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Review Article

THE POLLEX – INDEX COMPLEX AND THE KINETICS OF OPPOSITION

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Abstract :

The term opposition is exclusive to human manual articulation. The origin and development of the opposable thumb was a milestone in evolutionary history of man. The transition from pongid, pithecoid to paranathropus and thereon to anthropoid apes was witness to the transformation of the apposable thumb to an opposable one. While a few marsupials, primates and prosimians can and do 'oppose' their digits (either of the forelimb or hind-limb) these articulations are non-classical and cannot be categorized as opposition. The shortness of the thumb in proportion to the size and length of the palm / foot handicaps performance of functionally efficient 'opposition' in most species [1].

According to evolutionary biologists, one of the more singular factors elevating man as a higher mammal, as compared to any other, is the modification in the functional capability of the thumb. The human thumb stands alone in its talent to 'oppose'. Anatomically, 'opposition' implies the movement by which you can touch the tip of your thumb to the tips of other fingers of the same hand. No animal except the human kind has a truly opposable thumb [2]

The biomechanics of opposition of the pollex with special reference to its preferred digit, the index is discussed in this paper, in the light of increasing stress and usage of these digits in modern man exposed to newer personal communication devices and technologies which demand dexterity and speed in manipulation of these specific joints for specialized functions

Keywords: pollex, opposition, retroposition, apposition, human evolution, physical anthropology

Introduction :

The development and evolution of the unique function of opposition has been subject of much research and debate. Its role in possibly being the progenitor of erect gait and bipedal locomotion has also forms staple fare for research by evolutionary biologists and physical anthropologists. Classically, only two fingers possess the capability to oppose; the pollex (thumb) and the digiti minimi (little finger). These are the only digits with opponens muscles attached to them. However, the latter being weak, opposition has become the exclusive property of the thumb and it prefers the index to complete the bi-fulcrum kinematic chain with the index tip for efficient opposition.

Whilst much attention has been given to this osseous changes at the proximal pollex end, little, if at all any, has been concentrated on what has been recorded on the alteration, that opposition has induced in the 'favored for in opposition' digit, the index.

Physical anthropologists have long been fascinated by thumb biomechanics. The exclusively human opposition and its mastery, is landmark development in the evolutionary tree [3]. In early bipeds, the conferment of the capability to oppose, vested them with an additional range of use and combination of movements of his fingers, a fact that helped an explosion of cerebration. Liberated from coordinating locomotion, the human forelimb and its dextrous finger, became a tool – to craft, morph, draw, paint and build – attributes that make man what he is today – the top dog in the evolutionary pyramid.

Opposition is probably of as much significance in the differentiation of the higher primates into hominids, as are the modifications in the pelvic and post-pelvic skeletal elements. The performance of the uniquely human digital movement of opposition, is facilitated by the conversion of a once condylar joint into a saddle variety in the pollex. The value and worth of this seemingly routine articulation has long been underrated and unappreciated by physical anthropologists, evolutionary biologists and kinesiologists.

Anatomy of the 1st, 2nd & 5th Carpometacarpal joints: Bones

Fig.1: TRAPEZIUM

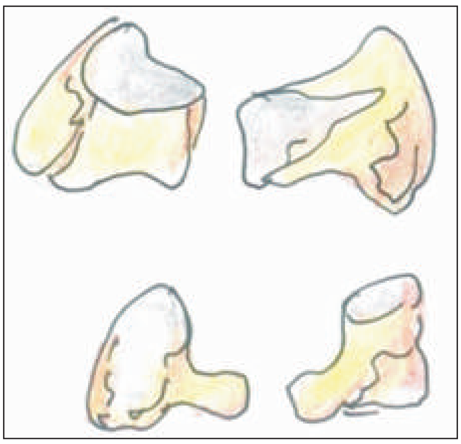

Fig. 2: TRAPEZOID & HAMATE

Trapezium: The inferior surface is oval, concave from side to side, convex from before backward, so as to form a saddle-shaped surface for articulation with the base of the first metacarpal bone. This saddle-shaped articulation is partially responsible for the thumb's opposable motion. This bone is sometimes referred to as greater multangular.

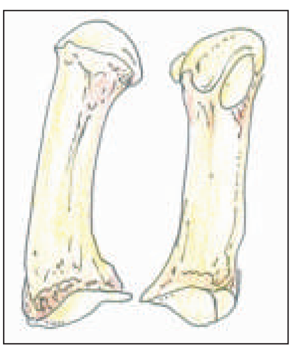

Fig: 3: 1st METACARPAL

The base is significantly different from the bases of the other metacarpals. It is trumpet-shaped and ends in a saddle-shaped articular surface matching that of the trapezial articular surface. The configuration of the thumb carpometacarpal joint plays an important role in the mechanism of opposition. Shape and extension of the cartilaginous articular surface first metacarpal bases show characteristics of a saddle joint.

The 2nd metacarpal's upper *intermediate* surface is the largest and is concave from side to side, convex from before backward for articulation with the trapezoid. The *lateral* surface is small, flat and oval for articulation with the trapezium; the *medial*, on the summit of the ridge, is long and narrow for articulation with the capitate. The articulation between the second metacarpal and the capitate is considered uniquely specialized in hominids. On the second metacarpal, the facet for the capitate is directed proximally, almost perpendicular to the facet for the third metacarpal, while the corresponding facet on the capitate is oriented distally. This is to receive compressive forces generated by the pad-to-pad opposition between the thumb and the index finger.

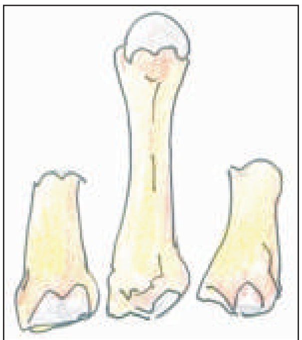

Fig. 4: 2nd METACARPAL

The inferior surface of the trapezoid articulates with the proximal end of the second metacarpal bone; it is convex from side to side, concave from before backward and subdivided by an elevated ridge into two unequal facets. The bone is sometimes labeled as lesser multangular.

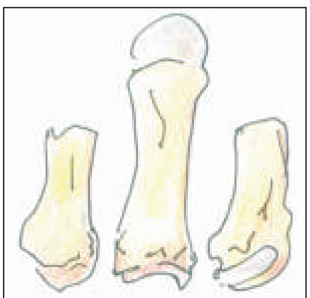

Fig. 5: 5th METACARPAL

5th Metacarpal presents on its base one facet on its superior surface, which is concavo-convex and articulates with the hamate and one on its radial side, which articulates with the fourth metacarpal. The inferior surface articulates with the fourth and fifth metacarpal bones, by concave facets which are separated by a ridge.

The carpometacarpal joints are five joints in the wrist that articulate the distal row of carpal bones and the proximal bases of the five metacarpal bones. The carpometacarpal of the thumb differs significantly from the other four.

The carpometacarpal joint of the thumb, also known as the trapeziometacarpal joint because it connects the trapezium to the first metacarpal bone, plays an irreplaceable role in the normal functioning of the thumb. The most important joint connecting the wrist to the metacarpus, osteoarthritis of the trapeziometacarpal joint is a severely disabling condition; up to twenty times more common among old women than in average. (Figures 1 – 5)

Muscles :

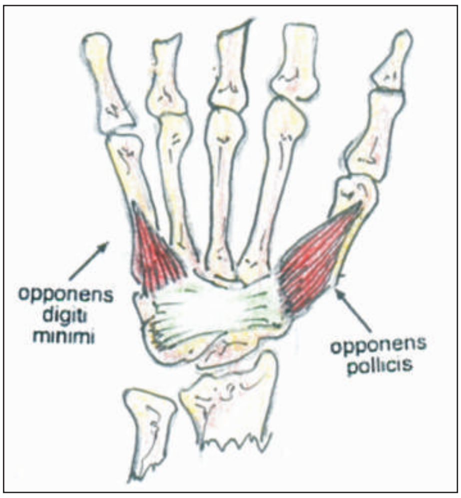

Fig. 6: The thenar and hypothenar opponens muscles

The opponens pollicis is a small, triangular muscle in the hand, which functions to oppose the thumb. It is one of the three thenar muscles, lying deep to the abductor pollicis brevis and lateral to the flexor pollicis brevis. The opponens pollicis originates from the flexor retinaculum of the hand and the tubercle of the trapezium. It passes downward and laterally, and is inserted into the whole length of the metacarpal bone of the thumb on its radial side.(Fig.6)

The extrinsic and intrinsic extensors, superficial and deep flexors, adductors and abductors along with lumbrical of the digit allow for a wide range of actions – including those occurring at the metacarpophalangeal and interphalangeal joints of the index finger. By forming the 'prximopalmar' fossa during preferred finger opposition by thumb, the index 'arch' formed during pulp to pulp approximation permits medail and lateral sortie through the dual contact kinematic chain

The opponens digiti minimi is a muscle in the hand. It is of a triangular form, and placed immediately beneath the palmaris brevis, abductor minimi digiti, and flexor brevis minimi digiti. It is one of the three hypothenar muscles that control the little finger. It arises from the convexity of the hamulus of the hamate bone, and contiguous portion of the transverse carpal ligament; it is inserted into the whole length of the metacarpal bone of the little finger along its ulnar margin. Opponens minimi digiti serves to flex and laterally rotate the 5th metacarpal about the 5th carpometacarpal joint, as when bringing little finger and thumb into opposition. It is innervated by the deep branch of the ulnar nerve.

Ligaments :

The description of the number and names of the ligaments of the first carpometacarpal joint varies considerably in anatomical literature. Imaeda et al 1993 [(4)] describe three intracapsular and two extracapsular ligaments to be most important in stabilizing the thumb: These are the Anterior oblique ligament, Ulnar collateral ligament, First intermetacarpal ligament, Posterior oblique ligament and Dorsoradial ligament.

The ligaments of the carpometacarpal articulations which unite the carpal bones with the metacarpal bones are the palmar and dorsal carpometacarpal ligaments. The ligaments of the intermetacarpal articulations which unite the metacarpal bones: the dorsal, interosseous, and palmar metacarpal ligaments

Movements :

It is by the movement of opposition that the tip of the thumb is brought into contact with the volar surfaces of the slightly flexed fingers. This movement is effected through the medium of a small sloping facet on the anterior lip of the saddle-shaped articular surface of the trapezium[4]. The flexor muscles pull the corresponding part of the articular surface of the metacarpal bone on to this facet, and the movement of opposition is then carried out by the adductors.

As a result of evolution, the human thumb carpometacarpal joint has positioned itself at 80° of pronation, 40° of abduction, and 50° of flexion in relation to an axis passing through the stable second and third carpometacarpal joints

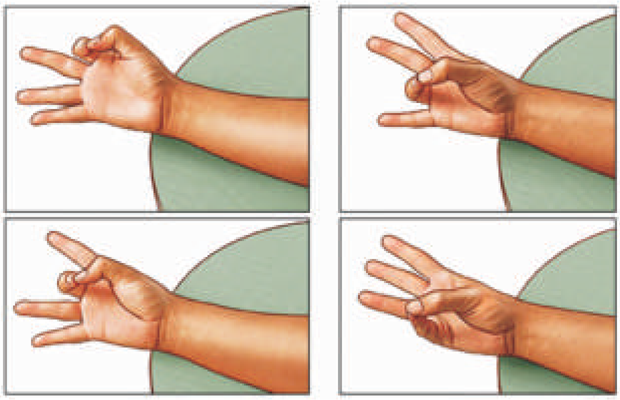

Fig. 7: Opposition of the thumb pulp to pulps of other digits
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The first joint is a saddle joint with two degrees of freedom which except flexion/extension also enable abduction/adduction and a limited amount of opposition. Together the movements of the fourth and fifth carpometacarpal joints facilitates for their fingers to oppose the thumb. The gradual demotion and devaluation of the little finger as an effective or useful oppose, has allowed the usurpation of the juxtaposition to thumb by the other three digits of the palm – the index dominating as a worthy opponent in the approximation of pulps.

The joints are capable of producing a wide range of movements which include flexion, extension, abduction, adduction, 'circumduction', opposition and retroposition. Pronation-supination of the first metacarpal is especially important for the action of opposition

The movements of the first carpometacarpal is limited by the shape of the joint, by the capsulo-ligamentous complex surrounding the joint, and by the balance among involved muscles, if the first metacarpal fails to sit well 'on the saddle'.

The movements at the 2nd carpometacarpal joint are flexion, extension, adduction and abduction. [5, 9] The modification of the articular surfaces of the bones involved allow for a certain degree of laxity in performance of the joint, permitting the metacarpal to additionally 'glide' and adapt to its special need to abut pollical pulp during opposition. The condylar joint found at the 2nd metacarpal head with proximal phalange allows not only 'sway' but also a minor degree of rotation, an important factor in choice of index as favored finger

Discussion :

The observations discussed here are with specific reference to the movement of 'opposition'. By definition, opposability is exclusive to the 1st and 5th carpometacarpal joints, both being the only digits to possess the special muscle 'opponens'. The opposable thumb can also be effectively opposed to pulps of the 3rd and 4th digits also, but by functional efficiency, the pollex 'favors' the pulp of the index finger. (Fig.7)

Whilst much attention has been given to this osseous change at the proximal pollex end, little, if at all any, has been concentrated on what has been recorded on the alteration, that opposition has induced in the 'favoured for in opposition' digit, the index. (Fig.8)

In early bipeds, the conferment of the capability to oppose, vested them with an additional range of use and combination of movements of his fingers, a fact that helped an explosion of cerebration. Liberated from coordinating locomotion, the human forelimb and its dexterous finger, became a tool – to craft, morph, draw, paint and build – attributes that make man what he is today – the top dog in the evolutionary pyramid.

May be it would educate were we to take a closer look at this odd thick short digit. For one, the thumb has one bone less than its sisters of the palm. While all others have three phalanges, the thumb has two. It can flex, extend, abduct, adduct and oppose, perform one function more than other fingers can, despite its having one component less.

The thumb is anatomically called the pollex – is serviced by a number of muscles, a few coming from as far away as the forearm and elbow. While most joints between the finger bones and the carpal bones of the wrist are planar or condylar, the thumb metacarpal forms a saddle joint. The pollex, its shape, movements, size or features are sometimes used by clinicians to clinch diagnosis. An additional digital transverse crease? Darrier's Syndrome. Thick broad thumb? Rubinstein-Taybi Syndrome, and so on – murderer's thumb, trigger finger are some of the terms used in medical sciences.

It must be recalled here that the liberation of the pollex (thumb) and the conversion of the first carpometacarpal joint from a condylar into a saddle, enabled the thumb to be opposed [6, 7]. The 'free'ing of the forelimbs into performance of higher, more compulsive, and educated tasks from its hitherto chore of supporting body weight and mobility, is claimed to be the cornerstone of bipedalism and thence into the explosion of cerebration that led to the genesis of bipeds into rational homos [1,6].

The evolution of the fully opposable thumb is usually associated with Homo habilis, a forerunner of Homo sapiens. This, however, is the suggested result of evolution from Homo erectus via a series of intermediate anthropoid stages and is therefore a much more complicated link.

It is possible, though, that a more likely scenario may be that the specialized precision gripping hand (equipped with opposable thumb) of Homo habilis preceded walking, with the specialized adaptation of the spine, pelvis, and lower extremities preceding a more advanced hand [7]. And, it is logical that a conservative, highly functional adaptation be followed by a series of more complex ones that complement it. With Homo habilis, an advanced grasping-capable hand was accompanied by facultative bipedality, possibly implying, assuming a co-opted evolutionary relationship exists, that the latter resulted from the former as obligate bipedalism was yet to follow. Walking may have been a by-product of busy hands and not vice versa. The evolution of the fully opposable thumb is usually associated with Homo habilis, the forerunner of Homo sapiens [8, 9]

Anatomically it is significant and pertinent to note that apart from the pollical opponens, one other digit, the minimus possesses an opponens muscle. Technically, by definition, 'classical opposition' is exclusive to two digits only (both paving opponens muscles), the thumb and little finger and the approximation of their tip pulps. This movement should qualify as 'principle opposition' whereas, approximation of the pollex to any other than the little finger should constitute 'auxilary opposition'. Among these secondary opponents, the index tip could be delineated as 'preferred auxillary opposition'. In fact so favored is the digit in performance of mechanically effective opposition that it surpasses by far, the capacity of the opponens muscle bearing digiti minimi in its effectiveness and usage.

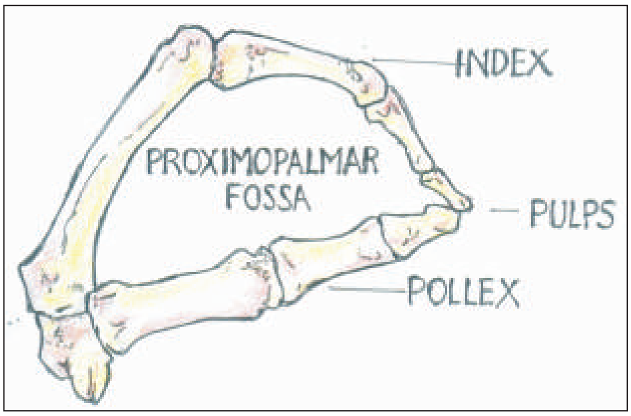

Fig. 8: Pollex-index pulp to pulp approximation during opposition

Interestingly, the terms, thumbprint, thumbnail, sore thumb, twiddling thumbs, thumbs up, thumbing through a book or thumb-sized are used by us so commonly that we tend to forget that in using them we pay tribute to this remarkable appendage of ours.

To scale measurements made of the shadow of a supine hand during performance of simple flexion and extension of the digits, especially the index, the favored digit for thumb in opposition; The shadow of the arc described by the exercise in the form of excursion of the flexing index tip when projected on a wall mounted white screen board shows that the resultant arc was mathematically very precise and periodic. (Fig: 9 & 10)

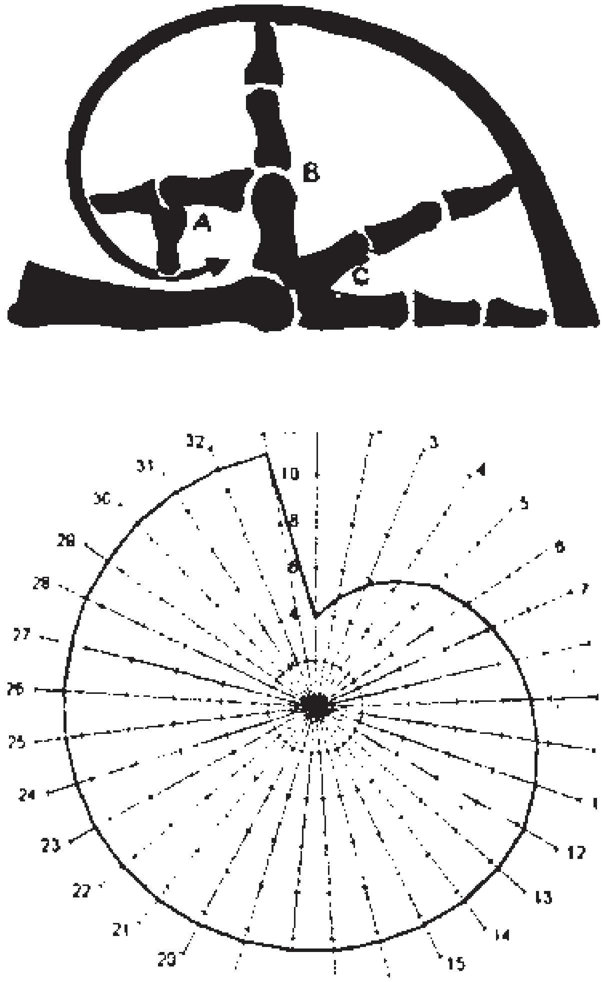

Fig. 9 & 10: Cochlead arc described by index during flexion – extension

The linear measurement of each individual bone element, from distal phalanx to base of second metacarpal for index digit when graphically reproduced through Computerized Assisted Designing (CAD) show that despite the soft tissue elements that bar precise and accurate measures, the inter-articular distances between the distal, intermediate, proximal phalanges and the metacarpal ends, repeat the Fibonacci sequence. That is the lengths are 17 mm, 28 mm, 45 mm and 72 mm respectively. Put in Fibonacci serial sequence, 17 +28+42+73, or at every joint an incremental ratio of 1.6 to 1 was evident.

Flexion at index interphalangeal, meta-carpophalangeal joints spiraled across a hub or axis, which was horizontally mobile for about 10 mms in a complete range of flexion-extension. Taking the midpoint of the axis, as referral point, when the arc was plotted through CAD (Fig.9 & 10) the spiral created displayed a splayed-out form, akin to the molluscan shell. Measurements at fixed

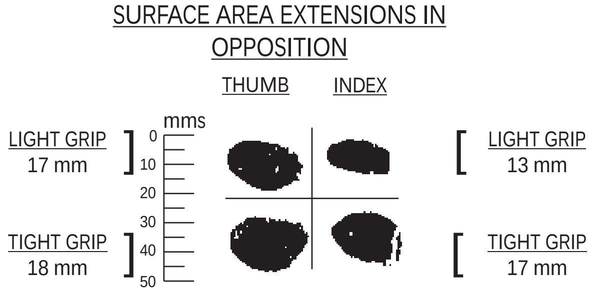

Fig. 11: Pulp surface area juxtaposed during index-pollex in light / tight pinch grip

reference points along the spiral show a progressive increment at angulation or its reverse, in extension and flexion of index. Approximately, the increment followed the 'golden mean' ratio first enunciated by the European mathematician, Fibonacci, centuries ago, which is 1: 1.63[10]

The index and pollex pulps of right and left hand of volunteers were made to grip standard sized thick paper. Two impressions, one with light and another with hard (tight) grip were taken. The transverse (breadth) of each imprint was measured in mms. It was observed, consistently, that for every 1 mm increment in the transverse dimension of the pollex pulp in tight grip, the index pulp exercised a roll of 3 mms. (Table:1)

With minor variations, the ratio of 1:3 was maintained for tight grip, in all age groups and in both sexes. In this paper we are presenting a part of the exhaustive data compiled, only restricting to the measurably-clear records made in 152 impressions of right hand digits in 76 individuals of both sexes, of adult age groups [11]

AGE	MALE	FEMALE
20-30	3.12	3.44
30-40	2.9	3.18
40-50	3	4
50-60	3.33	2.75
60-80	3.4	3.22
80+	4.8	2.77

Movement of the Index (in mm) for every 1 mm of the Thumb

It is clear that for best performance of opposition, the preferred adjunct digit is the index. Close observation of the distal index shows that, apart from a slight ulnar deviation a discernible lateral rotation. This anomalous anatomy is seen even in a position of rest and in situ. It is obvious from this observation that the index has in its own unique way, adapted itself to becoming a favored digit for opposing. The lateral rotation of the more distal phalanxes of the index along its longitudinal axis confers on this finger a distinct mechanical advantage vis-a-vis grip and purchase during approximation with the pollical pulp in performance of opposition. This hypothesis has stood the test of time and readily explains on why the index has attuned itself, congenitally or by acquirement and usage the favored finger status for the opposable thumb.

The fact that the index takes a crucial role in tight gripping proves that in some anatomical manner, this digit has probably adapted itself to the requirements of its partner for opposition; Kumar [12, 13, 14] reported that the index in its rest or anatomical position, lies in an axis that is rotated radiad and that this in-situ rotated status confers on it, the capacity to augment opposition power. The pre-opposed index is so positioned, that on reception of the pollex pulp in tight grip, the purchase area (transverse of approximated surface) exhibits an inbuilt augmentative potential. (Fig: 11). The power of grip in opposition is augmented in index –pollex approximation by the combined strengths of the extrinsic forearm muscle, flexor digitorum superficialis et profudus along with the lumbrical of the digit.

As an offshoot, could it be of value, were hand surgeons re-implanting amputated index digits, not in the accepted anteroposterior orientation but in the radially rotated positus?

As mentioned earlier, the human hand prefers thumb-index approximation for its mechanical efficiency and convenience of use. While the pollical metacarpal joint is sellar and adapted for opposability acting through its special muscle opponens pollicis, the index interphalangeal are basically condylar joints, non-congruent in its performance of movements other than flexion-extension, adduction – abduction; the index is yet a preferred digit for opposition due to some factors that confer it with 'preferred' status.

One, it is the digit closest to the pollex. Second, it range of mobility is far more extensive when abducting, mainly due to the enhanced interdigital space between it and the pollex. Thirdly, the index has an extra extrinsic muscle, the indicis and fourthly, the index has been described as possessing an in-situ laterally rotated axis that facilitates easier approximation to the pulp of the thumb during opposition. This inbuilt lateral rotation of index has been shown as aid in increasing in power of grip between the its own pulp surface by rolling over the pollical pulp surface when pinch power is raised from light to tight.

It is evident that for the best performance of opposition, the preferred adjunct digit is the index. The fact that the index takes a crucial role in tight gripping proves that in some anatomical manner, this digit has probably adapted itself to the requirements of its partner for opposition, the index in its rest or anatomical position, lies in an axis that is rotated radiad and that this in-situ rotated status confers on it, the capacity to augment opposition power. The pre-opposed index is so positioned, that on reception of the pollex pulp in tight grip, the purchase area (transverse of approximated surface) exhibits an inbuilt augmentative potential.

In humans, opposition and apposition are two movements unique to the thumb but these words are not synonyms: Primatologists and hand researchers defined opposition as: 'A movement by which the pulp surface of the thumb is placed squarely in contact with - or diametrically opposite to - the terminal pads of one or all of the remaining digits.' For this true, pulp-to-pulp opposition to be possible, the thumb must rotate about its long axis (at the carpometacarpal joint). Arguably, this definition was chosen to underline what is unique to the human thumb.

Anatomists and other researchers focused exclusively on human anatomy, on the other hand, tend to elaborate this definition in various ways and, consequently, there are hundreds of definitions. Some anatomists restrict opposition to when the thumb is approximated to the fifth digit (little finger) and refer to other approximations between the thumb and other digits as apposition. To anatomists, this makes sense as two intrinsic hand muscles are named for this specific movement (the opponens pollicis and opponens digiti minimi respectively).

Researchers use another definition, referring to opposition-apposition as the transition between flexion-abduction and extension-adduction; the side of the distal thumb phalanx thus approximated to the palm or the hand's radial side (side of index finger) during apposition and the pulp or palmar side of the distal thumb phalanx approximated to either the palm or other digits during opposition. The joint is biaxial, not triaxial: its loose capsule permits rotation, and the metacarpal rotates automatically when it moves in the other two planes.

Combined flexion and abduction produces opposition while a combined extension and adduction produces retroposition. A combination of all possible movements of the pollex is loosely mimics circumduction.

Conclusions :

In conclusion, it is evident that much remains to be said and done on the articular kinetics of the pollex. The thumb's oposability has played a far more significant role than is credited for, in the evolution of hominids. The complementary adaptation in articular mechanics and osseous elements of the other digits to augmenting the functional capacity of the thumb to oppose has received much less attention from human anatomists and kinesiologists [14]

As an anatomical instrument given to complex range of activity and multiplicity of functions, movements and usage, the human hand is prone to injury, insult or trauma [15]. Even a temporary loss of a partial or full function and use of fingers, especially the thumb, engenders loss in work output and man-days. The economic havoc the lesions of the deep branch of the ulnar nerve can cause is inestimable, especially as it supplies the so called 'educated muscle' of the palm, the lumbricals. The advent of newer personal communication technologies such as computers and mobile phones with numerous applications for worldwide internet access, downloading and texting; hand-held and digitally operated devices of rapid communication and the consequent stress and strain on hand and finger biomechanics; indeed, there are already a few named afflictions such nature finding way into clinical medicine [16]. The pollex and index, the most used digits in texting and mouse control, respectively, are expected to become common sites of trauma and lesions in the near future.

A more comprehensive understanding of the anatomy, role and function of the hand as a whole with special attention on the thumb as its lead player, is mandated: Much remains to be unraveled in opposition biomechanics and kinetics of articulations in the first and fifth carpometacarpal joints.[17] The hand and its closely held secrets are yet to be fully understood by physical anthropologists or applied anatomists.

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