RADIOLOGICAL CRITERIA IN DIAGNOSING DYSBARIC OSTEONECROSIS

JOHN A. B. HARRISON

The purpose of this presentation is to define the criteria by which it is possible to make a definitive radiological diagnosis of the lesions of dysbaric osteonecrosis (McCallum *et al.*, 1966). The difficulty in an accurate early diagnosis of these lesions is twofold: Is one looking at a variant of normal bone structure (Blank and Lieber, 1965; Kim and Barry, 1968; Ngan, 1972), perhaps a minor dysplasia of bone; or is one looking at aseptic bone necrosis caused by something other than a dysbaric environment (Bucky, 1959; Golding, 1962, 1966; Edeiken, 1967; Jaffe, 1969)?

Most investigators are now familiar with the following classification of lesions, which frequently precede symptoms. Developed in England by the Medical Research Council's Decompression Sickness Panel, this classification has received fairly wide international acceptance as radiological evidence of early aseptic bone necrosis.

Juxta-Articular

A1 Dense areas with intact articular cortex
A2 Spherical segmental opacities
A3 Linear opacity
A4 Structural failures
  a. Translucent subcortical band
  b. Collapse of articular cortex
  c. Sequestration of cortex
A5 Secondary degenerative arthritis (osteoarthritis)

FIG. 1. (*a*) Standard survey X-ray film of a shoulder, in which a juxta-articular lesion can be seen. (*b*) Inferosuperior view of same shoulder, showing lesion more clearly.

Head, Neck, and Shaft

B1 Dense areas (*not* bone islands)
B2 Irregular calcified areas
B3 Translucent areas and cysts
B4 Cortical thickening

As Dr. McCallum has mentioned in this Symposium, these criteria have been used in England for a considerable time (Golding *et al.*, 1960; Davidson, 1964; McCallum, 1968; Davidson and Griffiths, 1970; Walder, 1970). One great advantage of their use in a survey of aseptic bone necrosis is their applicability to the whole gamut of lesions caused by exposure to pressure changes. It has been found that this classification applies both to the more extensive, more rapidly developing lesions of caisson workers and to the apparently less serious, more slowly developing lesions found in Royal Naval divers. The individual lesions have been described many times; but, basically, a radiological diagnosis of osteonecrosis can be made when ill-defined densities or translucencies are detected, provided that these changes are definitely pathological.

For those experienced in diagnosing osteonecrosis, the real problem concerns juxta-articular lesions. One can usually be certain about dense areas found close to the articular cortex (A1 lesions). But the exact description of A2 lesions, such as spherical segmental opacities, has long been argued. Opacity is fairly obvious in an advanced lesion; but in an early lesion it is difficult to be certain on a single radiograph. The linear opacity of A3 lesions is somewhat easier to identify. Radiological identification is more certain with the structural failures involved in A4 lesions. Degenerative arthritis caused by aseptic bone necrosis must be distinguished from arthritis of other etiology. It does appear that the joint space is maintained rather longer in degenerative arthritis resulting from dysbaric osteonecrosis than from other causes.

Figure 1*a* shows the standard survey view used for the shoulder, in which a lesion can be seen. The inferosuperior view (Fig. 1*b*) shows this lesion much more clearly, with a lucent area just below the cortex and ill-defined densities in the head. The question of how far to go with radiography immediately arises. The Royal Naval approach is to carry out the initial survey with a minimum number of radiographs and then to investigate any doubtful lesions found with further radiographic projections.

Figure 2 shows the progression of one of the few juxta-articular lesions found among Royal Naval divers. The subject had ceased active

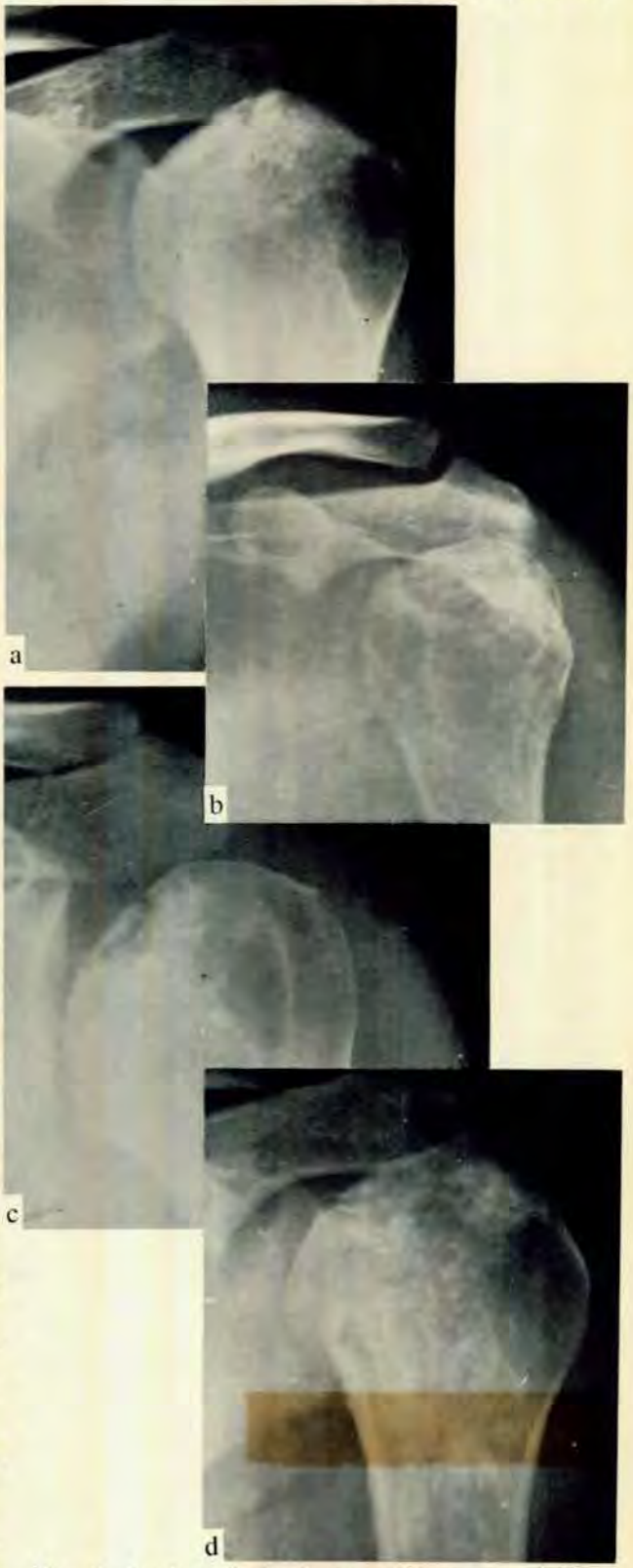

FIG. 2. Juxta-articular lesion of humerus of diver in (*a*) 1960; (*b*) 1963; (*c*) 1964; and (*d*) 1967.

FIG. 3. A-P and lateral views of medullary lesions in femora and tibiae.

diving when he was included in the 1967 X-ray survey conducted by the Royal Navy (Elliott and Harrison, 1970; Harrison, 1971). Once the lesion (which is extensive compared with those found in other RN divers) was found, a search was made of RN X-ray film records for earlier evidence of bone disease in this man. The radiographs made in 1960 and 1963 show earlier collapse of the articular cortex. This degeneration, in which the intact articular cortex collapses into the area of necrosis below, is typical. The 1964 radiograph clearly shows separation in the cortical area. By 1967 the cortex is disrupted and there are widespread opacities and lucencies in the humeral head, indicating a large area of aseptic bone necrosis. Since the subject continued diving after 1960, progression of the disease process in this instance was obviously a relatively slow one, even for a juxta-articular lesion (although this lesion did produce symptoms).

Figures 3 and 4 illustrate lesions in the neck and shaft of the tibiae and femora, which Lent Johnson, M.D. (personal communication, February 1972), suggested should be differentiated. He may be correct in his assertion that, pathologically, there are different types of lesions. But it is not possible to differentiate among them on an ordinary radiograph; it is difficult to state with certainty whether a lesion is in cancellous or medullary bone. *Cortical thickening* is perhaps a crude term, because a radiologist can divide the cortex into periosteal, cortical, and endosteal bone. Perhaps this term should be refined in the classification.

Most of the symptomless lesions found in Royal Naval divers are of the B2 type. These are the irregular calcified areas described in earlier papers (Kahlstrom *et al.*, 1939; Allan, 1943; Poppel and Robinson, 1956). It is difficult to judge to what extent the radiographic record of a lesion accurately reflects its actual extent, as illustrated in Fig. 3 and 4. But it is possible to define radiologically the extent of a femoral lesion much more accurately if a lateral view of the knees is available. A 15″ × 12″ film is used because, in British experience, femoral lesions extend quite a distance up the shaft; the lesions are not quite so extensive in the shaft of the tibia. It is therefore important in a survey to include more of the femora than of the tibiae when X-raying the knee region.

It is not vital to specify a rigid radiographic technique to be used in a survey of divers' bones. Different investigators use different methods, but comparison is facilitated by using standardized radiographic projections. High-quality radiographs with good bone detail are necessary so that any developing minor lesions, which may become apparent only on serial (annual) X-rays, might be assessed. This objective is difficult to achieve in a survey involving large numbers of people, when X-rays are taken in different establishments, and when it is desirable to limit the radiation of the subject.

It has been the practice in RN surveys to take a single A-P X-ray of each shoulder and hip, and A-P and lateral films of the knees. A definite positive lesion has not been found in the hips of RN divers, but it may well be that the frogleg position is rather better than the A-P in revealing these lesions.

A screen film with a Bucky, where suitable, is used. Every effort is made to protect the gonads from ionizing radiation by using a gonadal shield, particularly in projections of the femoral heads. For all projections except the knees, 12″ × 10″ radiographs are used; knees are X-rayed on 15″ × 12″ films (both A-Ps on one and laterals on another).

Because positive identification of early lesions of dysbaric osteonecrosis is difficult, it is important to substantiate the subjective impression by a second reading. The results must obviously be recorded at whatever facility the X-rays are taken in the event that a lesion requiring immediate attention is found. But the films should then be sent to a central registry for reading and comparison with any earlier films of the subject to detect any minor alterations of trabecular structure and density, which are often the earliest signs of a lesion, particularly in the shaft. These lesions have been the ones most frequently found in RN divers.

The actual radiographic instructions used in the RN survey are as follows:

Shoulders

A-P radiographs of each head of humerus and proximal shaft. The trunk is rotated to bring the shoulder in contact with the table with the arm pulled down in a neutral position. Cone to show as much humerus as possible, but bring the lateral diaphragms in as much as possible to show only the head and shaft of the humerus.

Hips

A-P radiographs of each femoral head and proximal shaft. Center over the head of the femur (*i.e.*, 1″ below the midpoint of a line joining the anterior-superior iliac spine and upper border of the pubis symphysis. Cone with the light beam diaphragm to give a 4″ × 4″ result. The feet should be at a 90° angle with the table top.

Knees

A-P and lateral radiographs of each knee, including the distal femur from its midpoint and the proximal tibia and fibula to about the midpoint.

Instructions to the three or four centers at which the X-rays are taken stress that the humeral head must be clear of such structures as the acromion and the edge of the glenoid. The problem of overlapping is the same in the hip, which is why the frogleg position may possibly be better than the A-P projection as a single view of that joint. With the knee, it is primarily important to get good bone detail, including a fairly lengthy portion of the femoral shaft, as was said.

A three-year survey of 383 clearance divers completed by the Royal Navy in 1969 initially revealed 16 divers with positive lesions of osteonecrosis and 11 divers with doubtful ones. Further investigation was concentrated on the lesions in the 11 doubtful cases; by tomographs and further radiographic projections, 4 doubtful cases were eliminated. These 4 men have continued diving since 1970 and have had further annual X-rays; in our opinion they have remained radiologically negative. This reduction of doubtful cases from 11 to 7 resulted from further radiologic investigation leading to an altered opinion regarding the lesions. Of the remaining 7 doubtful cases, only 3 so far have had further radiological investigation and they remain doubtful. Two cases have not yet been traced for further X-ray (they have left the Navy). And 2 have not yet been X-rayed again.

Because of the possible differential diagnosis of dysbaric osteonecrosis, the following control sample of 100 nondiving naval personnel in the same age groups as the RN diver sample was X-rayed:

Rank	Age	Number
Lieutenant Commander	31 to 47	6
Lieutenant	23 to 30	11
	34 to 45	4
Sub-Lieutenant	29 to 34	2
Chief Petty Officer	32 to 49	9
Petty Officer	25 to 39	28
Leading Seaman	20 to 33	20
Able Seaman	to 30	20

It is felt that the samplings were comparable in every way, yet the control group revealed none of the bone lesions found in the X-ray films of the RN diving population.

The extensive differential diagnosis listed below tabulates pathological conditions in which aseptic bone necrosis undoubtedly occurs. From a radiological standpoint, however, the differential diagnosis is probably of significance only in the diseases marked with a single asterisk; in those marked with a double asterisk, the exclusion of other causes by diagnostic means presents a difficulty:

Diabetes mellitus	Trauma
**Chronic alcoholism	Rheumatoid arthritis
**Hypercorticism	Autoimmune arthritides
Cirrhosis	Gout
Hepatitis	Ionizing radiation
*Blood dyscrasia	*Syphilis
*Gaucher's disease	**Chandler's disease
*Chronic pancreatitis	Arteriosclerosis

Caisson's disease

There are, of course, other conditions in which aseptic bone necrosis occurs, but most of them can be accurately identified by radiology or by other methods of investigation. In all events it is felt that such conditions are not of common concern in naval divers.

Figure 5 illustrates another aspect of the differential diagnosis of osteonecrosis: *i.e.*, differentiating osteonecrotic lesions from other localized bone lesions. It was originally considered that the defined sclerotic area in this film of the fibula was a positive B2 lesion. But the Newcastle MRC decompression registry contained no X-rays of lesions in the fibular neck. We therefore remained doubtful, even though it is known that the Japanese have found lesions in the fibular neck in divers (Nagai and Ibata, 1965; Matsunaga and Shigeto, 1967; Asahi *et al.*, 1968). At this stage of reading the films, nothing was known of the diver's history. Although he had done some "dry" dives, he had been exposed to pressure changes mainly at high altitudes. A needle biopsy was carried out and the lesion proved to be an enchondroma.

Since completing the 1967–1969 survey we have continued X-raying a similar sample of RN divers annually. An extract of the results, shown in Table I, reflects the development of a lesion in serial observation. The recorded change is based not on radiological interpretation but on the appearance of the lesion itself. In 1967, Case 46 had, it was thought, a possible lesion in the left lower femur; by 1971 there were positive

FIG. 4. A-P and lateral views of lesions in distal femora.

Table I. PROGRESSION OF LESIONS IN TWO CASES TAKEN FROM RN OSTEONECROSIS SURVEY

Case no.	Year of X-ray	X-ray classification	Humerus (head and shaft)		Femur (upper)		Femur (lower)		Tibia (upper)	
			R	L	R	L	R	L	R	L
46	1967	–	–	–	–	–	–	?	–	–
46A	1971	+	–	–	–	–	B2	B2	–	–
105	1967	?	–	–	–	–	?B2	–	–	?B2
105A	1971	+	–	–	–	–	B2	?B2	–	B2

lesions in both lower femurs. In the interim the subject had been in the United States doing extensive diving in the SeaLab program. The U.S. Navy kindly sent us films taken in 1970 and 1971, in which a slight progression was evident between the two dates.

In Case 105, the survey similarly revealed two doubtful lesions in 1967 that, by 1971, had extended and were considered positive. The management of a doubtful case detected in our survey is different from that of a positive case. In our records, the notation *doubtful lesion* indicates that the existence of a lesion is uncertain and serial observation is necessary for a definitive

FIG. 5. Lesion in fibula of diver, originally thought to be B2 lesion, but shown on biopsy to be enchondroma.

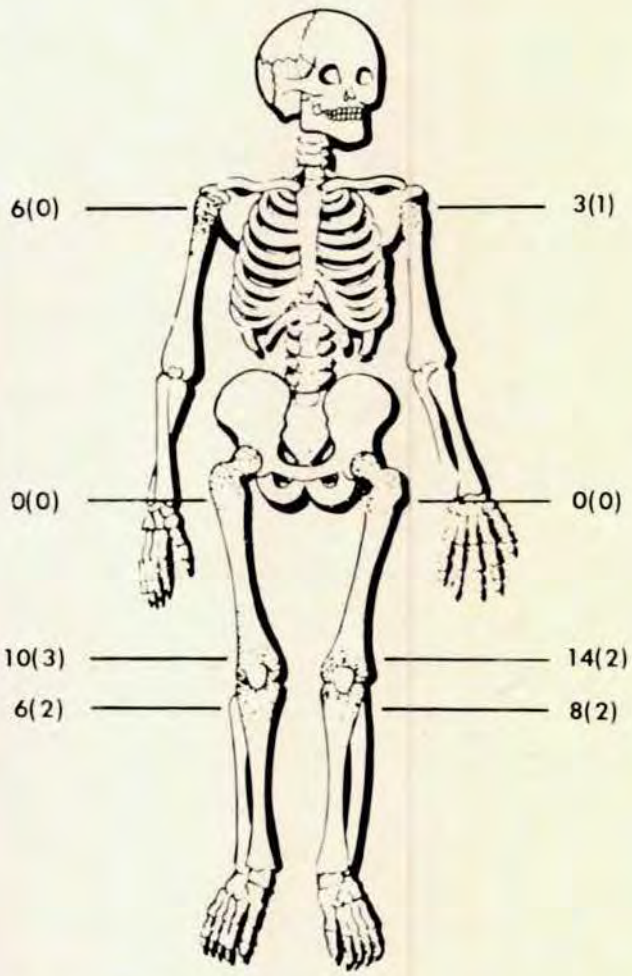

FIG. 6. Final determination (31 December 1971) of distribution of osteonecrosis lesions found in 19 positive cases among 383 clearance divers in 1967-1969 Royal Navy survey: 47 positive lesions and 10 doubtful ones (latter noted in parentheses).

diagnosis. This procedure is probably far more relevant in surveys of civilian divers than in the closed community of naval divers. In either group, a doubtful case needs closer surveillance than a single doubtful lesion.

Since the RN survey was completed (in 1969), three additional cases of osteonecrosis have developed in the sample, bringing the total of positive cases to 19. The distribution of lesions is shown in Fig. 6. In our early reading of the films some doubtful lesions were found in the hips in several divers, rather like those that Dr. Fagan has illustrated in this Symposium. But it is now our opinion that the lucent areas near the capsule attachment are not caused by aseptic bone necrosis. In some cases several positive lesions are evident; multiple lesions help greatly in making a definitive diagnosis in a particular case.

In Fig. 7 is shown the distribution of lesions in the cases still considered doubtful at the conclusion of the survey. It may be that the shoulder lesions are both difficult to detect and less common in divers.

The radiological classification set out in the beginning of this paper is the one that we should like to see adopted for all X-ray surveys, both of caisson workers and divers. A radiologist might find this classification quite difficult to apply in individual cases and to particular lesions. It may be impossible to classify precisely a mixed lesion as being A1 or A2. But an accurate analysis of the very minor change in the trabecular structure in an attempt at classification does help in detecting the early lesions of osteonecrosis.

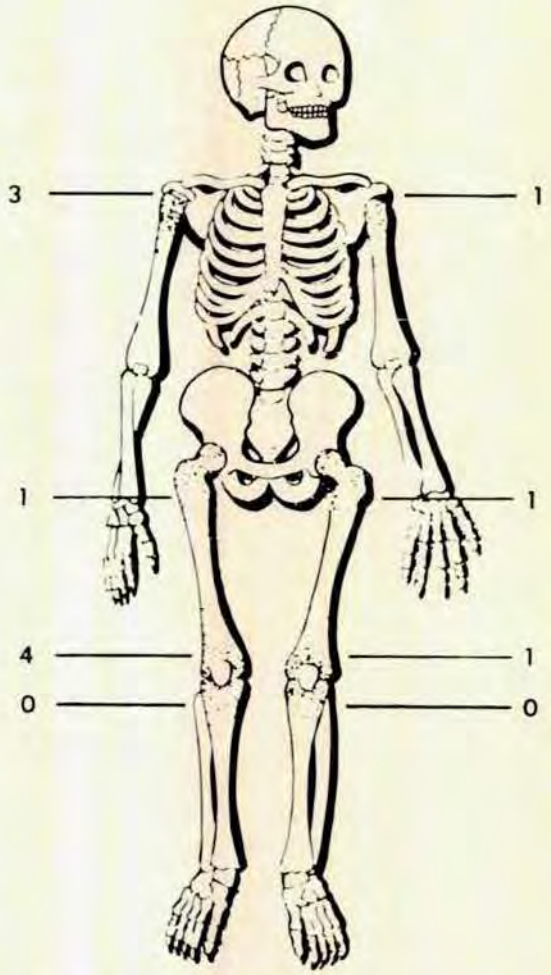

FIG. 7. Final determination (31 December 1971) of distribution of suspected lesions in seven doubtful cases among 383 clearance divers in 1967-1969 Royal Navy survey.

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