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"STRESS" OR "FATIGUE" FRACTURES OF BONE*

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"STRESS" or "fatigue" fractures as a group appear to be very little known in this country. It is true that March-foot has become widely recognised and much reported since 1855, when Breithaupt[1] was apparently the first to describe it, but until 1939 there do not appear to have been any examples recorded occurring in other bones.

This is interesting, because ever since the first Great War, large numbers of cases have been encountered in recruits to the Finnish, Swedish, Norwegian, and German armies.

There is evidently a curiously low incidence rate both in America and in Great Britain, for although I had been searching diligently since 1931, I had seen—until recent months—only fifteen examples, all in the upper third of the tibia and none (excepting March-foot) in any of the other bones in which the condition has been described. The normal incidence is further emphasised by the number of cases recent authors have been able to describe—for example, Professor Pfahler[2], one example in the tibia; Mullard,[3] one occurring in the neck of the femur; Jackson Burrows,[4] two examples in the fibula; Weaver and Francisco,[5] two in the tibia and one in the fibula.

Contrast this with a single German author—Sheller[6]—who records 590 examples reported from the German Field Hospitals, 1935 to 1936, among which we may note 70 in the tibia, 13 in the femur, 12 in the fibula, 4 in the os calcis, and 3 in the pelvis. The remainder (488) were in the metatarsals. A Japanese author, Kobayashi,[7] describes 13 examples in the tibia.

The introduction of conscription—or the preparation of a nation for war—appears to be followed by a large increase in the incidence rate of "stress" fractures. This is indicated by the selection of the term "Soldiers' fracture" in the description of four examples recently by Nordentoft (Norway).[8]

This moment then, is the supreme opportunity for Medical Officers and particularly for radiologists in the Services Field Hospitals of the Allied Nations to search for and study the behaviour of, this fascinating group of fractures. It is possible that "bone exhaustion" findings may prove to be relatively common when adequately sought for; just as has the developmental anomaly known as Craniolacunia, hitherto believed to be rare in this country, and now known to occur in 0·94 per cent. of births.[9, 10]

The relative frequency with which "stress" fractures occur in the lower limb (weight-bearing areas) is shown in the diagram (Fig. 1). It is apparent that the condition occurs seven times more frequently in the metatarsals than in the tibia, that it is seen between five and six times as frequently in the tibia as it is in the femur or in the fibula, and that it is seen only occasionally (about once in a 100 times) in the os calcis or in the pelvis.

The general incidence rate in this country may be gauged as being, up to the present, one example in the tibia seen every nine months; the same observer would probably see

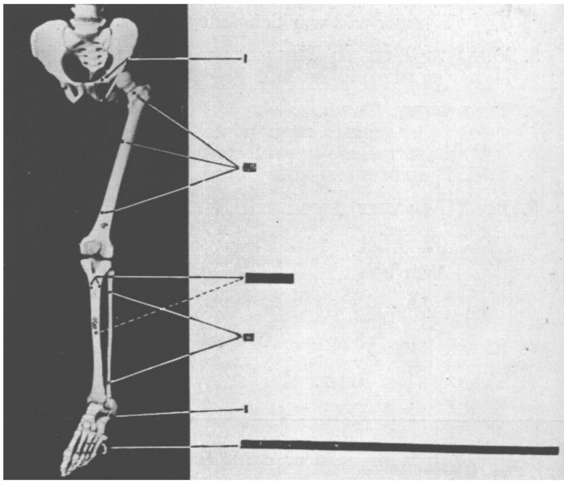

FIG. 1.
Diagram to indicate the relative incidence of "stress" or "fatigue" fracture at the various sites in weight-bearing bones.

five examples in the metatarsals in one month. The condition in the metatarsals is well known. In the tibia it occurs at least four times as frequently in the upper third as it does at any other site, which is usually mid-shaft. The fibular incidence is roughly equally divided between upper third and lower third. Similarly, in the femur the condition appears to occur either at the junction of the middle and lower thirds, in the upper third, or in the neck. The literature refers to the "os pubis," but the only case which I have seen illustrated showed the condition slightly to the

* This paper was read at a meeting of the Radiodiagnosis Section, Faculty of Radiologists, in February 1943.

pubic side of centre of left ischium. I have never seen an example of the condition in the os calcis.

"Stress" fractures are seen in other bones, but so rarely that one cannot assess their frequency at present. For example, they occur in the humerus in javelin, discus and grenade throwers, and they are reported in the ulna in diggers, and in the vertebræ due to tetanus, whilst spondylolisthesis may be another example.

AGE INCIDENCE

These "stress" fractures are most common in the years of adolescence and early manhood. The youngest in my tibial series[11] was 7 years of age; the youngest in the recent American series[12] was 4 years. The oldest in my series was 20; the oldest in the American series was 16. It must be noted that these figures refer to the civilian populations in democracies. Most of the cases recorded in soldiers occurred in the early twenties. One or two isolated cases in older patients have been reported—for example, there is one recorded by Jackson Burrows[4] in the lower third of the fibula in a woman aged 61, but I think this probably ought to go under the title of "Spontaneous fracture due to age."

TABLE I

The diseases in which pathological fracture *or* "pseudo-fracture" may be found can be classified as follows:—

1. PAGET'S DISEASE OF BONE.
2. DISEASES DUE TO DIETARY INSUFFICIENCY AND AVITAMINOSIS.
   (*a*) Rickets and osteomalacia.
   (*b*) Coeliac disease.
   (*c*) Chronic idiopathic steatorrhœa.
   (*d*) Puerperal.
   Senile.
   Hunger and war deficiency.
3. DISEASES DUE TO HORMONIC IMBALANCE, *e.g.*, Hyperparathyroidism and Hyperthyroidism.
4. CONGENITAL DEFECTS:—
   (*a*) Osteogenesis imperfecta.
   (*b*) Osteogenesis imperfecta tarda.
   (*c*) Fragilitas ossium.
5. BONE ATROPHY ASSOCIATED WITH:—
   (*a*) Disuse.
   (*b*) Fractures.
   (*c*) Arthritis.
   (*d*) Neurotrophic or circulatory disorders.
   (*e*) Old age.
6. RENAL RICKETS.
7. TUMOURS OF BONE.

It is important before proceeding further that we should examine the name, and identify accurately the group we are to consider. The various names which have been used to describe examples of the condition are stress fracture; insufficiency fracture; overload fracture; wear and tear fractures; recruit's disease; periostitis ab exercitio; osteopathia itineraria; soldiers' fracture; spontaneous fracture and even pseudo-fracture. Insidious fracture and creeping fracture are apparently the latest additions to the list.

It is essential at this stage that we should clear the air of misconceptions and faulty terminology, for confusion does already exist in the literature. I mean by *stress, insufficiency or fatigue* fractures, those conditions in which partial or complete fracture can be shown radiologically to have occurred in *apparently normal bone* or in which submicroscopic or molecular fracture can be inferred to have taken place either by the callus formation early in the case, or by the subsequent radiological and clinical progress. There must be *no* evidence of systemic disease of a nature known to be associated with, or causative of, bony pathological change, nor must there be a history of violence.

Spontaneous fracture is a term which may not be used for this group of fractures; obviously it can refer either to "fracture through pathological bone" or to "fatigue" fracture.

The use of the term pseudo-fracture must be restricted to those cases in which "Umbauzonen" are seen—appearances simulating fracture, and always occurring in *pathological bone*.

"Pathological fracture" is a self-explanatory term, which becomes linked to pseudo-fracture because complete fractures do supervene through bones which are, or have been, the sites of pseudo-fractures (Looser's Transformation Zones).

I maintain that the most accurate name is *"fatigue" fracture*: I believe that the condition is analogous to "fatigue-" or "exhaustion-fracture" occurring in metals. Henschen[13] has shown by spectro-radiographic methods that in bone under duress, "exhaustion fracture" does occur if the rest period is inadequate; exactly as "fatigue" fracture develops in over-stressed metals, and I am inclined to accept this view after studying these infractions in detail in the tibia, and in the metatarsals, and after delving into the facts and theories of "fatigue" in metals. (I shall indicate one or two facts in support of this view later.) The more important thing is that it should be clearly understood that pseudo-fractures, spontaneous fractures and pathological fractures comprise an entirely different group of conditions, and that, therefore, none of these names is permissible in referring to fractures, callus formations or zones of rarefaction of the "stress" or "fatigue" type (*i.e.*, when referring to radiological findings in normal-looking bone).

This pseudo-fracture group should be clearly set aside, except in so far as it enters into the differential diagnosis. "Fatigue" fractures are not, and have nothing to do with Looser's Umbauzonen (pseudo-fractures).

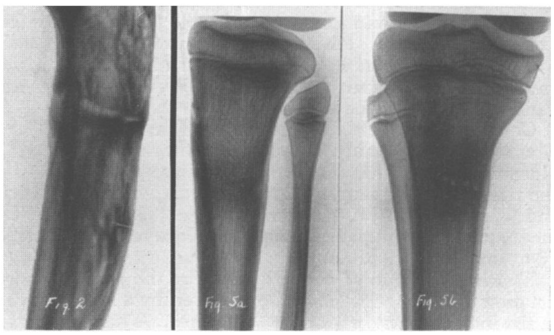

FIG. 2.
Typical Looser's zone occurring in Paget's disease of the tibia. Above it "pathological" fracture has occurred through a similar zone of rarefaction. At neither site is there callus.

FIGS. 5A AND 5B.
Typical appearances of true "fatigue" fracture occurring in the tibia of a boy of 15 years.

Fig. 2 is an example of what I regard as the typical appearance of a pseudo-fracture occurring in a case of Paget's disease. Immediately above this area of rarefaction there is to be seen a pathological fracture. Note the *absence* of callus at the pseudo-fracture site. In Fig. 3 are seen further examples of pseudo-fractures presenting in the femora in a case of late rickets. Note that the zones of rarefaction extend into the bone on the convex aspect in each femur. There is no reaction around—the margins are quite well defined, and there is practically no callus formation around the cortical extremity of the transformation zones. Note also that the bones in which these Looser's zones are seen are obviously pathological. Fig. 4 shows the forearms of the same case, *i.e.*, non-weightbearing bones. Note the similarity of these zones in the ulnæ to those in the femora—their clear-cut margins, and the lack of callus or of sclerosis around. Figs. 5A and 5B, by way of contrast, depict a true example of "stress" or "fatigue" fracture occurring in the tibia of a schoolboy. Note that in the lateral view the outstanding feature is *callus formation* posteriorly. The fracture of the cortex is visible, but it has to be carefully searched for, unlike the Looser's zones which we have just seen, and which are strikingly apparent. In the antero-posterior view of the same case (Fig. 5B) the outstanding feature is again callus formation at the typical tibial site—the rest of the bone and the fibula being normal. One must be prepared to find the infraction of the cortex in either view, but in the tibia always on a *concave* aspect, usually postero-medially or postero-externally, but occasionally on both of these aspects.

In order to demonstrate and emphasise the differences between "fatigue" fractures and pseudo-fractures, I have prepared the following Table. I regard assimilation of the observations which it sets forth as a *sine qua non* in the study of "fatigue," "exhaustion," or "wear and tear" fractures of bone.

Having emphasised that there are real differences between transformation zones and "stress" fractures, and having seen what those differences are, it is permissible now to proceed with our study of *stress* types of fracture.

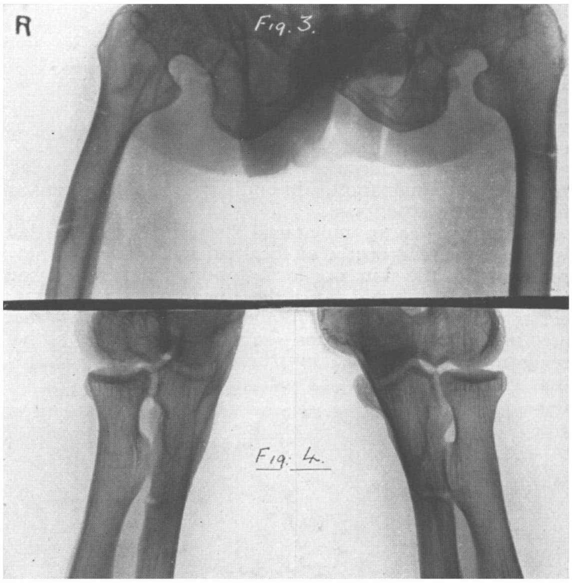

FIG. 3.
Pseudo-fractures occurring in the femora in a case of late rickets.

FIG. 4.
The right and left forearms of the same case, revealing a pseudo-fracture in each ulna.

TABLE II

TABLE SHOWING THE DIFFERENCES BETWEEN "STRESS" FRACTURES AND "PSEUDO"-FRACTURES

Features Encountered	In "Stress" (or "Fatigue") Fractures	In "Pseudo"-Fractures ("Umbauzonen")
1. Symptoms.	Local pain—during or after exercise. Never at rest.	May be no pain—when present shows no direct relationship to exercise.
2. Callus.	(*a*) Is an outstanding feature. (*b*) Increases rapidly; within days. (*c*) Steady organisation — *normal* behaviour. (*d*) Appears immediately *after* infraction occurs—and is evidence of its occurrence.	(*a*) Conspicuous by absence or paucity of amount and extent. (*b*) Remains static for weeks or months. (*c*) Alters only by cure of the systemic disease or by obliteration due to disease advancing. (*d*) Absent; or not significant.
3. Characteristic "zone" or "infraction."	(*a*) Fine "nick" *obliquely* into cortex *or* hair-line fissure; easily missed. Usually not across whole thickness of bone. Margins ragged or ill-defined. (*b*) Appears within *days* of onset of symptoms.	(*a*) Relatively *broad*, clear-cut zone, its long axis *at right angle* to long axis of bone. Often extends right across the bone (or almost). Margins parallel (Osteomalacia) or nearly (Paget's disease). (*b*) Appears at any time during the disease.
4. Site of findings.	Tendency to occur on *concave* surface, *i.e.*, on the "stressed" aspect.	Almost invariably on *convex* surface, *i.e.*, on the "stretched" aspect.
5. Multiplicity?	Always *single* lesion (tibial lesion may be bilateral—but never simultaneously).	Multiplicity is characteristic. (Lesions may occur symmetrically.)
6. Radiological appearance of remainder of bone.	Always normal.	Always pathological.
7. Systemic disease found?	No.	Yes—always.
8. Bones affected.	"Long," weight-bearing, or heavily stressed (femur, *tibia*, fibula, *metatarsals*, chiefly).	No relation to weight-bearing or stress (*e.g.*, ribs, forearm, scapulæ, phalanges, patella).

SUMMARY OF CLINICAL FEATURES

These, as one would expect, vary according to the stage of the malady at which one first makes an examination. Early, the outstanding symptom is pain. This may vary from an ache to a severe and sharply localised "nagging" which will cause the patient to be sent for radiological examination because of the suspicion of osteomyelitis.

There may be muscular "stitch" and there may be local tenderness to palpation, although this is not a constant feature in my experience.

Sometimes—as in metatarsal "stress" fracture—there will be a variable degree of local œdema. There is never reddening of the skin, nor local "calor," nor a raised body temperature. (Should any of these be found, it is likely that either one is dealing with another condition, or that there are unusual complications—so unanimous are authors regarding their absence in true "exhaustion" fractures.)

to a greater degree. It always develops quickly, organises, and then usually leaves the bone-structure stronger or thicker. Most frequently it occurs at a site at which torque, stress, or over-load can be demonstrated to occur, *e.g.*, in the tibia it is seen most frequently at the point postero-medially where the "axis of vertical stress" through the internal condyle cuts the cortex. Exceptions to this rule are noted in the os calcis and in the neck of the femur.

In many cases a crack, or a definite fracture line is demonstrable at some stage—not necessarily at the onset of symptoms nor usually within two weeks. The most usual time to demonstrate it is about three weeks from the onset of pain. The majority of authors are agreed that this is true. It is of the utmost importance that a careful search be made of radiographs in which the diagnosis of "stress" fracture may be suspected, for the detection of a clean nick in the cortex, or of a hair-like fracture line, does enable one to

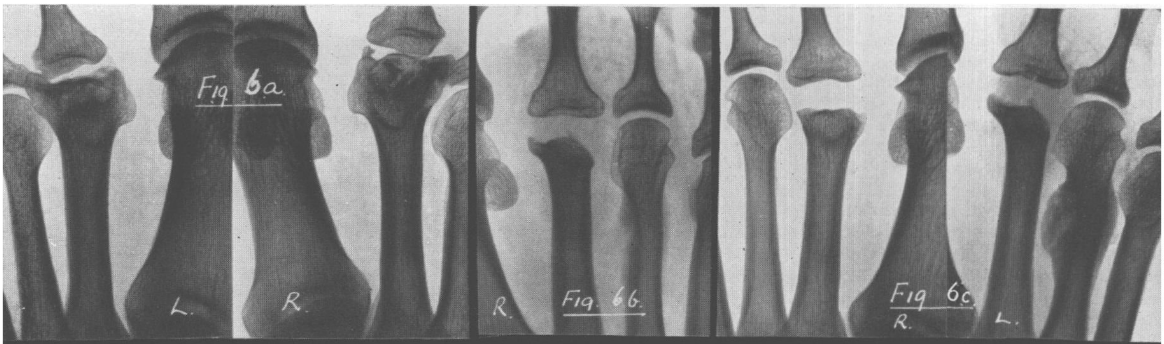

FIG. 6A.
Right and left foot exhibiting Köhler's disease of the 2nd metatarsals.

FIG. 6B.
The right foot seen eleven weeks after operation for removal of the heads of both 2nd metatarsals. "Stress fracture" of the previously normal 3rd right metatarsal is demonstrated.

FIG. 6C.
The right foot of the same patient to show confirmation and progress of "stress fracture." Compare also with Fig. 7B.

FIG. 7A.
Showing fracture of 2nd and 3rd left metatarsals known to be of traumatic origin. Films taken on day of injury.

FIG. 7B.
Radiographs of the same foot taken six weeks ater. The patient was not immobilised: Novocain was injected shortly after the accident and the patient allowed to walk about. The callus response bears a striking resemblance to that seen in "March-foot."

Almost invariably the pain subsides when adequate rest is obtained: it returns during weight-bearing, either on walking, marching or running, or immediately after. It should be noted here, that it is not enough in the case of a soldier merely to put him on "light duties" or to excuse him from duty—he must be given prolonged *rest from weight-bearing*, if necessary making certain of this by applying an adequate plaster.

SUMMARY OF RADIOLOGICAL FINDINGS IN GENERAL

The characteristic feature is always callus formation. This varies from case to case—most commonly it is localised to one side, and is seen first in the form of a tiny bead—but in some instances it does spread along or round the shaft

eliminate the suspicion of sarcoma or of Ewing's tumour, precisely because in "stress" fracture the infraction line appears relatively early, whereas should pathological fracture occur in bone tumour it will be relatively late, or associated with trauma.

Speed and Blake[14] reported ten fractures demonstrable in nine cases of March-foot. Hansson[15] showed it in two examples out of three. I have seen it sufficiently frequently and seen so many reported cases in which illustrations revealed it, that I regard it as a diagnostic feature in this class of case. Like many another point of diagnostic value, it will not necessarily be identifiable in every patient. It will depend for example, on the stage at which one first obtains radiographs. If late, it may be obscured by dense organising callus. It will certainly be frequently missed in radiographs of poor quality.

The findings may be bilateral and symmetrical: they may be bilateral and asymmetrical. I have never seen a case in which the onset of symptoms, or in which the radiological findings, occurred simultaneously in both limbs.

Rapid organisation of callus, the formation of a zone of *sclerosis*, or the rapid healing of the fracture site are normal to the condition, provided adequate rest from stress obtains. All these findings are of good prognostic significance.

Should a transverse area of osteoporosis develop, extending across the bone, this is of bad prognostic significance (see Case 3, Figs. 15–19). It means that over-stress had persisted too long after the "bone fatigue" stage had been reached, and that (*a*) recovery will be slow—months instead of weeks, and (*b*) there is the danger of complete fracture supervening (as occurred in one of my tibial series; a soldier in which diagnosis was missed and in which "rest" to the fatigued bone was inadequate).

No abnormality will be found either in the affected bone or elsewhere in the bony skeleton, with the exception that the condition is occasionally demonstrated bilaterally; an important feature to bear in mind.

ETIOLOGY

With regard to the etiology, no convincing evidence of a causal disease has been advanced. Fromme,[16] Seeliger,[17] and Hoenigman[18] favoured the theory of a nutritional deficiency, whilst Wilhelm[19] accepts polyhypovitaminosis as the ultimate cause. These views together with isolated suggestions that local or systemic infection, vascular changes or muscular or ligamentous pull are contributory factors, are almost entirely ignored by the majority of observers, and rightly, in my opinion.

My view that Looser's Transformation Zones are distinct and different from "stress" fractures is supported by Brailsford[20] and by Schmorl,[21] whilst the contributions to our knowledge of Stechow,[22] Hopfengartner,[23] Muller,[24] Koch,[25] Aleman,[26] Hansson,[15] and others, support my contention that the main, if not the only factor in their production lies in "disproportion between the 'required' and the 'inherent' capacity of the bone to bear stress," as Brandt[27] has expressed it.

I do not propose to spend much time in the consideration of "stress" fractures of the metatarsals. They may occur in the 2nd, 3rd, 4th, or even 5th. They are often situated at or near the neck of the metatarsal, but they may occur at any point along the shaft. Two facts are however outstanding; the first being the wide consensus of opinion already evident that this condition does closely resemble "stress" fracture occurring at the other sites which I have mentioned, in the following particulars[4]:—(1) Its affection of the shaft of a long bone, (2) The onset *without* violence, (3) Its frequent association with prolonged muscular effort, (4) The absence of any audible snap or of any suspicion by the patient that fracture has occurred, (5) The fact that pain is usually the outstanding feature, (6) The liberal formation of callus and its behaviour once formed, (7) The presence of a variable degree of œdema.

Secondly, there is precisely this failure of the protagonists of a causal disease to establish their theories or to convince the profession as a whole. I am satisfied that there is no adequate evidence against the stress theory. The variations in site destroy the theory that the nutrient foramen is an etiological factor, and I have been unable to demonstrate the constant existence of a nutrient foramen at the typical site. The stress theory seems to me to have been proved by the fact that the condition can be "experimentally" produced. This is illustrated in the following case (which I quote by courtesy of my colleague, Mr. Sayle Creer). Fig. 6A shows the feet of a girl, aged 14 years, showing well-marked bilateral Köhler's disease. Note that although the 2nd metatarsals are abnormal, the 3rd right metatarsal in particular presents normal appearances. Excision of the heads of both 2nd metatarsals was carried out on October 19, 1942. On November 25, 1942, there was some pain in the right foot. Clinically a diagnosis of incompetent 1st metatarsal was made, and Fig. 6B shows that March-fracture of the 3rd right metatarsal has occurred. Clinical signs corresponded. Fig. 6C shows organisation of the callus around the fractured metatarsal one month later. Fourteen days later the patient reported, without pain or tenderness in either foot.

Further evidence that "March-foot" is indeed due to fracture of the metatarsal, is revealed in a recent series of cases investigated and treated by Mr. Sayle Creer, exhibiting fracture of one or more of the metatarsals known to be of traumatic origin, and treated only by local injection of novocaine. Feet which are treated thus, and the patient allowed to walk normally (the pain having been relieved), reveal that callus around the fracture sites develops exactly similarly and presents identical radiological appearances to that seen in "March-foot." This point is well illustrated in Figs. 7A and 7B.

Apart from March-fracture, in my own experience, and so far as I am able to discover in the literature, "stress" fractures occur most frequently in the tibia and almost always in the upper third. Since the appearances in the upper third of the tibia are similar to those described at the other sites, and since there are several interesting features to be noted there, I propose to deal with this particular site in somewhat greater detail.

I think it is reasonable to assume that examples of the condition occurring in the tibia are more frequent than has hitherto been suspected, for between 1931 and 1942, I had seen only a total of fourteen cases, whereas since June 1942, I have seen one example myself, and have had two sent to me from Dr. Attlee of Eton, one from Major Bonnell, one from Dr. R. I. Roberts, and recently Dr. E. D. Gray found a good example amongst some 1933 films which he was sorting out, *i.e.*, five cases have been seen in the last seven months, as against fourteen cases in ten years.

I feel certain that now that the younger age groups are being called to the fighting forces, and as a result of the high-pressure training of commando-units (and possibly also as a result of parachute training) many cases will come to light, and much new information may be gained.

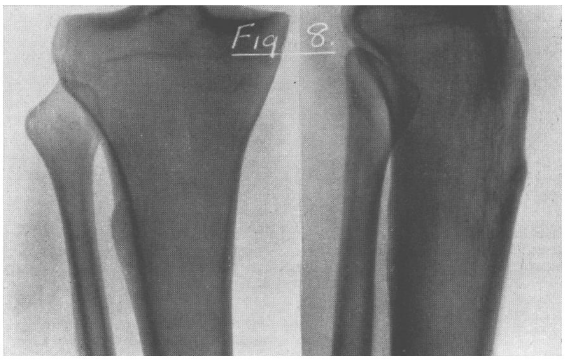

FIG. 8.
Radiographs of an adult tibia picked at random from a day's casualty films, and showing buttressing on medial, lateral and posterior aspects of upper third of tibia.

DEMONSTRATION OF TIBIAL FEATURES

Here I would like to demonstrate one or two facts which I have noted, and which appear to support the view that the condition of "stress" fracture really is a "fatigue" or overload fracture, and not a pseudo-fracture or Looser's zone.

With the foot straight to the front, which is the normal position in running, it will be noted that the internal condyle lies well behind the external condyle; that the *point d'appui* of weight transmission, which is usually chiefly delivered to the internal condyle, lies well behind the long axis of the tibia; and that there is well-marked concavity posteriorly, from the tibial condyles to about the junction of the middle and upper thirds of the shaft. Finally, radiographs of the tibia in the lateral views usually show evidence of the maximum transmission of weight posteriorly to the long axis of the shaft, in that the bony architecture reveals stress lines to be accentuated in the triangular area behind the mid-point of the internal condyle. These stress lines run down vertically to meet the cortex, in the adult, usually some three inches below the level of the condyle, at a point which is at, or very near, the site at which these "stress" fractures will be found to occur most frequently. It will also be found that in the rare cases which are untreated and which proceed to true fracture through both bones, the upper fragment will be seen to be slightly displaced backwards. That is, the evidence in the tibia favours a diagnosis of "compression fracture," which supports the view that the condition is one either of bone fatigue or of bone-exhaustion analogous to the phenomena observed in metal; a proposition which may seem startling to histologists but which will not appear so to those who realise that the microscope no longer has the *obiter dicta* in the examination of matter.

There is further evidence that this "site of election" in the tibia is an area normally subject to considerable stresses, and therefore liable to "over-threshold" effects. A considerable number of legs examined in the course of the day's routine casualty-reporting reveal evidence of buttressing in this area of the tibia, on the medial, lateral, or posterior aspect, and in some instances at all of these sites. (Fig. 8.)

It may well be that these changes occur frequently without symptoms—it has not been possible to check: many of them may have been attributed to growing pains or to "a touch of rheumatism"; or the patients may have "cured" themselves by instinctive insistence on adequate rest to their "fatigued" bones. Alternatively, the "rest-to-work" ratio may have been adequate and the bony reconstruction been carried out slowly, deliberately, and without the patients being aware of the architectural changes proceeding; as in fact, we know to be possible in response to long continued muscular pull, usually of occupational origin, *e.g.*, in the humerus. It is probable that not a few adolescents are hidden in the surgical records of cases where exploration for suspected osteomyelitis has been carried out with negative findings, and cure having resulted, no radiological examination was invited.

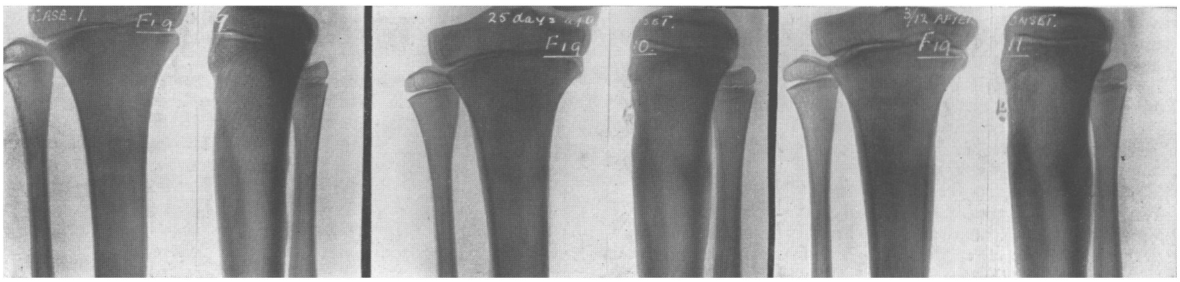

Fig. 9.
Case 1. Radiographs of right tibia of a girl, aged $9\frac{3}{4}$ years, taken four days after onset of pain in the calf. Note the two faint nodes of callus posteriorly.

Fig. 10.
Radiographs of same eg taken 25 days after onset of pain. The diagnosis, which previously might have been challenged, is now established.

Fig. 11.
Case 1. Same leg three months after onset, showing the callus now firmly organised with the bone structure normal except for the buttressing posteriorly and to either side of the upper third of the shaft. This probably represents the earliest and mildest form of the condition likely to be diagnosed radiologically.

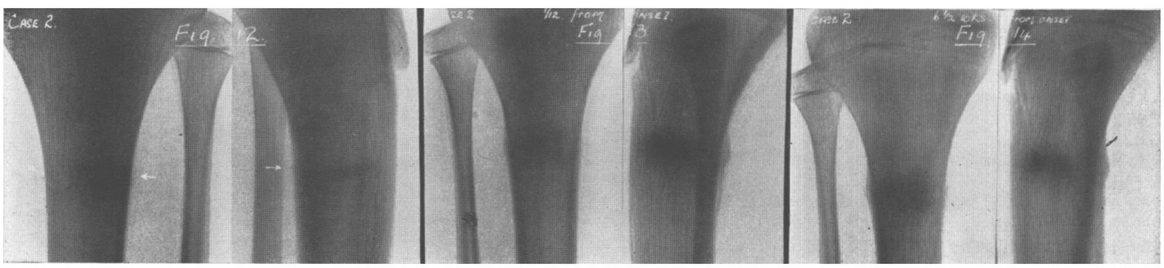

Fig. 12.
Case 2. The radiographs of the right tibia of a boy aged $14\frac{1}{2}$ years taken 17 days from the onset of pain, showing the diagnostic features of the cortical "nick" on the medial aspect with a tiny bead of callus only just visible on the lateral and posterior aspects.

Fig. 13.
Case 2. Same leg 14 days later (one month from onset). Callus at all sites has increased, and the sclerosis deep to it and seen right across the bone is now recognisable. It is this feature which enables one to give a confident diagnosis and a good prognosis.

Fig. 14.
Case 2. The same leg 17 days later ($6\frac{1}{2}$ weeks from onset). Callus organising. Still no suggestion of upward or downward spread of lesion. Patient now symptomless.

Treatment

The importance of early diagnosis of "stress" or "fatigue" fracture will be apparent from consideration of Cases 1–4 (Figs. 9 to 21B).

The early stages or mild cases (bone neuralgias) or mild examples of "periostitis" require only rest for a few days without immobilisation, followed by graduated resumption of weight-bearing and of muscular effort. See Cases 1 and 2 (Figs. 9 to 14).

"Stress" or "Fatigue" Fractures of Bone

The later stages and the more severe cases (periostitis more marked; or actual bone "fatigue") require more prolonged rest with immobilisation by plaster, and a more gradual resumption of weight-bearing and of exercise. Case 4; Figs. 20A to 21B.

The late stages, or very severe cases, will require immobilisation in plaster for weeks or months, and very gradual return to normal weight-bearing and exercise. It is in this type of case that consideration must be given in future to the question of operative interference. (See Case 3; Figs. 15 to 19.) Should one be satisfied that actual bone "exhaustion" (as defined by Henschen[13]) has occurred, it would seem reasonable to remove all bone which is incapable of complete recovery, exhibiting ultra-violet body baths and a full diet, so that the area from which defective bone has been removed may be restored by normal bone-materials.

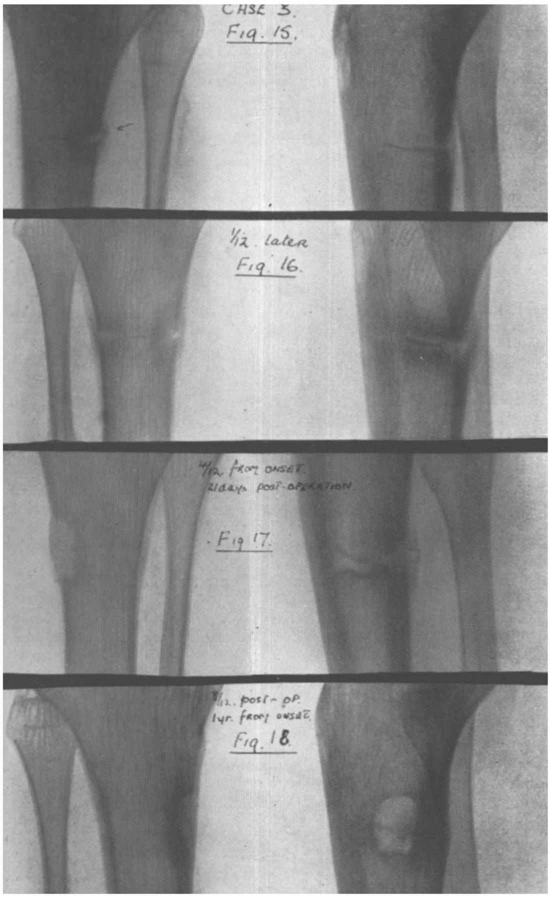

FIG. 15.
Case 3. Radiographs of a boy, aged 18 years, taken three weeks from the onset of pain. Note the cortical interruption and faint callus on the lateral aspect, and the fine dense line running across the shaft.

FIG. 16.
Case 3. The same tibia one month later (seven weeks from onset of pain). Infraction of cortex now visible on medial and lateral aspects. Callus has increased, and the area of osteoporosis is seen extending across and almost completely through the bone.

FIG. 17.
Case 3. The same tibia. Films taken 21 days after operation (16 weeks from the onset of symptoms). Operation area still clearly visible, but zone of osteoporosis has now almost disappeared. Callus is organising and the operation site filling in.

FIG. 18.
Case 3. The same tibia, seen at eight months after operation and twelve months after onset. The bone is now functionally sound and the patient at work and symptomless.

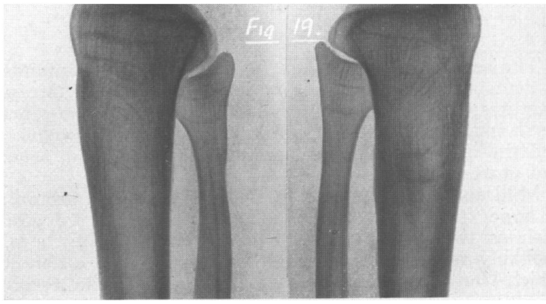

FIG. 19.
Case 3. Lateral views of right and left tibia for comparison two years later. There is still buttressing of the affected tibia posteriorly and increased density at the old "fracture" site. Patient symptomless, and when last heard of was serving in the army

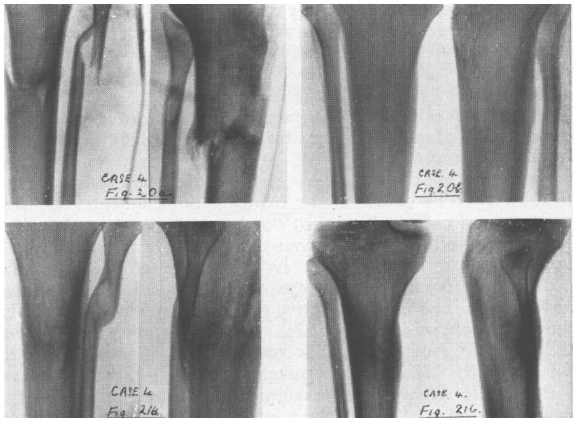

FIG. 20A.
Case 4. Radiographs of a rifleman, aged 21 years, showing fracture of tibia and fibula without violence, due to missed diagnosis and consequent inadequate treatment of "fatigue" fracture of tibia.

FIG. 20B.
Case 4. The opposite leg of the same case radiographed the following day. These appearances confirmed the diagnosis made the previous day on the left leg. History elicited confirmation of onset four months previously, during pace-marching.

FIG. 21A.
Case 4. Radiographs of the left leg seven months after fracture through both bones, showing excellent progress towards normal contours and firm bony union of both bones.

FIG. 21B.
Case 4. The opposite leg at the same time (that is eleven months from the onset of pain in that leg).

DIFFERENTIAL DIAGNOSIS

This lies between the following groups or conditions, and has been elaborated elsewhere within recent months.[11]

1. Pathological fracture in:—
   - Congenital defects.
   - General systemic disease.
   - Metastases; or bone tumours, etc.
2. Umbauzonen or pseudo-fractures in:—
   - Paget's disease.
   - Osteomalacia.
   - Rickets, etc.
3. Primary malignant disease of bone:—
   - Sarcoma.
   - Ewing's tumour.

4. Osteitis due to:—
   Tuberculosis..
   Syphilis.
   Low-grade hæmatogenous osteo-periostitis.
5. Simple fracture due to violence.
6. Osteomyelitis.

The series of illustrations (Figs. 9 to 21B) are intended to demonstrate the outstanding features typical of "stress" fractures; in particular the behaviour of the bone where rest is inadequate, the findings which indicate the prognosis, and the differences in healing time between mild, severe and untreated cases.

Mild and moderate cases represent in general, examples of bone "fatigue"; severe, and untreated or missed cases, such as the soldier which I have reported elsewhere,[11] probably represent true bone "exhaustion"—a difference which Henschen emphasises in his studies of the leptonic structure of bone and of fatigue dystrophies in bone.

SIGNIFICANCE

These infractions are important because of the following reasons: (1) Missed diagnosis may lead to recurrence or to involvement of the opposite leg, or to complete fracture of tibia and fibula. (2) Incorrect diagnosis may lead to unnecessary operation for suspected bone infection, and even to threat of amputation of a limb. (3) Correct treatment is simple and leads invariably to recovery. (4) The Medico-Legal aspect cannot be avoided (*e.g.*, re army pension in cases of discharge from the Services. The condition *may* be due to war service).

Much investigation remains to be done. Detailed observation of many cases by many observers should rapidly lead to a majority view or even to unanimous opinion regarding etiology, and there are new methods of investigation likely to be of use in the future. For example, the fact that normal cell replacement occurs more rapidly than has been imagined hitherto by many, is suggested by the recent investigations carried out by the use of radio-active indicators. Nearly all the ordinary chemical elements can now be obtained in radio-active modifications having exactly the same chemical properties as the usual forms. The radio-active isotope will accompany its inactive isotope through any series of chemical processes, but the active isotope can always be recognised by its radio-activity, which acts as a label enabling one to detect the presence of a particular group of atoms, and to follow this group throughout the chemical processes. Thus, if we wish to study the distribution of a certain element in a series of biological processes, we can mix it with a radio-active isotope and can follow the distribution by means of radio-activity.

Radio-phosphorus was first used as an indicator by Chiewitz and Hevesy[28] in the study of phosphorus metabolism in rats, and their experiments confirmed the idea that the mineral matter of bone is not in a dynamic state in which the bones are continually losing phosphorus atoms and taking up others. There is a kinetic interchange of phosphate ions between the plasma phosphate and the bone phosphate. The method has also been used to find out how much of the phosphorus taken in the food finds its way to the teeth—how rapidly the phosphorus atoms in the teeth are replaced by atoms originating in other organs of the body. It may well be that this method of using radio-active indicators will lead to exact estimation of the rate of replacement normally occurring in normal bone. We may therefore be able to establish, in the not far distant future, whether or not there has been, or actually exists at the time of symptoms, any deviation from the normal rate of replacement in "fatigue" fractures, and whether bone "exhaustion" disturbs or delays normal replacement.

It is written in the book of Ecclesiastes that "there is no new thing under the sun," but here in our own observations of the behaviour of this type of fracture at the sites which I have mentioned, and in their correlation with the discoveries which are certain to eventuate from this new application of science to medicine, I think it may be safely claimed that there is something not only new, but of absorbing interest to those whose work or hobby it is to study the structure and behaviour of bone.

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