STUDIES IN CALIFORNIA PALEOPATHOLOGY:

II. COMMINUTED FRACTURE OF A HUMERUS WITH PSEUDOARTHROSIS FORMATION

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T. Dale Stewart (1974) has recently called attention to several prehistoric New World cases of one of the orthopaedic surgeon's worst fears - nonunion of fractured bone. In his review of five new cases of nonunited fractures of the forearm, Stewart presents several instances of pseudoarthrosis, i.e., 'false joint,' accompanying the nonunited fractures. While Stewart's discussion centers on the questions of recognition and differential diagnosis of forearm fracture nonunion, the present paper presents a case of pseudoarthrosis of the humerus following a comminuted fracture and discusses the etiology of false-joint formation.

Description of Case (LMA # 12-6430)*

The specimen is from Marin County, CA, site CA-Mrn-242, also known as the Cauley Mound. Field notes from Mrn-242, in the possession of the Archaeological Research Facility, Berkeley, contain only information about burials rather than the site in general. Unfortunately the notes associated with this burial are missing and we cannot, therefore, discuss associated artifacts and attendant dates for the material.

Pelvic morphology, general skeletal robusticity and size of articular surfaces indicate a male specimen of adult age. Definitive aging is not possible because there is no pubic symphysis or cranium; however, all extant epiphyses are closed.

The left humerus has sustained a comminuted fracture (i.e., bone broken into three or more fragments) with subsequent formation of a pseudoarthrosis (or pseudarthrosis). The bone was originally fractured into three segments, the two fracture planes located 1) approximately 12 cm from the proximal extremity and 2) just proximal to the deltoid tuberosity.

The proximal end of the middle fragment has been drawn superomedially and is now fused to the medial surface of the proximal fragment just below the surgical neck. There is strong callus formation with extensive remodelling to give the union a smooth surface appearance. The fused middle fragment projects 35° inferomedially from the proximal segment.

A pseudoarthrosis has formed between the distal end of the middle fragment and the proximal end of the distal humeral segment to the extent that a well-formed ball-and-socket joint has developed. The proximal aspect of the false-joint presents a concavity directed inferolaterally, approximately 4 cm X 6 cm in diameter, with the greatest curvature of the concavity in the superior aspect of the articular surface. The concavity itself has been formed from remodelled callus and appears as a rounded expansion of the fused middle fragment when viewed from its medial aspect. The distal articular surface, directed superomedially and slightly posteriorly, is convex and slightly larger around than the more distal shaft diameter (in part the result of the deltoid tuberosity).

*LMA = Lowie Museum of Anthropology

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Both false articular surfaces evidence deep pitting. But the outline of the articular surfaces is rather smooth without any noticeable bony projections from the surfaces, thus allowing a rather freely moving joint restricted only by the fibrous capsule which probably surrounded the pseudo-arthrosis.

The pitting noted in the articular surfaces is also seen to extend distally a few centimeters from the proximal end of the distal fragment. The pits are of a smaller size here and they are accompanied by a few small foci of newly-formed bone (probably of periosteal origin). Some of the pits have the appearance of sinus tracts which extend into the medullary cavity.

Examination of the radiographs of the fracture fragments reveal a picture consistent with the gross appearance of the bones. The fused fragments show extensive remodelling and solid fusion throughout their area of attachment. The distal fragment is notable for the appearance of several focal radiolucent areas representing bone lysis as is typically seen in osteomyelitis. The reactive new bone formation and the pitting/sinus tract formation are consistent with this possibility of bone infection.

Discussion

Aegerter and Kirkpatrick in their discussion of fracture healing state that

if bone production is deficient and the healing process delayed substantially beyond a year, especially in the areas in which there is repeated motion, a pseudarthrosis is likely to be formed. The organism is slow in bridging with rigid bone an area in which motion is constant. Instead the callus remains fibrous and pliable. Evenutally a bursa-like sac develops in the region and its walls may undergo cartilaginous metaplasia. This is a marvelous imitation of a joint with articular plates covering the bone ends, an illustration of the adaptability of tissues to new environmental conditions. (1975:235)

The initial problem, then, in pseudoarthrosis formation is the delayed union of fractured bone, continuing to a state of nonunion with subsequent false-joint formation. The distinction between delayed union and nonunion of fractures is important. In the former the processes of bone repair are retarded but still going on and, with sufficient time (and ideal healing conditions), should produce bony union; in the latter the reparative processes have stopped. There are many causes of delayed and nonunited fractures and the two processes can be seen as a continuum which is affected by various etiologic agents acting in concert with individual variability to repair damaged tissue. These causes include (after Verbeek and Dubbelman 1962, Lichtenstein 1970, and Rosse and Clawson 1970):

nature of the fracture (is it simple or compound, greenstick or comminuted?)
size of the fracture surfaces (can they be adequately apposed?)

distance between fracture surfaces (is the distance too great to be
    bridged?)
loss of bone substance (again, can the distance be bridged or will the
    extremity be shortened?)
condition of adjacent soft parts (is circulation impaired? do soft
    tissues intervene between fracture fragments?)
infection (is the fracture compound?)
constitutional factors (age, nutritional status, systemic diseases, etc.)
quality and nature of treatment (is infection controlled? is there
    adequate immobilization and is it applied long enough? is bony
    apposition sufficient? is there adequate alignment of fragments?).

If the individual's healing abilities, in concert with one or more of the
above factors, are inadequate to the task, then delayed union or nonunion
will result. The boundary between these is rather arbitrary as Verbeek and
Dubbelman (1962) note; the important elements appear to be time and the
adequacy of callus formation.

Although we have noted the many causes of delayed and nonunion of
fractures, the single most important element leading to pseudoarthrosis
formation apparently is inadequate immobility of the fracture site. Con-
tinued movement at a fracture site inhibits the vascular growth and
metaplasia necessary for callus formation. Even intermittent movement may
disrupt the integrity of an already formed but weakly developed callus. In
short, pseudoarthrosis may be seen as the result of repair with motion. As
long as motion is present cartilage will develop from the fibrous tissues
of the fracture site and will remain and function as cartilage until
completely immobilized.

Even in nonunited fractures, the fragments may be connected by fibrous
or fibrocartilaginous connective tissue; but in a pseudoarthrosis the bone
ends are covered with hyaline cartilage and the joint space is surrounded
by a thick bursal sac containing synovial fluid (Shands and Rainey 1967).
Strictly speaking, then, even a 'nonunited' fracture may be united.

Regarding the importance of adequate, sustained immobilization, Cameron
(1966) presents the results of a series of experimental studies of shaft
fractures in the femoral diaphyses of dogs. The importance of immobili-
zation apparently lies in its ability to prevent or reduce torsion in the
fracture fragments, thereby allowing adequate vascularization, metaplasia
and callus formation.

At this point we should entertain the possibility of whether this
fractured humerus had been immobilized, at least for some period of time.
Obviously, without direct evidence of splints or other devices we cannot be
sure; but the ethnographic record would argue for its possible presence.
In his treatise on American Indian therapeutics and medical practices,
Vogel makes the following general observation regarding the empirical
treatment of obvious injuries:

Indian treatment of externally caused injuries, in which the
origin of the ailment was perfectly obvious, was usually
rational and often effective. In such a category were fractures,
dislocations, wounds of all kinds, including snake and insect
bites, skin irritations, bruises, and the like. (Vogel 1970:13-14)

Specifically in regard to handling fractured bone, he notes the following:

An interesting native achievement in fracture treatment was the
use of form-fitting splints. Padding of wet clay or rawhide
was often used, as well as poultices. The Ojibwas washed a
fractured arm with warm water and greased it, applied a warm
poultice of wild ginger and spikenard, covered with a cloth and
bound the arm with thin cedar splints. The Pimas used splints
from the flat, elastic ribs of the giant cactus. The Mescalero
Apaches rubbed dislocated parts until warm and then with a
quick jerk forced the bone into place, rubbing medicine on
afterward to allay the pain, and finally tied with a bandage.
In fractures, rubbing and straightening as well as pain-
allaying medicine was employed, and finally sticks were applied
all around as splints, being bound tightly with rags. (Vogel 1970:215)

What, though, about the situation for California? Culley (1936:337)
has noted that California Indians used a species of Datura as an anesthetic
for patients who were having fractures set. Bard, an early California
physician, makes mention of the use of splints by native Californians
during the 1800's:

Quite a number of the thousands of skeletons which have been
exhumed in Southern California show evidences of fractures
which have been so nicely adjusted that no deformity resulted.
To accomplish this purpose they used splints made of wood or
of tules, twined together and smeared with asphaltum. (Bard 1930:22)

Fractures were a not uncommon injury in prehistoric California as
attested to by the numerous examples in the literature. Roney (1959) found
fourteen fractured bones in six individuals; Brabender (1965) noted up to
4.5% of the population of Ala-328 sustained fractures; and Ryan (1972),
working with additional material from Ala-328 found an even higher
percentage. Ryan does note that of seventeen long bone fractures, fully
fifteen show malunion or pseudoarthrosis. He concludes by saying "the
evidence also points strongly to the fact that these people did not set
broken bones or in any way use great care to immobilize them." (Ryan
1972:28)

The ethnographic record, then, would have us believe that fracture
setting and immobilization were not unknown to native Californians, while
the archaeological record would severely weaken the notion of its presence,
or at least its efficiency. One possible interpretation, which includes
the merits of both arguments, is that some knowledge of fracture management

(setting and immobilization) was probably present but was, at the same time, inefficient. The argument for some sort of immobilization practice could be made solely on the grounds of its use to reduce pain without having to argue for its utilization as a device to immobilize realigned fracture segments. In the initial stages of fracture healing, before callous formation begins, immobilization (with or without rigid splinting) helps immeasurably to reduce the pain associated with the traumatic incident. Once callus formation began and the fracture site became somewhat stabilized intrinsically, the pain would be lessened and, if splints were used, they might be discarded regardless of the adequacy of alignment the fracture segments displayed. So splinting for immobilization to reduce pain may indeed have been practiced, even immobilization for realigned bone fractures but without modern radiographic techniques or internal fixative devices at their disposal, we should not expect much better results than the archaeological record tells us. We should also keep in mind that well-set and -immobilized fractures after a period of time will escape our detection unless a radiographic survey is performed to seek them out.

A combination of imperfect immobilization (thus allowing movement about the fracture site) and infection create a milieu for pseudoarthrosis formation that is vastly superior to either one alone. The gross and radiographic appearances of the fracture fragments would argue that an osteomyelitis was present at the fracture site, though probably of low-grade virulence and partially healed. The fragmented, comminuted nature of the fracture might allow us to propose that the fracture was also compound, i.e., fracture fragment/s protruding through the skin. With the proximal fragment being abducted to the degree it is here it is quite probable that its sharpened distal end penetrated the fibers of the overlying deltoid muscle, subcutaneous tissues and skin. A port of entry was thus readily available for microorganisms to penetrate to the traumatic region and allow infection to begin. That the infection was not terribly virulent, or host resistant very low, can be seen in the degree of healing and remodelling. The healing and remodelling, however, we can assume took place at a much slower rate than normal.

The literature distinguishes three kinds of pseudoarthrosis: congenital, defect, and pseudoarthrosis in the strict sense. Aegerter and Kirkpatrick (1975:184) have defined the congenital, hereditary variety as "a pathologic entity characterized by deossification of a weight-bearing long bone, bending, pathologic fracture, and inability to form normal callus in healing." Defect pseudoarthroses occur following injuries which cause large osseous defects and are often associated with soft tissue damage and infection (Verbeek and Dubbelman 1962:5). Pseudoarthrosis in the strict sense refers to false-joint formation following delayed or nonunion in the manner we have been discussing so far.

The specimen presented here reveals the typical appearance of a pseudoarthrosis with a ball on the longer and a socket on the shorter fracture segments. Because of the loss of normal functional movements in many instances, the bones distal to the pseudoarthrosis become decalcified;

but since the forearm, wrist and hand bones are missing we cannot examine this phenomenon here. The highly developed nature of this false ball-and-socket joint, though, suggests a fairly loose, unstable joint with at least a moderate loss of normal distal functions.

The fracture fragment ends in a pseudoarthrosis are nearly always broadened and this should be considered a degree of adaptation. For as Verbeek and Dubbelman (1962:10) note, "with failure of union, nature resorts to the makeshift of a broadening of support surfaces (bone ends) and the formation of a fibrin capsule of connective tissue to connect these surfaces. This leads to an unusual structure [the pseudoarthrosis]."

Shands and Rainey (1967) note that ununited fractures (with or without pseudoarthrosis) of the middle third of the humerus are relatively common (no figures given) and usually result from inadequate initial approximation of the fragment ends and poor immobilization. In all probability this was the case for our prehistoric resident of Marin County. That adequate apposition and realignment was not obtained is obvious. However, we are confronted with interpreting a comminuted fracture in which one end (the proximal) of the middle fragment fused while the other end failed to do so. Adequate interpretation here relies on a knowledge of muscle attachments, i.e., their origins and insertions, and their pull on bone fragments when there is a complete fracture. Muscle pulls on fracture fragments usually present a characteristic appearance.

In this instance the proximal fracture site shows overriding of the proximal fragment and shortening. This consequence is produced by the action of the supraspinatus m., which inserts on the greater tubercle of the humerus and abducts the proximal fragment while the long muscles which bridge the fracture site (i.e., deltoid, coracobrachialis, biceps and triceps mm.) draw the distal fragment superiorly. The result of this overriding and shortening is a fairly well immobilized, but poorly apposed, proximal fracture site. Even without proper, sustained immobilization this fracture site has a fair chance of uniting. The distal fracture site which has been drawn superiorly by the action of the long muscles mentioned above, does not have the stability of the proximal site resulting from the impaction caused by overriding and shortening. Consequently the distal fracture site is liable to much more instability and motion – the perfect prerequisites for pseudoarthrosis formation. Mobility of the proximal fragment is also greatly lessened by the counterbalanced pull of the muscles which make up the so-called rotator cuff.

An omnipresent problem in paleopathological analysis and interpretation is the differential diagnosis of the specimen. Stewart (1974) concludes his discussion of nonunited forearm fractures with a plea to keep in mind the simpler explanations rather than exploiting the more bizarre opportunities which, although certainly more exciting, have no better basis in terms of etiology. Stewart cites two cases of supposed amputation (Brothwell and Moller-Christensen 1963; Saul 1972) and reasonably argues that nonunited fractures are just as viable alternative interpretations.

More recently in this regard, Rogers (1973) has presented a case of putative amputation at the midshaft of the humerus from aboriginal Peru. The specimen is the proximal half of a humerus with a smoothly rounded end and without the distal fragments. Rogers' interpretation of this specimen apparently relies heavily on the indirect association that since the precolumbian Peruvians practiced surgery, i.e., trephination, and since a pottery figurine depicts a man with an amputated foot and stump cap, they must have practiced surgical amputation; therefore this specimen represents such an instance. This argument appears reasonable, and it is; but other possibilities (i.e., a differential diagnosis) must be entertained and this Rogers has failed to do. Even granting this is a case of amputation, to emphatically state it is surgical in origin precludes the possibility of autoamputation through some disease process (e.g., leishmaniasis, blasto-mycosis, leprosy, gangrene and others) or the remains of a nonunited fracture or pseudoarthrosis.

The point is, whenever one is faced with a diagnostic problem in paleopathology one should, just as the practicing physician, propose a differential diagnosis and not exclude, without good reason, any diagnostic alternative which could manifest itself in the form at hand. A single disease process may have numerous and highly variable manifestations, but many distinct diseases and other processes often appear identical. This is especially true in the interpretation of dry osseous lesions in which a more definitive diagnosis based cellular detail cannot be accomplished.

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Plate 1:   Fractured humerus with pseudoarthrosis formation, site Mrn-242
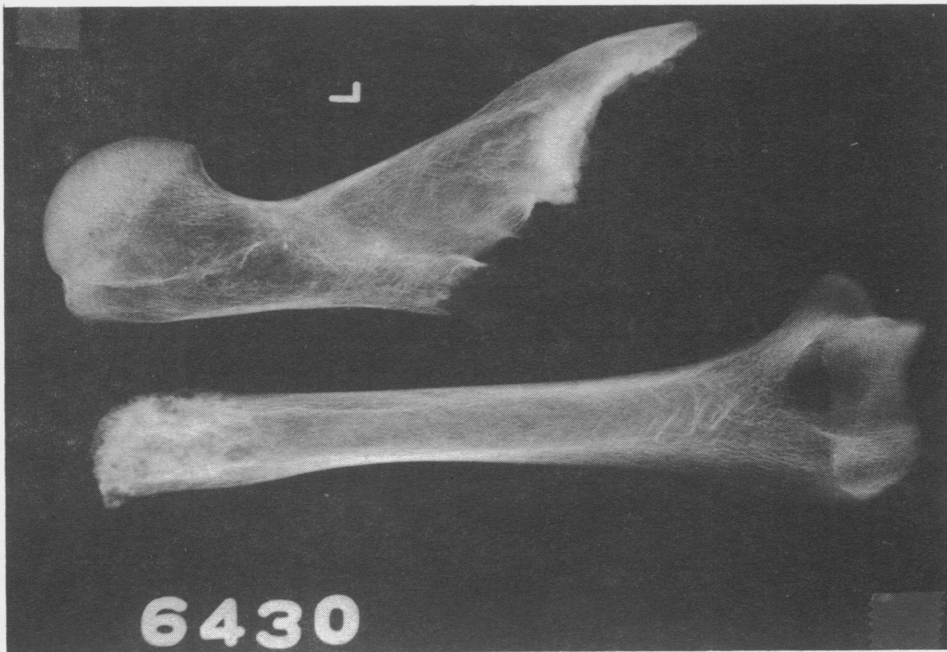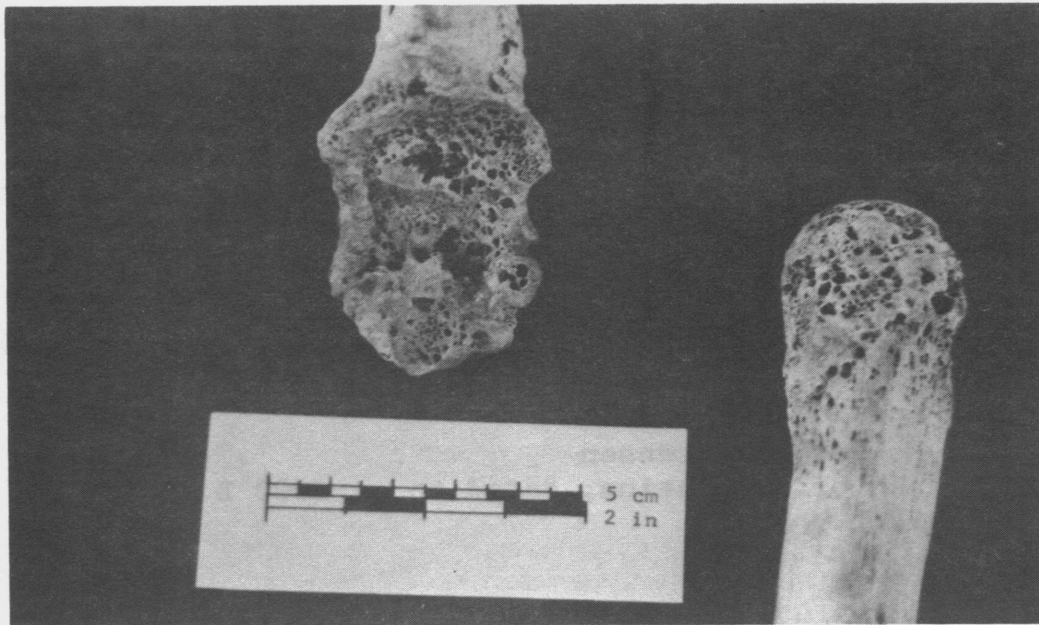
Plate 2:   Detailed view of articular surfaces of pseudoarthrosis
           X-ray of pseudoarthrosis.

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