The morphological characteristics of the antebrachiocarpal joint of the cheetah (*Acinonyx jubatus*)

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ABSTRACT

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A morphological study of the structures of the antebrachiocarpal (AC) joint of the cheetah was carried out by dissection of eight forelimbs obtained from four adult cheetahs culled from the Kruger National Park, Republic of South Africa. The aim was to evaluate the deviations of this joint from the normal feline pattern and to consider their possible relationship to the cheetah's adaptation to speed.

Although published data on the AC joint of the other felids show general resemblance to that of the cheetah, there are nevertheless slight, but significant variations and modifications which tend to suggest adaptation to speed. The shafts of the radius and ulna of the cheetah are relatively straight and slender, with poorly developed distal ends. The ulnar notch is reduced to a very shallow concavity while the corresponding ulnar facet is a barely noticeable convexity, separated from the distal ulnar articular facet by an ill-defined groove. The movement of the distal radio-ulnar joint is highly restricted by the presence of a fibro-cartilaginous structure and a strong interrosseous membrane, limiting pronation and supination normally achieved by the rotation of the radius around the ulna. The extensor grooves at the distal extremity of the radius are deep and narrow and are guarded by prominent ridges. A thick extensor retinaculum anchors the strong extensor tendons in these grooves. The distal articular surface of the radius is concave in all directions except at the point where it moves into its styloid process. At this point it is convex in the dorsopalmar direction, with a surface that is rather deep and narrow. The proximal row of carpal bones presents a strongly convex surface, which is more pronounced in the dorsopalmar direction with the greatest convexity on the lateral aspect. Medially, there is a ridge-like concavity across the base of the tubercle, which rocks on the flexor surface of the radius, limiting excessive flexion as well as restricting lateral deviation of the AC joint.

Keywords: *Acinonyx jubatus*, antebrachiocarpal joint, cheetah, radius, ulna

INTRODUCTION

Samiento (1988) linked specialization of the AC joint of the various hominoid genera to their behavioural differences. A marked involvement of both the AC and ankle joints has been reported during motion in the cheetah (Hildebrand 1961). Specific articles on the AC joint of the cheetah are scarce in available literature. Hopwood (1947) published a comparative description of the adaptation of the forelimbs of the lion, leopard and the cheetah to their various habits. He noted that while the leopard emphasized extreme forearm rotation, which is of greater importance in climbing species than in cursorial ones, the cheetah, with a strong, rigid and straight manus is more adapted to speed. Yalden (1970) described, with illustrations, the functional

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morphology of the carpal bones of the carnivores. More recently, Kunzel & Probst (1999) compared the carpal bones of the cheetah and the domestic cat.

These accounts, although contributing valuable information in the understanding of the biomechanics of the AC joint, failed to focus on the entire architectural design of the joint, which appears to adapt the cheetah to swift movement. In the present study, an attempt was made to co-ordinate the role(s) played by the articular surfaces, ligaments and tendons as well as the peculiar structures of the distal radius and ulna in the evolution of movement in the cheetah.

MATERIALS AND METHODS

Eight forelimbs from four formalin-embalmed adult cheetahs, culled in the Kruger National Park, Republic of South Africa, were used for this study. The animals consisted of one female and three males and weighed between 30–35 kg. Each forelimb was amputated just distal to the elbow joint and in the midmetacarpal region. The AC joint was carefully dissected by successive removal from the dorsal surface of the skin, extensor tendons, ligaments and the joint capsule. A detailed morphological study of the articular surfaces of the component bones of the joint and the associated extra and intra-articular ligaments was carried out. A cross section of the frontal plane of the joint was cut in two limbs. The joint was opened and flexed fully in two other limbs to investigate the intra-articular ligaments and the opposing joint surfaces. The radioulnar joint with its opposing surfaces and associated soft tissue structures were also studied.

RESULTS

The AC joint of the cheetah is found between the distal ends of the radius and ulna proximally and the proximal row of carpal bones distally (Fig. 1). The shaft of the radius is relatively straight and slender, with the distal end measuring an average of about 30 mm lateromedially and 15 mm dorsopalmarly (Fig. 2). The distal articular facet is concave in all directions with the exception of the transitional zone between the facet and the styloid process. At the base of the styloid process, a transverse convex ridge demarcates the concave facet in the mediopalmar aspect of the bone (Fig. 3).

The dorso-medial aspect of the distal radius contains very deep and narrow extensor grooves, guarded by prominent ridges (Fig. 2) which house the very strong extensor tendons bound down by a very thick extensor retinaculum. Manipulation of this joint shows that these tendons add strength to the joint and restrict lateral or medial deviation.

The ulnar notch, (Fig. 2) is a slight concavity on the distal-lateral surface of the radius, and corresponds to the adjacent slight convexity, the ulnar articular circumference, on the medial side of the distal ulna (Fig. 4). Distal to these facets is a fibrocartilaginous structure which stretches distally to the terminal end of the distal radius and ulna where it forms part of the distal articular surface of the radius and ulna with the proximal row of carpal bones (Fig. 1). This close relationship between the radius and ulna is further reinforced by a strong interrosseous membrane, which is much thicker near the distal radioulnar joint and makes the rotation of the radius on

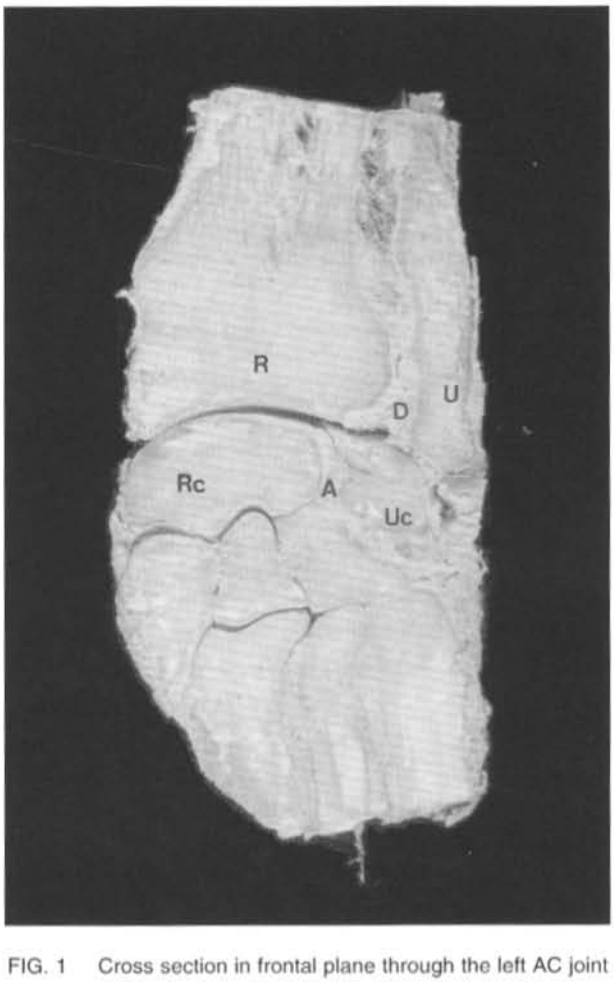

FIG. 1 Cross section in frontal plane through the left AC joint of the cheetah, showing the radius(R), ulna (U), fibrocartilage (D), radiocarpal bone (Rc), ulnarcarpal bone (Uc) and fibrous joint (A) between Rc and Uc

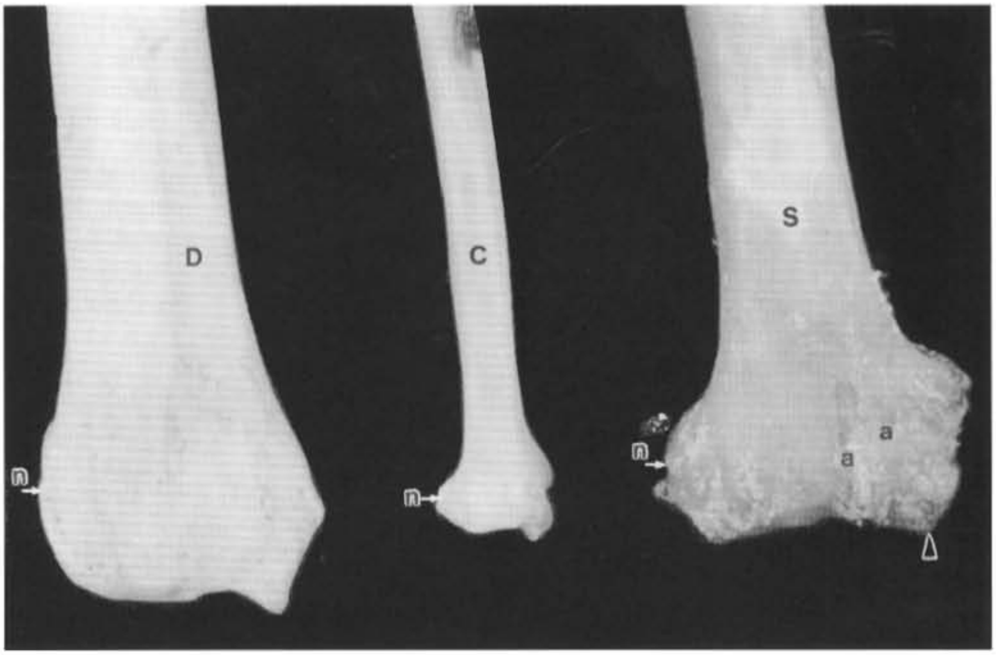

FIG. 2 Dorsal view of the distal parts of the radius of the dog (D), cat (C) and cheetah (S). Note the narrow and deep extensor grooves (a), the poorly developed styloid process (arrow head) and ulnar notch (n) in the cheetah

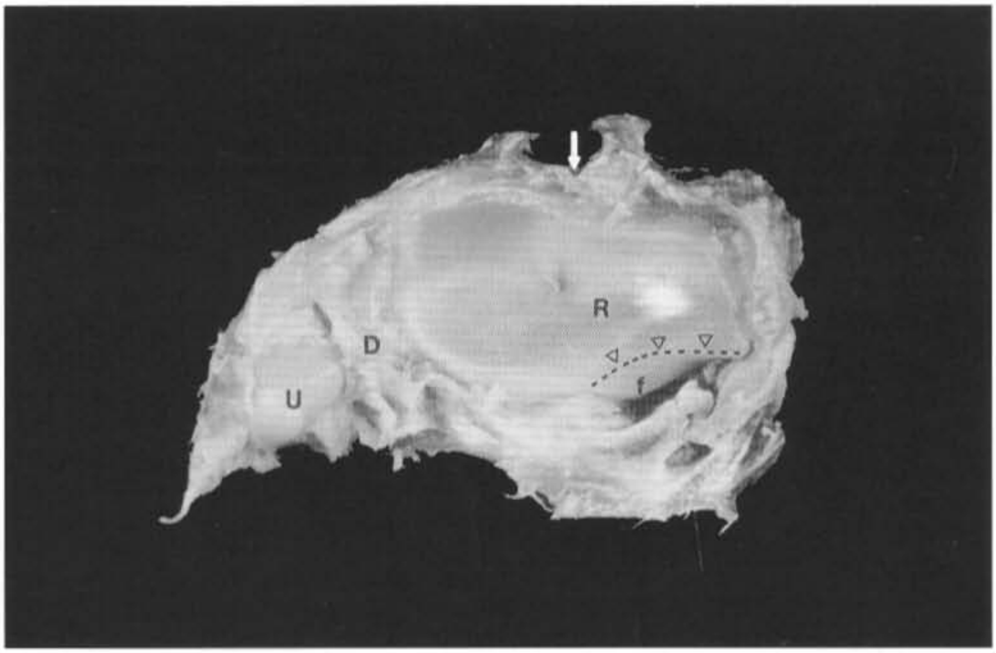

FIG. 3 Specimen showing the articular antebrachial surface of the AC joint of the cheetah. Between the distal radius (R) and ulna (U) is the fibrocartilage (D) with its radial extension over the lateral ridge of the extensor tendon groove (white arrow). The mediopalmar facet (f), at the flexor surface of the radius articulates with the tubercle of the radial carpal bone. The broken lines with open triangles mark the convex ridge separating the The mediopalmar facet from the concave facet of the antebrachial surface

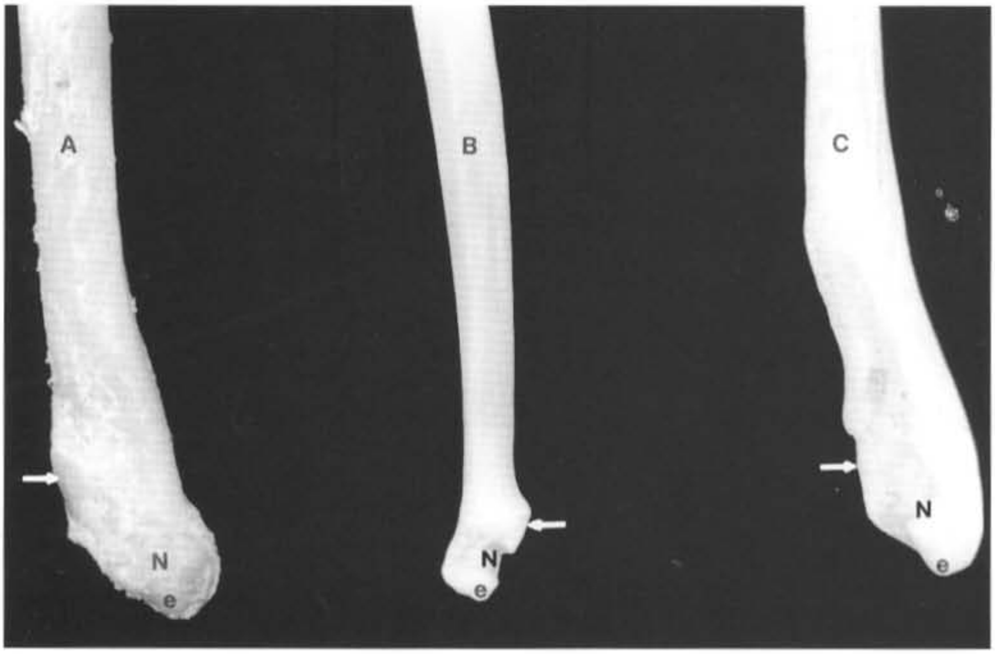

FIG. 4 Distal parts of the ulna of the cheetah (A), cat (B) and dog (C). White arrow is the convex ulnar articular circumference of the distal radio-ulnar joint. Note the distal articular facet of the ulna (e) and the notch (N) separating the radial articular facet from the distal articular facet of the ulna

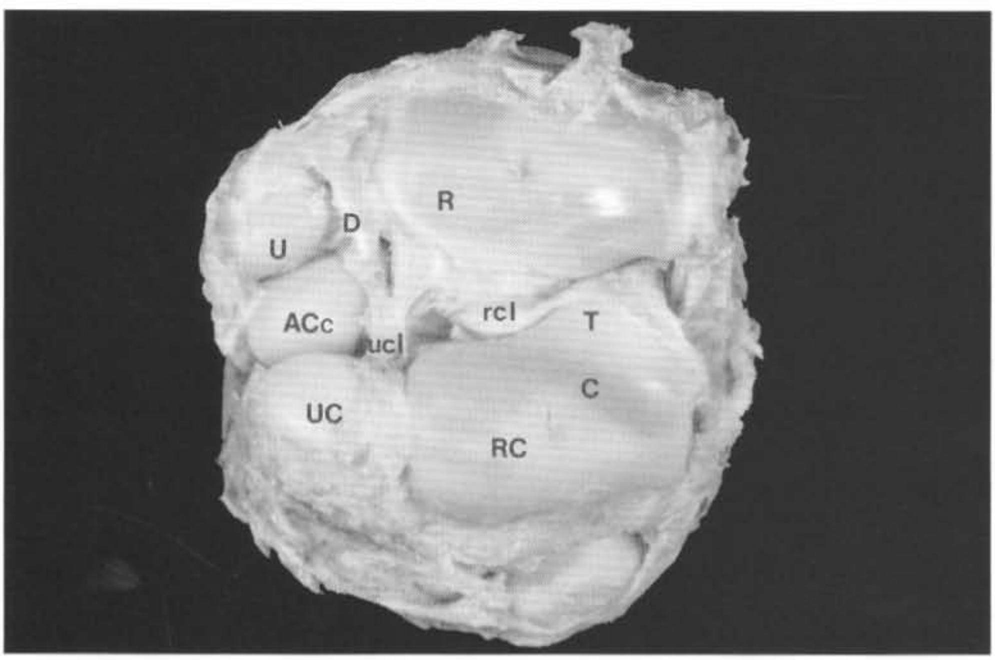

FIG. 5 Specimen of the AC joint of the Cheetah showing antebrachial and carpal articular surfaces with the joint fully flexed. Between the radius (R) and ulna (U), is the fibrocartilage (D). Note the palmar ulnocarpal ligament (ucl) (from the ulna and running obliquely towards the radial and ulnar carpal bones) and palmar radiocarpal ligament (rcl) (between the RC bone and the palmar margin of the radius). Note the radialcarpal (RC), ulnarcarpal (UC), accessory carpal bones (ACc) and tubercle (T). The concave ridge (C) separates the tubercle from the convex articular surface of the proximal carpal bones

the ulna almost impossible on manipulation. The distal ulna is slender and an insignificant notch separates the radial articular facet from the ulna articular facet (Fig. 4).

The proximal row of carpal bones has a convex articular facet in all directions with the greatest curvature at about the center of the radiocarpal bone. But this narrows medially until it reaches a transverse concavity, which fits the traverse convex ridge at the base of the styloid process of the radius (Fig. 5). Similarly, the prominent lip resulting from this concavity articulates with the facet at the flexor aspect of the radius. Manipulation of this joint shows that this prominent tubercle prevents full flexion of the joint. The joint between the radiocarpal and ulnar carpal bones is a fibrous joint (Fig. 1). Two intra-articular ligaments, the palmar ulnocarpal ligament extending obliquely from the medial side of the distal ulna, to the palmar surfaces of the radial and ulna carpal bones and the palmar radiocarpal ligament, which stretches from the palmar side of the radial articular surface obliquely to the lateral side of the radial carpal bone (Fig. 5).

DISCUSSION

As the results indicate, the various anatomical components of the AC joint of the cheetah are generally similar to those of other felids with only a few variations. The distal radius presents a concave articular surface that is more circular and deeper than in the cat, lion, leopard and dog (Hopwood 1947). Although this joint is closer to a ball and socket joint, the characteristic movement of such a joint medially and laterally is limited by the prominent styloid processes of the ulna and radius in the cheetah. This joint is functionally a hinge joint, which therefore allows flexion and extension and a very limited degree of lateral flexion. As is characteristic of modern carnivores, the radiocarpal bone, from paleontological and embryological evidences, represents the primitive radial, intermediate and central carpal bones. The fusion of these bones is regarded as a modification in animals adapted for running (Mikic 1989). Other adaptive features favouring stabilization of this joint include the presence of intra-articular ligaments and a fibrous joint between the radial carpal and ulnar carpal bones (Kunzel & Probst 1999).

The radius and ulna bones of the cheetah are straight and slender, with poorly developed distal ends. The distal radio-ulnar joint has reduced articular facets when compared to the dog, domestic cat, lion and leopard. Yalden (1970) reported the presence of prominent articular facets of the distal radio-ulnar joint in the leopard and lion with a well-developed and broad distal ulna with a flattened styloid process. He speculated that the reduction in the development of the distal ulna is synonymous with the loss of power of rotation of the forearm. Hopwood (1947) noted that the rotation of the forearm is more characteristic of animals which have a tendency to climb than in cursorial ones. This was demonstrated by Yalden (1970) when he showed that there is more rotation of the forearm in the leopard than in the lion and least in the cheetah. In primates, in which increased mobility of the hand and particularly an increased range of pronation and supination is required, the ulna does not articulate with the ulnar carpal bone and there is full development of the distal radio-ulnar joint (Mikic, Ercegan & Somer 1992). The articulation of the ulna with the ulnar carpal bone and loss of rotation of the radius around the ulna are regarded as an adaptation of the AC joint of mammalian quadrupeds to running. Rotation of the forearm in the cheetah is further limited by the presence of a fibrocartilagenous structure and a strong interrosseous membrane. This fibrocartilage has been described in the dog as a strong band between the distal radius and ulna (Mikic 1989). Palmer & Weiner (1981) agreed that this acts as a radio-ulnar ligament.

The extensor grooves in the distal radius of the cheetah are peculiar by being deeper and narrower than in the cat and leopards. Unlike in these felids, the distal radius has an additional groove for the extensor digitorum communis muscle. These strong and well anchored extensor tendons give the manus added rigidity and maintain straightness of the joint. These features appear to be paramount in the development of speed. Hopwood (1947) had reported that full flexion of the AC joint is necessary in animals such as the leopard which are adapted for climbing. Flexion in the cheetah is limited by the very prominent medio-palmer tubercle, which rocks on the flexor surface of the radius.

The joint between the radiocarpal and ulnarcarpal bones is a fibrous joint. The proximal row of carpal bones forms a functional unit, providing a base for the distal row of carpal bones hence affording additional stabilization to the joint complex.

In conclusion therefore, the observed poor development of the distal radius and ulna; the articulation of the distal ulna with the ulnar carpal bone and the strong bond between the distal radius and ulna are evolutionarily, in line with the loss of rotation of the radius around the ulna bone. The strong extensor tendons lodged in the unusually deep and narrow extensor grooves; not only limit lateral and medial deviation of the AC joint but also limit rotation of the forearm, thereby maintaining straightness and rigidity of the manus. This is consolidated by the intra-articular ligaments and the amphiarthrodial joint between the radiocarpal and ulnar carpal bones. The presence of a well-defined tubercle on the medio-palmar aspect of the radiocarpal bone limits flexion of the AC joint. These features are deviations from the normal feline pattern, which appear to confer some mechanical advantage on the AC joint in its adaptation for speed in the cheetah.

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