Kenneth A. R. Kennedy,[1] *Ph.D.*

Morphological Variations in Ulnar Supinator Crests and Fossae as Identifying Markers of Occupational Stress

REFERENCE: Kennedy, K. A. R., "**Morphological Variations in Ulnar Supinator Crests and Fossae as Identifying Markers of Occupational Stress,**" *Journal of Forensic Sciences*, JFSCA, Vol. 28, No. 4, Oct. 1983, pp. 871-876.

ABSTRACT: Recent morphometric studies of ulnae of prehistoric skeletal remains from populations known to have used spears, atlatls, and similar projectile weapons for hunting and warfare reveal a high incidence of hypertrophy of the ulnar crest, to which the supinator muscle is attached, along with pronounced depth of the adjacent supinator fossa, especially in the upper extremities of males. Similar features occur in the right ulnae of living persons of both sexes who are habitually engaged in certain occupational and athletic activities involving angular displacement of the forearm as a result of medial rotation of the arm at the shoulder, shoulder and arm rapid extension, and abrupt shifts from forearm supination to pronation. Aside from its forensic science implications in determination of right- or left-handedness as a trait peculiar to the individual, observation of these markers of stress on the proximal end of the ulna are significant in identification of skeletal remains of persons known to have engaged in specific brachial activities during life. The biomechanics of these movement patterns and activities in which they occur, when properly interpreted, are relevant to forensic science problems of individual identification and paleoanthropological studies of occupational stress factors in extinct populations for which a skeletal record is available.

KEYWORDS: physical anthropology, musculoskeletal system, human identification, occupational stress markers, ulnar supinator crests and fossae

Laboratory studies of prehistoric skeletal remains from terminal Pleistocene archaeological sites in central India have led to observations of a high incidence of hypertrophy of supinator crests associated with considerable depth of adjacent supinator fossae on the ulnae of specimens identified as adult males. Well-marked ridges marking the insertion of the anconeus muscle were noted as well on these skeletons. These features of muscular robusticity were especially prominent on right ulnae. Skeletal specimens identified as adult females do not exhibit these modifications of supinator crest and fossa and anconeus ridge attachment to the same degree as males, nor do preadult skeletal specimens of the same study series show these traits [*1*] (Fig. 1).

These observations led to an investigation of (1) the frequency of these traits in other prehistoric skeletal series from South Asia as well as from mortuary sites outside of the Indian subcontinent, (2) the biomechanical-behavioral factors operative in producing these developmental

Received for publication 20 Aug. 1982; revised manuscript received 22 Jan. 1983; accepted for publication 25 Jan. 1983.

[1]Professor of ecology, anthropology, and Asian studies, Division of Biological Sciences, Cornell University, Ithaca, NY.

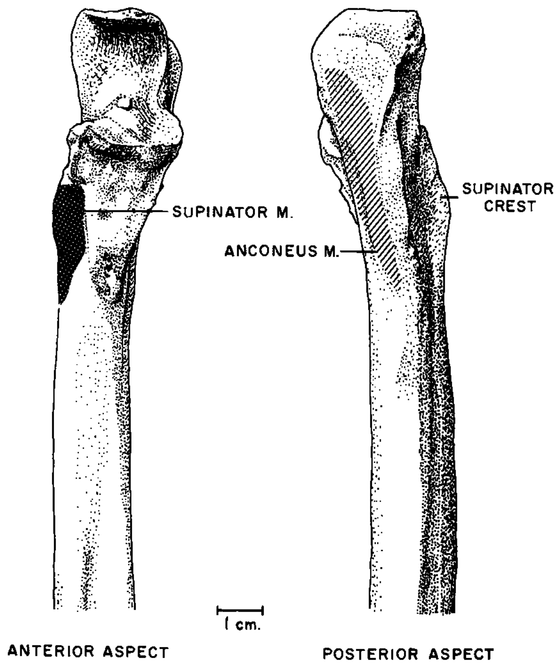

FIG. 1—*Right ulna—proximal half.*

characteristics, and (3) the forensic science significance of these features when similar conditions of ulnar modification are encountered in contemporary human remains requiring personal identification. In short, a paleontological problem of evaluating a set of traits in the skeletal biology of an extinct population led to a forensic science problem involving individual identification and definition of a marker of habitual or occupational stress.

A search of the scientific literature for specific information about ulnar modification in fossil and modern hominids is not rewarding. McCown and Keith [*2*] note the prominence of the supinator crest and the long ridge on the dorsal border of the ulna which marks the insertion of the anconeus muscle in the ulnae of the Tabun and Skhul skeletons from Mount Carmel, Israel. Most other studies of fossil hominids do not mention these features, even when ulnae are present, as in the case of the detailed report of the Amud Neanderthal by Suzuki and Takai [*3*]. The author's survey of prehistoric human skeletal remains from South Asia has established the presence of these features among a fair number of adult male specimens from postglacial Mesolithic sites in Gujarat and Rajasthan, the Gangetic plain of Uttar Pradesh, and southwards to the island of Sri Lanka. Further documentation of these ulnar characteristics in earlier and contemporary populations in different parts of the world is being sought in a survey of the anthropological literature and examinations of skeletal collections.

However, one feature of ulnar morphology is discernible. Well-formed and sharp supinator crests and deep fossae occur in highest frequency in hunting-gathering populations known to have used missile weapons in their predatory activities. These would include spears, bolas, slings, and boomerangs. The use of the woomera, or atlatl, by native Australians added a considerable segment for increased leverage in spear-throwing and was an important innovation, as were the aerodynamic principles incorporated in the design of returning boomerangs. Spears and slings continued into relatively recent times as major weapons of war in many societies. As pointed out by Blanksby and his colleagues [*4*], there are no animal parallels for throwing skills in this order, stories of branch-hurling and dung-hurling apes notwithstanding. Dolphins in marine parks who are trained to use their snouts to throw balls in simulated games are not considered relevant to the present study. Rather, it is the finer movements of pronation, supination, and hyperextension of the arm, as these have evolved in hominids, that distinguish us from other primates. Habitual practice in throwing missiles, as in the development of hunting and fighting skills in earlier populations and in certain athletic activities today, leaves its evidence in distinctive patterns of ulnar morphology.

Throwing involves angular displacement of the forearm as a result of medial rotation of the arm at the shoulder, shoulder and arm hyperextension, and abrupt shifts from forearm supination to pronation. There are variations in these biomechanics depending upon individual anatomical differences, the style of training, and the nature of the missile itself. For example, in throwing a baseball the angular displacement of the forearm resulting from medial rotation of the arm at the shoulder is obtained by measuring the angle of inclination of the forearm. This is 45° when the hand and the ball are at the back of the head. The forearm moves overhead in a pathway of 90° and then moves forward to 180° with an angular displacement of 45° in the brief interval before the release of the ball. The pelvis is held motionless just before release, but there is a spiral rotation of 10° angular displacement [*5*].

The force and skill behind this type of overarm throw is measured in terms of the maximum initial velocity imparted by the performer to a softball. In a study by Atwater [*6*], five skilled men on the University of Wisconsin Varsity baseball team achieved velocities of 33.5 to 38 m/s (110 to 125 ft/s). Five skilled women achieved velocities of 21 to 24.5 m/s (70 to 80 ft/s), and five average women scored 12 to 15 m/s (40 to 50 ft/s). Subjects with the fastest ball velocities at release were those with the most rapid sequential acceleration and deceleration of the trunk and arm segments before release of the ball.

Starting and terminal follow-through positions involve the entire body, and these postures are relevant to successful performance, varying with the nature of the missile. Thus the baseball player affects a backwards lean of the body preparatory to the throw in order to obtain maximum summation of force, but the feet may remain in continuous contact with the substrate. However, in javelin throwing, the terminal position of the body may include a brief aerial flight [*7*].

There is a considerable literature about biomechanics in the sports world, where knowledge of kinesiology and physical fitness may enhance victory in shotputting, discus throwing, hammer and javelin throwing, baseball, softball, cricket, basketball jumpshooting, and water polo overhead throwing. Sports medicine has engendered a number of clinical sources relating to acute and chronic effects of pitching, golfing, and tennis playing. These medical problems fall under the colloquial terms of *beat elbow, pitcher's arm, tennis elbow, Little League elbow*, and *golfer's elbow*. These conditions are variations of syndromes of cumulative effects of chronic, repetitive overuse of joint movements rather than syndromes of sudden impact forces. Discomfort arises from severe whiplash action of the upper limb, snapping of the elbow into extension, edema, excessive fibrosis, bursitis, osteochondrosis (inflammation of bone and articular cartilage), and osteochondritis dissecans (inflammation of bone and cartilage resulting in the splitting of pieces of cartilage into the joint), and, among preadolescent Little Leaguers, epiphysitis and other juvenile syndromes of upper extremity stress.

A survey of professional pitchers revealed a 44% incidence of bony spurs on the medial surface of the ulnar notch as a consequence of traction that tears soft tissues, removes chips of bone, and induces formation of small exostoses [*8*]. In Hunter's *Diseases of Occupation* [*9*], these stress factors are accorded little attention, but in a discussion of dangers from lead poisoning, Hunter notes that the old-fashioned method of crushing lead silicate glaze in a pottery mortar can lead to subcutaneous cellulites resulting from prolonged friction or pressure about the elbow of the worker who stands over the vessel and pounds a pestle equal in length to his own stature. Most of the literature on stress and strain in bones is related to microscopic rather than gross macroscopic structure [*10,11*]. It is from sources on kinesiology, sports medicine, and applied anatomy that it is possible to document correlations of the peculiar morphology of supinator crests and fossae and anconeus ridges with the habitual stress involved in throwing.

Muscular strength is the most critical factor in throwing performance and in the formation of prominent supinator crests. The supinator is a broad oblique sheet of muscle situated under brachioradialis. It has its origin on the lateral epicondyle of the humerus and the adjacent portion of the ulna along the supinator crest. It inserts on the lateral surface of the upper third of the radius. Supinator acts alone in slow, unresisted supination or in fast supination when the elbow is extended. It requires the assistance of biceps in supination during rapid movement with the elbow flexed. Below the radial notch the triangular supinator fossa is hollowed to permit movement of the radial tuberosity with its biceps tendon, and this depression is bounded posteriorly by the supinator crest. There is no space here for muscular attachment, so ulnar origin of supinator is formed by a thin aponeurosis from the back margin of the area. As we have noted, supinator crests are massive and fossae deep in ulnae of individuals who are using their arms in certain habitual activities, namely throwing.

Triceps brachii is the prime mover for extension of the elbow joint, its short leverage favoring speed rather than strength. The three heads unite to form a large muscle on the posterior side of the arm with their origin on the scapula just below the glenoid fossa, on the posterior-lateral side of the middle portion of the humeral shaft, and on the posterior surface of the humerus distal from the radial groove and extending nearly two thirds of the length of the bone. It inserts by means of a common tendon to the end of the olecranon process of the ulna. Triceps is the antagonist of biceps and brachialis and is assisted in the function of forearm extension by anconeus, which initiates this movement and fixes the ulna and is particularly active during pronation of the elbow.

Anconeus is a small triangular muscle that lies on the back of the elbow joint and appears to be a continuation of triceps. It arises by a separate tendon from the posterior surface of the lateral epicondyle of the humerus. Its fibers diverge and are inserted into the lateral surface of the olecranon and the posterior surface of the proximal fourth of the dorsal surface of the ulna. This insertion is marked by a long ridge descending from the olecranon to the dorsal border of the ulnar shaft. This is the region of attachment of the annular ligament and oblique ligament on the anterior aspect and by the inferior margin of the radial facet on the medial aspect. This ridge is prominent on ulnae with well-defined supinator crests and deep fossae, as would be expected from its combined functions of supination and extension in throwing actions. Hence it serves as an equally reliable marker of habitual throwing stress.

These observations were made in the context of a paleoanthropological, paleodemographic study of ancient skeletal remains from South Asia. However, their implications for forensic science are obvious. Aside from their importance in determining handedness as a trait peculiar to an individual, these markers of stress on the proximal end of the ulna are significant in identification of skeletal remains of persons known to have engaged in specific brachial activities during life. When present, these signs of occupational stress may supplement some of the familiar, longer established indicators of handedness with respect to morphometric variables of the bones of the pectoral girdle and upper extremities, as discussed by Stewart [*12*]. It is anticipated that these observations may prove to be useful in the future in a context broader than that of reconstructing habitual behavior patterns of prehistoric hominids. A research project is now under way that has as its focus the documentation of other examples of supinator crest hypertrophy and pronounced anconeus fossae depth in ulnae of skeletal specimens from known hunting-gathering cultures in widely separated parts of the world.

In conclusion, this study has focused upon the supinator and anconeus-triceps muscles for the reason that their attachments on the ulna are clear indicators of habitual stress related to throwing. It would be valuable to extend these observations to other morphological features of the ulna that may be related to the same function, such as degree of curvature of the shaft, comparisons of the Robusticity Index, which is a ratio of ulnar length to transverse diameters at several loci along the diaphysis, the ratio of metrical values of the ulna to the humerus, and so on. Certainly habitual throwing actions would involve the musculature of pronation and the morphology of hand bones, especially of the phalanges, which are modified by forceful grasping actions. The ulnar variables also provide useful clues to right- or left-handedness, which are important in cases of personal identification.

It would be valuable, too, to assess these morphological variables with respect to the broader picture of bone remodeling and Haversian reconstructions associated with maintenance of continuous anchorage of muscles, tendons, ligaments, and membranes into resorptive surfaces on the ulna. As Enlow [*13,14*] has observed, in the bones of a young growing individual, scattered clusters of secondary osteons are characteristically located at points of muscle insertion on resorptive surfaces, a feature quite unrelated to bone remodeling involving localized necrosis or mechanical fatigue. As the resorptive front proceeds, new osteons continue to form at progressively deeper levels. The study of the relationship of osteon formation to developmental changes in bone resulting from growth as well as to response to localized muscular stress is an examination of habitual stress markers at the microscopic level.

It is anticipated that ulnar variations of the kind described here may have applicability to paleodemographic research with skeletal series of extinct populations, as well as to problems of personal identification in forensic anthropology.

Acknowledgments

This research was carried out in 1980 and 1981 under sponsorship of Grant BNS 8014293 from the National Science Foundation, the American Institute of Indian Studies, and Cornell University. Special thanks is given to Mr. Christopher B. Burrow, who was the research assistant in India. Appreciation is extended to those colleagues in charge of human osteological collections that were made available to me in the course of this work: Dr. S. B. Deo of Deccan College, Poona; Dr. H. Rakshit of the Anthropological Survey of India, Calcutta; Dr. G. R. Sharma of Allahabad University; Dr. V. S. Wakankar of Vikram University, Ujjain; and Dr. James Garlick and Mr. Bernard Densten of the Duckworth Laboratory of Physical Anthropology at the University of Cambridge, England. The research reported here is a part of a broader project concerned with the evolution of Mesolithic humans in South Asia.

References

[*1*] Kennedy, K. A. R. and Burrow, C. B., "Preliminary Report on the Mesolithic Human Remains from Sarai Nahar Rai: Their Skeletal Biology and Evolutionary Significance," *History and Archaeology*, Vol. 2, G. R. Sharma, Ed., Centre of Advanced Study, Allahabad, India (in press).

[*2*] McCown, T. D. and Keith, A., *The Stone Age of Mount Carmel*, Vol. 2, Clarendon Press, Oxford, England, 1939, pp. 170-175.

[*3*] Suzuki, H. and Takai, F., *The Amud Man and His Cave Site*, University of Tokyo, Tokyo, Japan, 1970, pp. 256-266.

[*4*] Blanksby, B. A., Wood, G. A. and Freedman, L., "Human Kinesiology," *Yearbook of Physical Anthropology*, Vol. 24, 1981, pp. 75-100.

[*5*] Ortner, D. J. M., "Description and Classification of Degenerative Bone Changes in the Distal Joint Surfaces of the Humerus," *American Journal of Physical Anthropology*, Vol. 28, No. 2, March 1968, pp. 139-156.

[*6*] Atwater, A. E., "Movement Characteristics of the Overarm Throw: A Kinematic Analysis of Men and Women Performers," Ph.D. thesis, University of Wisconsin, Madison, 1970.

[*7*] Rasch, P. J. and Burke, R. K., *Kinesiology and Applied Anatomy*, 6th ed., Lea and Febiger, London, 1978, pp. 222-241, 532.

[*8*] King, J. W., "Analysis of the Pitching Arm of the Professional Baseball Player," *Clinical Orthopaedics*, Vol. 67, 1969, pp. 116-123.

[*9*] Hunter, D., *The Diseases of Occupation*, 4th ed., Little, Brown, and Company, Boston, 1969, pp. 235-283.

[*10*] Evans, F. G., *Stress and Strain in Bones*, Charles C Thomas, Springfield, IL, 1957.

[*11*] Evans, F. G., *Studies on the Anatomy and Function of Bones and Joints*, Springer-Verlag, New York, 1966.

[*12*] Stewart, T. D., *Essentials of Forensic Anthropology*, Charles C Thomas, Springfield, IL, 1979, pp. 239-244.

[13] Enlow, D. H., "An Evaluation of the Use of Bone Histology in Forensic Medicine and Anthropology," *Studies on the Anatomy and Function of Bone and Joints*, F. G. Evans, Ed., Springer-Verlag, New York, 1966, pp. 93-112.

[14] Enlow, D. H., "The Remodeling of Bone," *Yearbook of Physical Anthropology*, Vol. 20, 1976, pp. 19-34.

Address requests for reprints or additional information to
Kenneth A. R. Kennedy, Ph.D.
Ecology and Systematics
Cornell University
E231 Dale R. Corson Hall
Ithaca, NY 14853-0239