of thigh for gas gangrene at casualty clearing station, Sept. 19. Flaps stitched. Stitches removed at end of four days and pus evacuated. Gradual failure of circulation for three days before death, with frequent vomiting and sweats. Death 10.0 p.m. Sept. 29.

For the last forty-eight hours the extremities were cold and blue, and the radial pulse was absent, but patient was quite conscious. The stump was distended with extreme oedema and a moderate quantity of gas. There was no jaundice or local bronzing of the skin.

Clinical Picture.—Toxic failure of circulation. (Figs. 246, 247, and Table 24.)

FIG. 246.—Case 4. Death from gas-gangrene toxæmia. Terminal failure of circulation.

Case 5.—Lieut. K., age 27. Absence of saprophytic invasion, associated with maintenance of the circulation till death.

FIG. 248.

FIG. 248.—Case 5. Death from streptococcal septicæmia. Absence of terminal failure of circulation.

FIG. 249.—Case 5. 10 cm. of shaft of tibia from case dying of streptococcal septicæmia after amputation (A). Absence of any considerable penetration by organisms when circulation is maintained to the end. Growth at (5) of septicæmic origin.

FIG. 249.

FIG. 247.—Case 4. Upper 32 cm. of femur from patient dying of gas gangrene after amputation. Penetration by organisms to 24 cm. accompanying terminal failure of circulation. A, Amputation.

Clinical History.—Wounded Feb. 8, 1917. Left foot shattered by shell. Amputation in lower third of leg, Feb. 9. Flaps stitched. Stitches removed after twenty-four hours. Oedema of leg up to knee. Death Feb. 18, 11.20 a.m.

Clinical Picture.—Septicæmia. (Figs. 248, 249, and Table 25.)

Table 25.—Case 5.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Tibia 1 ..	1.5 cm.	Streptococcus, staphylococcus. <i>B. coli</i>	+
„ 2 .	3.5 „	Streptococcus, staphylococcus	0
„ 3	5.5 „	0	0
„ 4 . . .	7.5 „	0	0
„ 5 . . .	10.0 „	Streptococcus	0
Blood culture 18½ hours before death	..	„	—

Ante-mortem exposure of bone to sepsis.—9 days.

Bone in ice.—From 11.50 a.m. to 5.45 p.m.

First culture taken from bone.—5.50 p.m.

Last culture taken from bone.—6.10 p.m.

Order of cultures.—5, 4, 3, 2, 1.

From a comparison of these two cases, it is seen that the condition of the peripheral circulation before death has an important bearing on the bacteriological findings. In *Case 4*, the prolonged failure of circulation which preceded somatic death is reflected in the temperature chart with its terminal fall, in the absence of radial pulse, in the anaerobic cellulitis of the stump, and in the extension of organisms throughout the whole length of the femur (see *Table 24*). The bone is, in fact, comparable in its absence of resistance to infection to *Cases 1, 2, and 3*, and the growth of organisms is in reality a post-mortem phenomenon occurring during life.

In *Case 5*, where death from streptococcal septicæmia was accompanied by a terminal rise of temperature and maintenance of the peripheral circulation up to the end, the circulatory conditions in the bone-marrow of the stump remained practically constant till death. In this bone, although the length of exposure to sepsis was the same as that of the previous case, organisms grew up only 4 cm. from the cut end (see *Table 25*). The growth at Section 5 is of septicæmic origin, while the absence of growth at Sections 3 and 4 can best be explained by the assumption that the septicæmia had not long been established.

In drawing deductions from observations on bones removed at autopsy, therefore, due consideration must be given to the clinical picture of the case before death. Material obtained at operation is free from this necessity for analysis, and conclusions may be drawn from it with greater directness and less error of interpretation. With the exception of the two bones just referred to, the whole of the material was obtained by operation.

Additional Examples of Penetration through Normal Bone (*Cases 6, 8*).

Case 6.—L.-Cpl. A. [*Ref. No. 201*] Amputation through normal cancellous tissue.

Clinical History.—Wounded April 22, 1916. Flapless amputation 5 cm. below knee at casualty clearing station before April 26 (exact date not known). Upper end of fibula removed. Streptococcal infection of knee-joint through popliteus bursa. Re-amputation above knee at base, 12.30 p.m. May 12. (*Fig. 250*.)

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Table 26.—Case 6.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA	DIRECT SMEAR
Tibia 1	0.5 cm.	Streptococcus, staphylococcus	0	0
„ 2	1.5 „	Streptococcus, staphylococcus	0	0
„ 3	4.0 „	0	0	0
Knee-joint		Streptococcus	0	Very few cocci
Femur, cancellous tissue (control)		0	0	
Femur, medulla (control)		0	0	

Exposure of bone to sepsis.—16 to 20 days.
First culture taken from bone.—2½ hours after amputation.
Last culture taken from bone.—3½ hours after amputation.
Order of cultures.—Femur. Tibia 3, 1, 2.

FIG. 250.—Case 6. Tibia from flapless amputation exposed to infection 16 to 20 days. Growth to 1.5 cm. from cut surface.

Case 8.—Lieut. M., age 23. [Ref. No. 203.]

Lesion.—Penetrating shell-wound of knee. Small fracture of articular surface of internal condyle of femur, with tear of semilunar cartilage. No injury to tibia.

Clinical History.—Wounded Aug. 22, 1916. Shell fragment removed at casualty clearing station Aug. 24. Arrived at base Aug. 27. Knee distended aspiration —pus—streptococcus. Resection of knee-joint Aug. 28. Persistent œdema of leg. Amputation for sepsis Sept. 20, 2.35 p.m. Transferred to England Oct. 1.

Examination of Limb after Removal, Sept. 20.—Leg œdematous, pus behind head of tibia, carious patch, not covered by granulations, on sawn surface of internal tibial tuberosity. No other pus collection in leg. (Fig. 251 and Table 27.)

FIG. 251.—Case 8. Tibia removed by amputation 23 days after resection of knee-joint, showing penetration to 2 cm. in normal bone. (Cf. Figs. 250, 212, 214.)

FIG. 251.

Table 27.—Case 8.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Tibia 1 ..	Surface	Streptococcus, staphylococcus	0
„ 2	2.0 cm.	Streptococcus	0
„ 3	11.2 „	0	0
„ 4	27.7 „	0	0
Femur 2 cm. from resected surface	.	Streptococcus	0
Pus from wound	.	Streptococcus, staphylococcus	0
Blood from vein at amputation	.	0	—

Exposure of bone to sepsis between resection and amputation.—23 days.

Bone in ice.—From 2.35 p.m. to 3.0 p.m.

First culture taken from bone.—3.0 p.m.

Last culture taken from bone.—4.0 p.m.

Order of cultures.—Tibia 4, 3, 1, 2. Femur.

Note.—Tibia 2 is probably near the limit of penetration, because only the sample grown aerobically yielded streptococcus, whereas the anaerobic culture of tibia 1 grew streptococci and staphylococci.

Illustrations of Low Penetrating Power of *B. coli* (Cases 9, 10).—In *Case 9*, well-drained bone was exposed in a septic flesh-wound into which a continuous feed of *B. coli* was maintained from the comminuted head of the fibula and the knee-joint. In *Case 10*, the fracture had originally been opened up, but the wound was allowed to close until drainage was reduced to that afforded by a narrow sinus.

FIG. 252.

FIG. 252.—*Case 9*. Tibia removed by amputation 14 days after injury. Shell fracture of external tuberosity. Penetration of *B. coli* did not reach limits of bruise. Section 3 bruised.

FIG. 253.

FIG. 253.—*Case 9*. Transverse section of tibia shown in *Fig. 252* at level of (1) and (2). A, Fracture.

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Case 9.—Lieut. B., age 22. [Ref. No. 204.]

Lesion.—Compound fracture of head of fibula and external tuberosity of tibia by high-explosive shell.

Clinical History.—Wounded June 17, 1916, 9.0 p.m. No operation at casualty clearing station. First operation at base on admission, June 19, 10.30 p.m. Wound foul, with local gas infection of muscle. Wide resection, knee-joint open. Knee-joint aspirated June 26. pus, *B. coli*. Amputation above knee July 1, 2.45 p.m., for suppurative arthritis. Transferred to England July 21.

Examination of Limb, July 1.—Joint-fluid viscid, yellow pus. Synovial membrane thickened. Articular cartilage soft and eroded. Tibia bruised bone of external tuberosity, softened and grey on surface. (Figs. 252, 253.)

Table 28.—Case 9.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Tibia 1	0.8 cm.	<i>B. coli</i>	+ (including <i>B. perfringens</i>)
" 2	4.7 "	0	0
" 3	3.8 "	0	0
" 4	12.3 "	0	0
" 5	17.3 "	0	0
Femur (control)	"	0	0
Knee-joint, June 20	"	0	0
" June 26	"	<i>B. coli</i>	0
" July 1	"	"	0
Blood from vein, July 6	"	0	—

Exposure of bone to sepsis before amputation.—14 days.

Tibia in ice.—From 2.45 p.m. to 6 p.m.

First culture taken from tibia.—6.20 p.m. Last culture.—6.45 p.m.

Order of cultures.—Tibia 4, 2, 1, 3, 5.

Femur in ice.—From 2.45 p.m. to 7.40 p.m.

Culture taken from femur.—7.50 p.m., 1 cm. beneath erosion of articular cartilage.

Case 10.—Pte. L. [Ref. No. 205.]

Lesion.—Penetrating side-to-side high-explosive shell wound of outer aspect of knee-joint, with fracture of posterior part of external condyle of femur.

Table 29.—Case 10.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Femur 1	0.5 cm.	<i>B. coli</i>	0
" 2	1.8 "	0	0
" 3	2.8 "	0	0
" 4	3.8 "	0	0
" 5	8.5 "	0	0
Tibia (control)	"	0	0
Knee-joint	"	<i>B. coli</i> , staphylococcus	0

Exposure of bone to sepsis.—21 days.

Amputation.—11 a.m.

Culture from joint.—2 p.m.

First culture taken from bone.—3.0 p.m. Last culture.—4.30 p.m.

Order of cultures.—Femur . 5, 4, 3, 2, 1. Tibia.

Clinical History.—Wounded April 26, 1916. Lateral incisions for drainage of septic knee on either side of patella. Original wound on outer side of joint enlarged and shell removed. Thomas knee-splint with strapping extension. Amputation for continued sepsis.

Examination of Limb, May 17, 2.0 p.m.—Lateral incisions for drainage granulating and no longer communicating with joint cavity. Moderate distention of knee by blood-stained fluid, which discharged through small sinus in centre of granulating original wound. Early erosion of articular cartilage. Synovial membrane intensely injected. No extracapsular extension of pus. Popliteal vessels intact. Tibia uninjured. (Figs. 254, 255 and Table 29.)

FIG. 254.

FIG. 254.—Case 10. Lower end of femur removed by amputation 21 days after injury. A, Foul wound of upper and back part of external condyle. Penetration slight, probably on account of nature of infection (*B. coli*).

FIG. 255.

FIG. 255.—Case 10. Transverse section of femur shown in Fig. 254 at level of (1) and (2).

Additional Examples of Extensive Penetration Associated with Interruption of the Medullary Artery (Cases 15, 16).

Case 15.—Capt. S., age 28.

Lesion.—Rifle-bullet fracture of middle of shaft of femur.

Table 30.—Case 15.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Upper fragment 5	3.4 cm.	Streptococcus	0
Lower " 1	In fissure	"	+
" " 2	Limit of fissure	"	+
" " 3	2.1 cm.	"	+
" " 4	7.8	"	+
Blood from vein, Nov 9	.	"	0

Exposure of bone to sepsis.—42 days.

Bone in ice.—From 9.45 p.m. to 10.25 p.m.

First culture taken from bone.—10.40 p.m.

Last culture taken from bone.—11.0 p.m.

Order of cultures.—Lower fragment 4, 3, 2, 1. Upper fragment 5.

Clinical History.—Wounded Sept. 29, 1916. Left out thirty hours. Septic from commencement. Tube drainage established at casualty clearing station. Severe secondary hæmorrhage Nov 9, forty-one days after original injury, when union was commencing. Blood transfusion, followed by amputation, Nov 10, 9.45 p.m. Pneumonia. Death, Nov 14.

Examination of Limb after Removal, Nov 10.—Entry wound on outer side. Pocket of pus on inner side of femur beneath vastus internus. Hæmorrhage from small undetermined artery. Consolidation commencing in fracture, healthy-looking callus from bone ends. No appearance of inflammation of bone away from fracture.

Clinical Picture.—Septicæmia. (Fig. 256 and Table 30.)

The interpretation of *Case 15* is complicated by the interval of twenty-four hours between the hæmorrhage and the amputation. It is conceivable that, in consequence of the diminution of the general circulation which followed the hæmorrhage, penetration of anaerobes was facilitated during this interval.

Case 16, although no opportunity of examining the upper fragment offered, is useful as a control on this point, since only forty-five minutes elapsed between secondary hæmorrhage and amputation. In other respects it is identical with *Case 15*.

Case 16.—Lieut. C., age 21.

Lesion.—Compound comminuted fracture of shaft of femur.

Clinical History.—Perforating wound, just above middle of thigh, opened up at casualty clearing station. Condition on admission to base hospital Nov 3, 1916, one of collapse. Severe secondary hæmorrhage Nov 4, 10.0 a.m. Amputation Nov 4, 10.30 a.m. Recurrence of hæmorrhage from stump. Death Nov 6, 1.30 a.m.

Clinical Picture.—Septicæmia.

Examination of Limb after Removal, Nov 4.—Muscle of limb normal in appearance except in immediate neighbourhood of fracture, no gas. (Fig. 257 and Table 31.)

Fig. 256.—*Case 15.* Upper and lower fragments of fractured femur removed by amputation 42 days after injury and 24 hours after severe secondary hæmorrhage. Penetration of whole lower fragment by anaerobes associated with interruption of medullary artery.

In view of the similarity of the bacteriological findings in *Cases 15* and *16*, no stress can be laid on the possibilities of penetration being accentuated by loss of blood during the twenty-four hours which followed the hæmorrhage in

the former. From the nature of the cases it is difficult to draw any conclusion from them of the effects of secondary hæmorrhage. The bones can only be examined after either amputation or death. Amputation, if performed at all, is usually done immediately, and no opportunity occurs for any possible effects of the hæmorrhage to develop. If the bone were examined after death, such effects could not certainly be dissociated from those of the terminal failure of circulation.

FIG. 257.—Case 16. Lower fragment of femur removed by amputation 7 days after injury and immediately after severe secondary hæmorrhage. Penetration of whole lower fragment by anaerobes. Control on Fig. 256.

Table 31.—Case 16.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION cm.	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Femur 1	Surface	Streptococcus	+
" 2	1.3 cm.	"	+
" 3	3.3 "	"	+
" 4	8.0 "	"	+
" 5	13.0 "	"	+
" 6	19.7 "	"	+
Tibia, cancellous bone (control)	"	"	0
Tibia, medulla of shaft (control)	"	"	0
Blood from vein $1\frac{1}{2}$ hours after amputation	"	"	0

Exposure of bone to sepsis.—7 days.

Bone in ice.—From 11.10 a.m. to 2.30 p.m.

First culture taken from bone.—2.30 p.m.

Last culture taken from bone.—3.5 p.m.

Order of cultures.—Tibia . 1, 2. Femur . 6, 5, 4, 3, 2, 1.

Additional Examples Illustrating (1) Early, and (2) Late Stages of Penetration in Untreated Septic Fractures (Cases 18, 20).

1. EARLY STAGE.

Case 18.—Lieut. O., age 23. [Ref. No. 209.]

Lesion.—Penetrating wound of external condyle of femur. High-explosive shell fragment and cloth embedded in cancellous bone.

Clinical History.—Wounded July 2, 1916. Severe multiple wounds by high-explosive shell. No surgical interference between infliction of wound and resection of knee-joint. Entry wound over most prominent part of condyle—i.e., very short track in soft parts.

Operation, July 5, 4.30 p.m.—Wound excised. External condyle cut away down to shell fragment. Subjacent bone black and foul-smelling, with crack into joint. Resection. Joint effusion blood-stained, sterile. Transferred to England July 27

Examination of Bone Removed, July 5.—External condyle deeply bruised, and separated from rest of bone by complete fissure. (Figs. 258, 259.)

FIG. 258.

FIG. 258.—*Case 18.* Lowe extremity of femur removed by operation $3\frac{1}{2}$ days after injury (diagrammatic), showing shell fragment embedded, and penetration to 0.8 cm. by anaerobes.

FIG. 259.

FIG. 259.—*Case 18.* Tracing from upper surface of resected lower end of femur shown in Fig. 258, to show fissure, bruise, and degree of penetration in early untreated fracture.

Table 32.—Case 18.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Femur 1	0.8 cm.	0	+
" 2	1.9 "	0	0
" 3	3.1 "	0	0
Knee-joint at operation		0	0

Exposure of bone to sepsis.— $3\frac{1}{2}$ days.

Resection.—4.30 p.m.

Bone in ice.—From 4.30 p.m. to 5.35 p.m.

First culture taken from bone.—6.0 p.m.

Last culture taken from bone.—6.40 p.m.

Order of cultures.—2, 1, 3.

2. LATE STAGE.

Case 20.—Pte. A. [Ref. No. 210.] Amputation in lower third of thigh for suppurative arthritis of knee.

Examination of Limb after Removal.—Vertical incision 5 inches long on either side of knee, opening joint and exposing condyles. Original shell-entry on inner side. Œdema of leg. No injury to tibia and fibula.

Bone Foul débris *in situ*, fracture into joint; transverse pus-track between femur and subcrural bursa, probably a tube track.

Knee-joint. Widely open, articular cartilage softened, synovial membrane sloughing, purulent effusion. Extracapsular extension of pus, commencing from popliteus bursa. (Figs. 260. 261.)

FIG. 260.

FIG. 261.

FIG. 260.—Case 20. Femur removed by amputation for shell fracture (A) of internal condyle. No surgical interference with actual fracture. Growth throughout bone.

FIG. 261.—Case 20. Femur shown in Fig. 260 from below to indicate fissure (A¹) separating internal condyle from rest of bone. Below is transverse section just above condyles to show penetration from fissure A¹

Table 33.—Case 20.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Femur 1	Surface	<i>B. coli</i> , staphylococcus	+ (including <i>B. perfringens</i>)
„ 2	1.5 cm.	Staphylococcus	0
„ 3	5.0 „	<i>B. coli</i> , streptococcus	0

Amputation.—12.30 p.m., June 28, 1916.

Limb in ice.—From 1 p.m. to 3.5 p.m.

First culture taken from bone.—4 p.m.

Last culture taken from bone.—4.30 p.m.

Order of cultures.—2, 1, 3.

APPENDIX II.

CULTURAL REACTIONS OF STAPHYLOCOCCI AND COLIFORM BACILLI ISOLATED FROM BONE.

Table 34—SHOWING THE CULTURAL CHARACTERS OF TYPES OF *B. coli* ISOLATED FROM BONES

SOURCE	TYPE	SACCHAROSE	PULCITE	GLUCOSE	MANNITE	LACTOSE	LITMUS MILK	GELATIN LIQUEFACTION	INDOL	MOTILITY
Case 24: Tibia 1 (and knee-joint)	Group I	0	0	AG	AG	AG	AC	0	0	0
Lt G.: Radius and humerus	" II	0	AG	AG	AG	AG	A	0	+	+
Case 10: Femur 1 (and knee-joint)	" III	AG	AG	AG	AG	AG	AC	0	+	+
Case 19: Tibia 1 (and knee-joint)	" "	AG	AG	AG	AG	AG	A	0	+	0
Case 4: Femur 1	" "	AG	AG	AG	AG	AG	AC	0	+	+
Case 5: Tibia 1	" "	AG	AG	AG	AG	AG	AC	0	0	+
Case 20: Femur 1 and 3	" IV	AG	0	AG	AG	AG	AC	0	0	+
Case 27: Femur 1	" "	AG	0	AG	AG	AG	A	0	0	+

A = Acid, AG = Acid and gas, AC = Acid and clot 0 = Absence of reaction

Table 35—SHOWING THE DISTRIBUTION OF *B. coli* FROM A VARIETY OF SOURCES

TYPE	BONE	SOIL	CRESSPOOL SEWAGE	HUMAN FAECES	HORSE, CALF, AND PIG FAECES
Group I	1	2	4	62	9
" II	1	0	1	49	33
" III	4	10	1	61	68
" IV	2	4	0	16	4

Note.—The figures represent the actual number of strains isolated

The cultural reactions of 20 strains of staphylococcus isolated from freshly-examined material have been tested as far as possible. Of these, 15 strains from 15 samples of bone, taken for culture from 8 patients, gave the following reactions—acidity in glucose, lactose, mannite, and saccharose, acidity and clot in milk, and liquefaction of gelatin. Five strains failed to liquefy gelatin, and two produced no acidity in mannite. None of the cultures showed any marked pigment production.

The cultural characteristics of a number of *B. coli* isolated from bones are arranged in *Table 34*, in the grouping suggested by MacConkey for the differentiation of coliform bacilli on the basis of their ability to ferment saccharose and dulcitol.*

Utilizing the data of this writer for the distribution of the four types in various materials (*Table 35*), and having regard to the limited sampling in some of the cases, it appears that the figures are at least significant of the source of the *B. coli* cultivated from bones, since the closest correlation exists between these strains and those recovered from the soil.

* A. T. MacConkey, "Further Observations on the Differentiation of Lactose-fermenting Bacilli, with special reference to those of Intestinal Origin," *Jour. of Hygiene*, ix, 86.