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Evolution of the Distal Humerus and Elbow Joint

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Hominid evolution started about 23 million years ago in the early Miocene. The elbow joint structure underwent many changes for that period of time but from 2,5 million years rests unchanged.

In our study we reveal the evolutionary stages of distal humerus supported by analysis of well-known fossil evidences.

Key words: humerus, elbow, human, distal humerus, evolution, joint.

Introduction

Humerus is the bone of the arm. It is divided into three parts [3, 4]. Central part is known as humeral body. Others are proximal and distal ends. It brings its origin from mesenchyme 4 to 6 week of the prenatal development [2].

Distal end of the humerus is a part of the elbow joint, which is the connection between the shoulder and hand, makes possible the mobility and transfers generated forces in both directons — proximal and distal.

Anatomy of the distal humerus responds to this dual function — rounded head of radius and spheric capitellum take part in wide range of the rotational movements — pronation and supination, while the specific configuration of the humeroulnar joint and the collateral ligaments form stability of the elbow joint [5].

A great part of the characteristics of human elbow' structure are known far before the appearance of Homo sapiens. Recent anthropologic evidences give us the possibility to trace the morphology of the distal humerus back in time, to the common ancestor of humans and apes — at about 15-20 mln years ago.

Material and Methods

Distal humerus of pelycosaurus was with bulb like capitellum stretched medially and laterally (late Paleozoic period — 255 — 235 mya). Articulation with ulna was accomplished by two separate surfaces — slightly concave ventral and a flat dorsal. Its proximal articular surface is separated in the same way at two surfaces crossed by low ridge [1].

The humerus was held more or less horizontal and the elbow was flexed, so they walked with limbs spread outside of the body. The locomotion was possible because of the rotation of the humerus around its axis and at the same time by straightening of the forearm in vertical direction. Having in mind that, we could say that flexion and extension in the elbow were necessary only in side-to-side motion. This shows that the stability was more imortant than the mobility [7].

A closer group of mammal ancestors, cynodonts, started to move with limbs underneath their bodies (235—160 mya). The distal articular surface was formed by lateral and medial epicondyles separated by a shallow groove. The proximal surface of the ulna for articulation had an elongate spoon shape. The lateral edge of the ulna for articulation with radius was separated from this surface by a low ridge. The ridge articulated with the groove between radial and ulnar condyles and represents the earliest evolutionary stage in the development of the recent humeroulnar articulation in mammals.

Early mammals from Triassic (210—160 mya) and Jurassic (160—130 mya) periods have still not well-developed radial and ulnar epicondyles, although the radial is more protuberant than the ulnar and the ulnar was more linear and obliquely oriented. The two condyles were separated by an intercondylar groove. Oblique orientation of humeroulnar joint helped to keep the forearm in sagittal plane, while the humerus acts in adduction, elevation and rotation during locomotion.

Widening of the intercondylar groove and the development of a ridge within it determine the development of pulley — like distal humeral articular surface. The articular surface of proximal ulna is also oblique in orientation.

Most small noncursorial mammals retained the spiral shape of the trochlear articular surface as in early mammals. In larger and more cursorial mammals, the trochlea could be with various ridges and grooves. It is very narrow to provide stability but sustain the join mobility.

Only in hominoid primates (chimpanzee, gorilla, orangutans, gibbons and humans) the trochlea is really trochleariform. Other monkeys could have cylindrical, conic or pulley-like trochlea. In most species the articular surface of trochlea spreads posteriorly to olecranon fossa. In larger monkeys the lateral edge of the posterior trochlear surface forms a ridge that extends proximally forming the lateral wall of the olecranon fossa. The articular surface of the capitellum spreads further onto the posterior surface of the distal humerus in human and chimpanzee, which results in larger range of extension in elbow joint, in contrast to baboon [1, 7].

In apes, so formed lateral ridge is a continuation of the lateral trochlear ridge and helps for shaping of more vertical lateral wall of the olecranon fossa. The distal articular surface is deeper with well-expressed medial and lateral edges. The ideal articular configuration for load bearing includes proximal orientation of the trochlear ridge nevertheless it restricts the elbow flexion. The differencies in humeroulnar joint in primates are determined most of all by the different kind of movements in which the upper extremity takes part.

It is not surprising that the most stable position of humeroulnar joint in most monkeys is in partial flexion, due to the development of the medial trochlear ridge anteriorly and distaly, and lateral ridge — posteriorly.

Anterior orientation of the trochlea is a direct adaptation to weight bearing in partially flexed elbow, but such spacial situation of the trochlea restricts the elbow motion to some extent.

Big apes (chimpanzee, gorilla, orangutan) and the lesser ones (gibbon) move to some degree in manner that differs from the monkeys. To achieve these movements, the humeroulnar joint with it deeply socketed articular surface and well developed medial and lateral ridges is constructed to sustain maximum stability during the whole range of motion.

The use of overhead suspensory postures in apes brought to evolutionary larger volume of extension in elbow joint, while the apes hold their elbow joints extended in their quadrupedal locomotion.

The ideal joint configuration for resistance to transarticular stress with fully extended elbow must be with trochlear notch directed proximally. In this position it serves as a cradle and supports the humerus during the act of locomotion. However, the proximal orientation of the trochlear notch restricts significantly the elbow flexion, because it is in contact with the distal articular surface. The anteroproximal orientation of the trochlear sulcus in monkeys is some kind of compromise in extension stability during motion, but without restricting the flexion range [8].

Elbow is a complex joint. As it is known, it is composed of 3 joints — humeroulnar, humeroradial and proximal radioulnar joint. All the movements are possible due to that structure — flexion, extension, pronation, and supination. In the apes, in contrast with monkeys, the capitellum spreads far more posterior, giving the radius possiblity for orientation along with the ulna in full extension.

The zone between capitellum and trochlea (zona conoidea) is relatively flat and ends distaly in most of the monkeys. Lateral lip of the radial head comes into maximum congruence with zona conoidea. It gives maximum stable joint configuration [8].

We could mention some additional features in elbow joint structure in common. In human and apes radial neck is relatively long. In apes it is connected with the demand of powerful elbow flexion to raise the center if mass of the body during climbing and suspensory postures in locomotion. Although the radial tuberosity is situated more or less anteriorly in most of the apes, in human is situated more medially. It increases the range of supination.

In apes and human the olecranon process is relatively short. This is determined by the need of fast extension during suspensory locomotion.

A significant biomechanical characteristic is the presence of so called "carrying angle". It is the acute angle formed by the long axis of the humerus as the long axis if the ulna projects on the plane containing the humerus- normally 10—20° in human. The presence of carrying angle is due to the need of moving the center of mass of the body under the sustaining arm in the locomotion. This resembles the valgus in human's knee, which moves the foot closer to the center of mass of the body during the single step in walkling.

Some differencies in elbow morphology between human and apes due to the elimination of the forearm from the locomotion [8].

In human, the lateral epycondyle is distally positioned and with not so expressed supracondylar ridge, in contrast with apes, because of the restricted volume of the extensory misculature of the hand and brachioradial muscle. The bending if ulna and radius is not so big in human, which is a result of the strenghtened lever action of pronator and supinator muscles of the forearm. And finaly the restircted size of trochlear ridges and oblique lateral ridge of the olecranon fossa in human are result of the total decrease of weight bearing in elbow and significantly greater need of elbow stability during all phases of motion.

Results

When exactly the elbow joint originate and how old is the structure of recent human elbow? To answer these questions we need to look at the various fossil evidences.

We could not say exactly, which of known Miocene (23—5 mya) species is the common ancestor of hominids. There are some unknowns concerning individual evolutionary histories of chimpanzee, gorilla, gibbon and human.

Dendropithecus macinnesi, Limnopithecus legetet and Proconsul heseloni (Africa) are among the hominoid species from early Miocene (23—16 mya). Distal humerus of the first two species resembles structure of the distal humerus in Cebus (capuchin monkeys). The trochlea is without prominent lateral ridge and the zone conoidea is relatively flat. The trochlear notch is situated anteriorly and the radial head is oval shaped and well-developed lateral ridge. It is considered that these characteristics are primitive for the rest of higher primates (monkeys, apes and humans).

Proconsul heseloni has some of the characteristics of later hominids. Its distal humerus has round capitellum, well-developed medial and lateral ridges and deep zone conoidea. This suggests significant stability of the joint in parallel to other mentioned two species. The limited and incomplete fossil material from the late Miocene (16—5 mya) suggests that many hominoid species; includings members of geners Dryopithecus (Europe), Sivapitehcus (Europe and Asia) and Oreopithecus (Europe) have the same characteristics in elbow morphology as modern human. Although it is possible that these features in structure to originate in different genera, the most probable explanation is that it is inherited from an early ancestor similar to Proconsul heseloni. Having in mind the listed characteristics and analysed fossil records we could affirm that the recent structure of the elbow joint originated 15 mya ago. The bigger part of paleoanthropologists agrees that the human is most closely related to the African apes (chimpanzee and gorilla) and these two lines are formed in late Miocene or early Pliocene (10—4 mya).

The earliest known fossil evidences of immediatae human ancestors are dated from the early Pliocene (4 mya). Three genera of these early hominids are known — Ardipithecus, Paranthropus and Australopithecus. Best studied is the last one because of its well-known representative — "Lucy" from Hadar, Ethiopy (Australopithecus afarensis) [9].

The genus Homo, to which we belong, origins 2,5 mya ago in East Africa. The earliest representative is Homo habilis. It is suggested that this species is predecessor of Homo erectus — 1,6 mya. It is considered that Homo erectus is an ancestor of all later hominoids, including Homo sapiens.

Fossil evidences could be divided in two groups according to the shape of the distal humerus, situation of the epicondyles and articular surface configuration.

First one is characterized by weakly projecting lateral epicondyle placed distaly, almost to the level of the capitellum and moderately developed lateral trochlear ridge. These characteristics are similar to modern human ones and because of that this group is referred to early Homo.

The second group includes Paranthropus and Australopithecus and is characterized by a well-developed lateral epicondyle more proximally situated. It is similar to modern apes.

In overview, as a result of the achievements of the comparative anatomy and fossil record it is known that the modern human elbow originated from the elbow of a common ancestor who lived 15—20 mya ago.

Discussion

The functional analysis suggests that the structural characteristics arose in primate ancestors as a need of providing elbow stability during the locomotion and to achieve wide range of motion of the forearm. As a consequence originated changes connected with upright posture and bipedal locomotion in the earliest representatives of hominids. The elbow joint and the forearm decrease their participation in locomotion but increase the elbow stability in all positions.

The fossil record indicates that our ancestor Homo habilis first appeared 2 mya ago and from then the structure of the distal humerus remained essentially unghanged during all subsequent stages of human evolution.

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