1 Principles of Thumb and Finger Reconstruction: Concept of Ray and Cascade

David T. W. Chiu, J. William Littler, and Joseph Upton

Abstract

This chapter contains the essence of basic hand anatomy and biomechanics, and introduces the basic principles for reconstruction of the thumb and fingers, which have been divided into functional levels of reconstruction. Emphasis has been placed upon the uniquely structured bones, joints, tendons, muscles, nerves, vessels, and integument, which are used to restore both dynamic function and beauty to the hand. The thumb and fingers are categorized into functional levels from the fingertip to the wrist, and each chapter presents multiple methods of reconstruction at each level. The DDI (Digital Defect Index) system is introduced for the evaluation of loss based upon specific anatomical structures. A broadened conception of functional cutaneous territories is also presented. The book has been illustrated by J. William Littler, MD, and contains many unpublished sketches and drawings as well as classic illustrations from his body of work.

Keywords: Fibonacci sequence, anatomy of human hand, skeletal system, musculocutaneous system, vascular system, functional and aesthetic subunits, principles, of hand reconstruction, functional zones of thumb and fingers, DDI classification system, Vitruvian hand

1.1 Key Points

- Refined knowledge of hand anatomy is a prerequisite for a successful reconstruction.
- Rebuilding a thumb or a finger involves both restoration of missing structures and a dynamic and harmonious cascade.
- In motion, the thumb and fingers move rhythmically in sequence simulating the well-known Fibonacci series.
- Emphasis is placed upon the details of skeletal, vascular, musculotendinous, and cutaneous systems as they pertain to a successful reconstruction of a thumb or a finger.
- Functional levels of loss are more accurate and pertinent than those based solely on radiologic appearance.
- Functional cutaneous units of the thumb, fingers, and hand are important parameters affecting treatment.
- The impact of microsurgical transfers has dramatically broadened the options for reconstruction at every level.

1.2 Introduction

Reconstruction of a thumb or finger is an artistic process. It involves accurate assessment of the anatomical deficit, discerning appreciation of the functional loss, insightful conceptualization of a simile of the normalcy, and of getting there. Execution of a well-conceived formulation also requires flawless skill, precise instrumentation, seamless logistics, figuring a way to get there, and harmonious teamwork. Rehabilitation could make or break the most well-conceived and executed repair efforts; timely therapy is crucial. Objective evaluation of results is the springboard to progress and demands utmost intellectual honesty. Such an effort may be likened to a journey, which is much more efficient when there is a compass to indicate the direction and a torch to brighten the path. Collectively, we call these “principles” (Gilles, 1957; Littler, 1964c:1612, 1977e:3103; Chase, 1983). Our teachers bestowed upon us many of these salient principles. Others we learn through critical deductions. This publication presents a careful analysis of these principles through the collective experience of five hand surgeons with a combined 225 years of clinical practice of hand surgery over a 75-year period. This is what we would like to share with our colleagues when they consider reconstructive surgery of the hand.

1.3 Concept of Ray and Cascade

In reconstructing a digit, one aims to rebuild not only a part that bears an anatomical similarity to a thumb or finger but also a subunit that complements the remainder of the hand, to restore a dynamic and harmonious cascade. In repose, the human hand characteristically projects in an orderly manner with the central digit being the longest, the thumb the shortest on one side, and the “pinky” the second shortest on the opposing side. In motion, the intercalated series of small joints in the hand move rhythmically in sequence. When a digit flexes or extends, this motion initiates at the metacarpophalangeal joint (MPJ) and propagates in a proximal-to-distal sequence to the proximal interphalangeal joint (PIPJ) and distal interphalangeal joint (DIPJ). Such orderliness in repose and rhythmicity in motion invite comparisons to the punctuated descent of falling waters in a cascade. Reconstruction of a ray is successful only when it restores the countenance of a cascade of the hand in both form and function (▶ Fig. 1.1).

Da Vinci’s interpretation of the Vitruvian man was an attempt to probe the questions of how the proportions of man fit into the orderliness of the universe: of squaring the circle, finding the relationships of geometric shapes, determining specific measurements of individual human proportions, and defining both science and art into “the golden ratio” or “divine proportion.” Littler’s version of the Vitruvian hand defines similar relationships within the human hand, which are like the well-known mathematical series so prevalent in Nature: the Fibonacci sequence. The hand is an embodiment of nature (Littler, 1974a; ▶ Fig. 1.2 and ▶ Fig. 1.3).

1.4 The Essence of Hand Anatomy

The beauty in form and grace in motion of the human hand results from the dynamic display of an ensemble of uniquely structured bones, muscles, tendons, nerves, vessels, and integument. The relationship between form and function is succinctly summarized by John Hunter who noted “…structure is the ultimate expression of function” and Littler who observed that “...function imparts beauty to form” (Littler, 1974a).

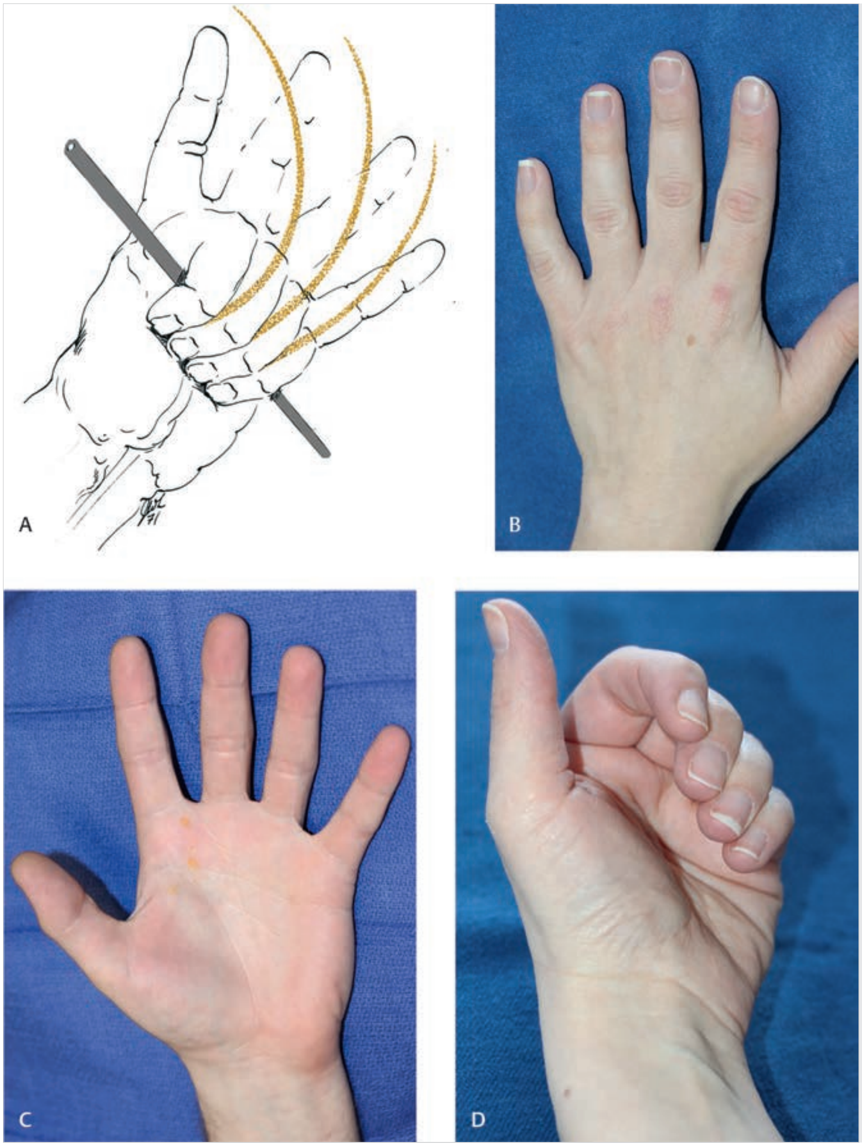

Fig. 1.1 Flexion arc of digits **(A)** The cardinal plane of motion of the digits through full extension-abduction to flexion-adduction traverses a gentle equiangular curve. This pathway (gold) enables the hand to grasp both small and large objects perfectly while exerting a powerful “chuck like” grip around a central axis (gray rod beneath the digits). **(B,C)** Dorsal and palmar views in full extension and slight abduction. **(D)** Cascade of the flexion posture in repose. Disruption of this cascade is indicative of fracture malunion, alteration of joint architecture, or asymmetric growth. (**A**: With permission from Littler JW Archives at New York Academy of Medicine (NYAM); **B-D**: © David T. W. Chiu M.D).

It all begins in the embryonic stage as a limb bud, recognizable at 3 weeks post fertilization as a swelling derived from proliferating mesodermal cells covered by ectodermal cells lateral to the 8th to 12th myotomes. The limb bud grows rapidly in a proximal-to-distal sequence and differentiates into a complete form by 8 weeks, which marks the end of embryogenesis. The central core of mesodermal condensation lays the foundation of the skeleton of the limb. Segmentation begins by the 4th week post fertilization. The humerus, radius, and ulna become identifiable. Eight foci of mesodermal condensation within the hand plate will become the carpal bones. Five cores of mesodermal projection immediately distal to these will become the future metacarpals, radiating toward the distal margin of the limb bud in the 5th week. Meanwhile, nerves in a fan-shaped projection have grown into the hand plate. By the 6th week, phalanges are formed; most of the skeletal elements of the limbs are chondrified in a proximal-to-distal sequence. The elbow joint emerges as a cavitary depression; dorsal grooves develop between digits. By the 7th week, musculature of the whole limb is well formed and clefts between digits are defined. The forearm and hand are pronated and resemble the adult form. This marks the completion of embryogenesis and the end of the differentiation stage of skeletal development.

What follows is the fetal period wherein skeletal development has evolved into the *ossification stage*. This will continue after gestation and is not complete until closure of all epiphyses at puberty. Ossification in the hand begins with the distal phalanges, followed by the metacarpals, proximal phalanges, and finally the middle phalanges. In the distal phalanges, ossification initiates at the distal tip through calcification and *intramembranous* ossification, while in the remaining phalanges it is through *enchondral* ossification, characterized by central bone collar formation followed by periosteal vessel invasion, as seen in all metacarpals. Flawed development of the proximal portion of a ray explains why terminal digits may be found on a hand containing only metacarpals designated as a symbrachydactyly (Al Quattan, 2005).

Joint formation in the hand coincides with the appearance of chondrogenesis centers during the 6th week and is complete in 9 to 10 weeks post fertilization. Joints first appear as trilayer

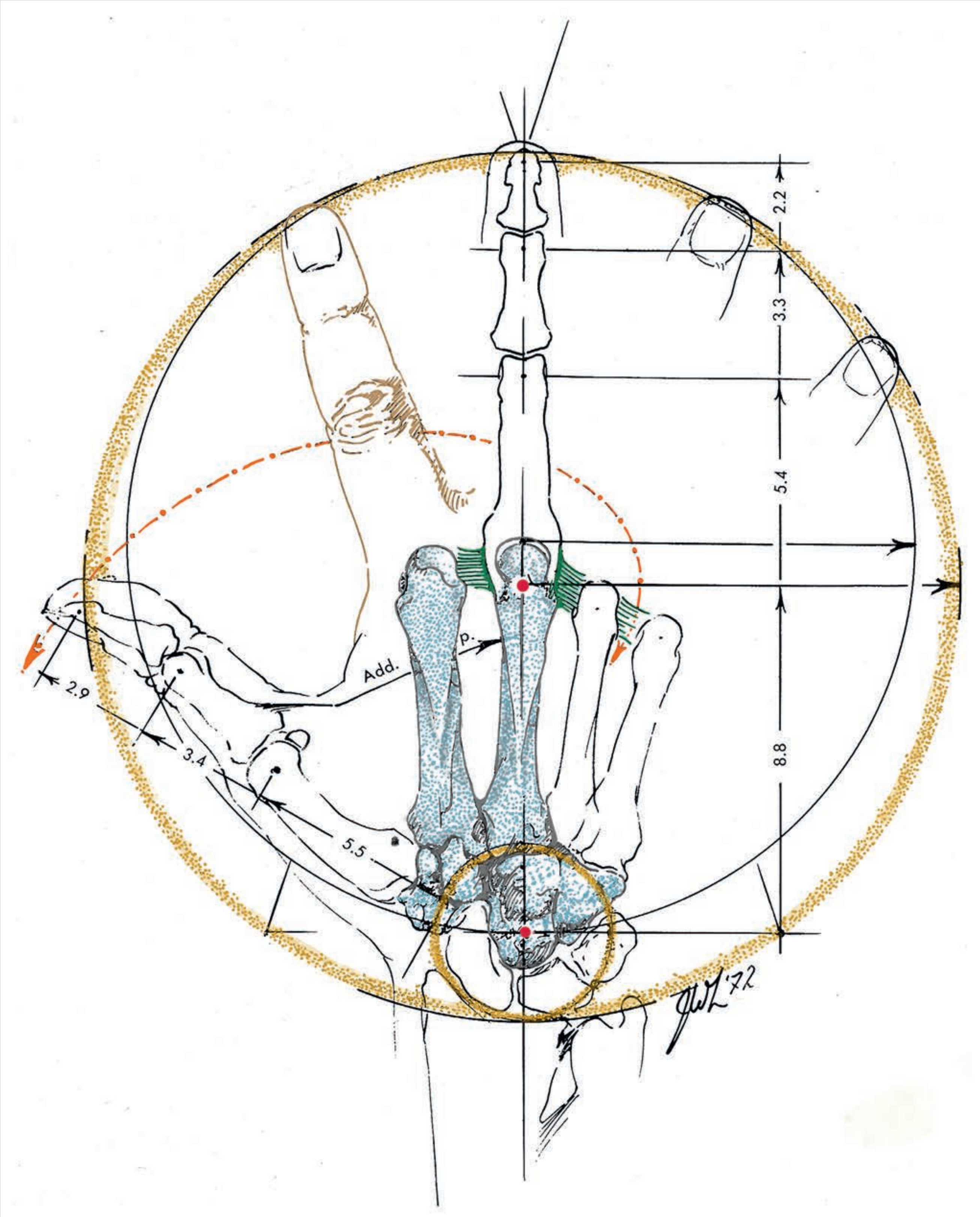

Fig. 1.2 The Vitruvian interpretation of a hand. The immobile "fixed unit" of the hand is stippled. In extension and abduction, the fingertips lie on the circumference of a circle (*gold*) with the center point (r*ed locus*) at the long metacarpal head. The lengths of the carpometacarpal and three phalangeal segments (8.8, 5.4, 3.3, and 2.2 cm) are like the well-known Fibonacci mathematical series, which gives order to Nature. The thumb is an exception and does not follow the primitive skeletal length sequence due to its specialization or adaptation with an increase in length, width, and pulp volume of the terminal two phalanges (i.e., 2.9 and 3.4 instead of 2.2 and 3.3 cm). Both the transverse and vertical axis of rotation of the hand and carpus are through the ball of the capitate (os magnum; *small red circle*). When the thumb moves through its cardinal plane from extension–abduction to flexion–adduction, the path of the tip is an equiangular curve (orange interrupted line). (With permission from Littler, Chapter 1,1974a:9).

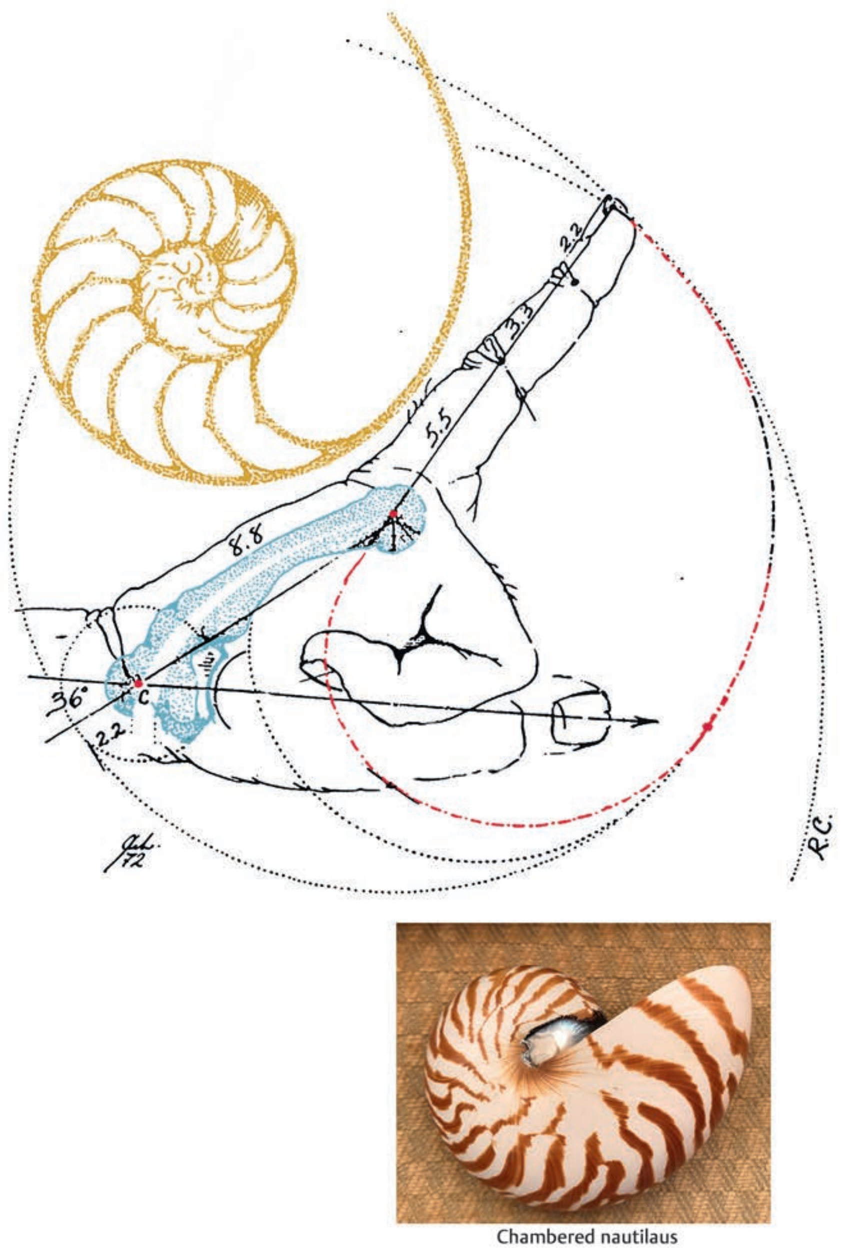

Fig. 1.3 A geometric analysis and the “golden ratio.” The flexion/extension sweep of the finger executes a curve like an equiangular spiral, which is a composite of one metacarpal (*blue*) and three phalangeal segments moving simultaneously while the metacarpal joint (MPJ), proximal interphalangeal joint, (PIPJ), and distal interphalangeal joint (DIPJ) flex in sequence. The lengths of these links (2.2, 3.3, 5.5, and 8.8) approximate the “golden ratio” of 1/1.618 as defined by the Fibonacci series. The length of a proximal segment is equal to the sum of the two more distant links. The length of an individual segment is 1.618 times that of the next distal link. In repose, the thumb lies at a 36-degree angle from the longitudinal axis of the central ray of the hand, which defines the fixed unit of the hand. Its flexion arc subtends an identical curve (*red*). In Nature this engaging logarithmic spiral is perfectly formed in the shell of the chambered nautilus (*lower right*).
(C, head of the capitate and center of the radiocarpal joint movement; RC, radiocarpal arc.)
(Reprinted from Littler, JW On the adaptability of man’s hand (with reference to the equiangular curve, Hand, 1973; 5(3); 187–191, with permission from Elsevier).

interzones of homogenous blastema tissue in between the chondrifying skeletal elements along the proximo-distal axis. Vessel ingrowth and cavitation initiating at the periphery are the key steps of joint formation, which is activated and modulated by motion affected by the musculature. Ossification centers of the carpal bones usually appear at birth and are complete by the age of 8 years.

1.5 Anatomical Characteristics of the Human Hand

Anatomy is the ultimate expression of function in form, and the harmony of both within a human hand is unique. Motions of the hand are derived from the seamless interplay of the stability of the skeleton, gliding facility of the joints, movement of the tendons, contractile force of the muscles, oxygenation enabled by the cardiopulmonary system and channeled by the vascular system, and integration of the sensory input and motor impulse output conducted by the nervous system, all within the protective, sensate, and thermodynamically active integument.

Like the understanding of music, which demands a mastery of the concept of sound, rhythm, melody, and harmony, the understanding of the hand requires knowledge of the following:

- Each tissue type and recognition of the ***theme*** of tissue distribution.
- The ***rhythmicity*** of serial patterns of lever arm components.
- ***Melody*** of movement progression.
- The ***harmony*** and progression of reciprocal parts moving in equilibrium.

The first two are structural and the last two kinetic.

To many medical students, therapists, and even surgeons, the anatomy of the hand may seem overtly complex and its restoration intimidating. Once the fundamental architecture has been familiarized, functioning of the hand is more readily appreciated. A reconstructive hand surgeon must, however, further recognize all the anatomical nuances and specialized functions of the components. Quality of the ultimate reconstruction often reflects the surgeon's understanding of the hand anatomy and biomechanics.

1.5.1 The Skeletal System

Common pattern: The phalanges of the finger and thumb punctuate to the rhythm of the Fibonacci series.

The skeletal core of the hand is a strategic orchestration of 19 slender small bones grouped into five rays of four bones each in four fingers and three in the most agile pollex (thumb). In each ray, the delicate phalanges punctuate at the rhythm of the Fibonacci series: the distal phalanx (DP) simulates the middle phalanx (MP) in length; the proximal phalanx (PP) equals to the sum of the length of the DP and MP; and the metacarpal measures to the sum of the length of the PP and the MP (▶ Fig. 1.2, ▶ Fig. 1.3). A similar pattern applies to the terminal three bones of the thumb. The resulting flexion arc simulates a pattern in *The Chambered Nautilus*. However, in contrast to fingers, the DP of the thumb is an exception as it has gained length, breadth, and pulp volume likely through adaptation.

General pattern: Cartilage of a joint surface provides gliding; configuration of the joint directs motion; ligaments on the periphery harness stability.

Linking the phalanges are two flexible, yet stable, bicondylar hinge joints: the PIPJ and DIPJ. They are comprised of the reciprocating convex and concave disks of cartilage on each side, a stout yet accommodating volar plate on the palmar aspect, and two pairs of laterally stabilizing collateral ligaments on either side: one horizontal (main or cord) and the other oblique (accessory; ▶ Fig. 1.4A). Each interphalangeal (IP) joint is motored by a dedicated set of tendons, which flex and extend the joint. The MPJ is a multiaxial, diarthrodial joint consisting of a relatively loose joint capsule, a pair of collateral ligaments, a pair of accessory collateral ligaments, and a volar plate. The collateral ligament, situated on the radial and ulnar side of each joint, is stout in flexion and relaxed in extension. The accessory collateral ligaments arise from the metacarpal head like a fan, investing onto the volar plate and guarding the lateral surface of the MPJ (▶ Fig. 1.4B). Through the intricate interplay of the extrinsic and intrinsic musculature, the MPJ can flex and extend, abduct and adduct, and circumduct clockwise as well as counterclockwise. The total range of motion in the flexion–extension plane exceeds that of any other joint and requires adaptation of its integument (▶ Fig. 1.5, ▶ Fig. 1.6).

The thumb, being the most specialized ray in the hand, has the greatest range of motion by virtue of its carpometacarpal joint (CMC). This unique saddle allows it to gyrate and assume a cone-shaped path of motion encompassing the entire sphere of the hand and reaching the pulp surfaces of each of the fingers in opposition (▶ Fig. 1.7).

General pattern: The shape of a joint determines its mobility and rigidity. Condylar shape indicates *mobility*, while flat surface implies *rigidity*.

Proximal to the metacarpals is the eight-bone carpal complex, which is an ensemble of two rows of four small bones of diverse size and shape. Together they form a cup-shaped foundation from which the five metacarpals spring. The carpometacarpal (CMC) joints are a marvelous study of the meaning of form. The thumb metacarpal, riding on a saddlelike trapezium, has the greatest mobility and ensuing adaptability (▶ Fig. 1.7). The second CMC joint is **W**-shaped with four flat facets solidly locking onto the trapezoid and trapezium and is practically immobile. The third CMC joint is flat and resolutely rigid opposing the capitate. It is practically immobile. The fourth and fifth CMC joints are hinged and flat with limited mobility.

The second and third metacarpals along with the capitate and hamate constitute the central fixed unit of the hand (▶ Fig. 1.2, ▶ Fig. 1.8A). The ulnar unit, consisting of the ring and little fingers, rotates slightly at the base of the CMC joint and converges toward the central fixed unit. When the distal carpal row articulating with the metacarpals is rigid, the proximal row articulating with the radius and ulna is mobile. The index and long fingers remain parallel to one another not only in the resting position but also during digital flexion, extension and abduction, adduction.

General pattern: The basic skeletal architecture of the hand consists of a central, fixed unit, flanked by one or more adaptive, mobile units.

The central fixed unit of the hand has on its radial side the very mobile and independent thumb, which functions primarily in tip-to-tip prehension with one or more of the fingers. In contrast, the less mobile ulnar component is more essential for grasp. Intrinsic muscles, innervated by both the median and ulnar nerves, maintain the mobility and variability of the transverse metacarpal arch (▶ Fig. 1.9). The limited mobility of the distal carpal row and its CMC articulations create a less mobile (fixed) carpal arch. Motion of the wrist derives mainly from the radiocarpal joint and the midcarpal joint.

The ideal resting position of the hand is the composite posture of 30-degree wrist extension, 45 degrees of radial and palmar thumb abduction, and 45 degrees of digital MP flexion with IP joint extension. In this position, supporting ligaments, joint capsules, and musculotendinous structures are in a balanced and relaxed state and are positioned for maximum ease for re-immobilization (▶ Fig. 1.8B).

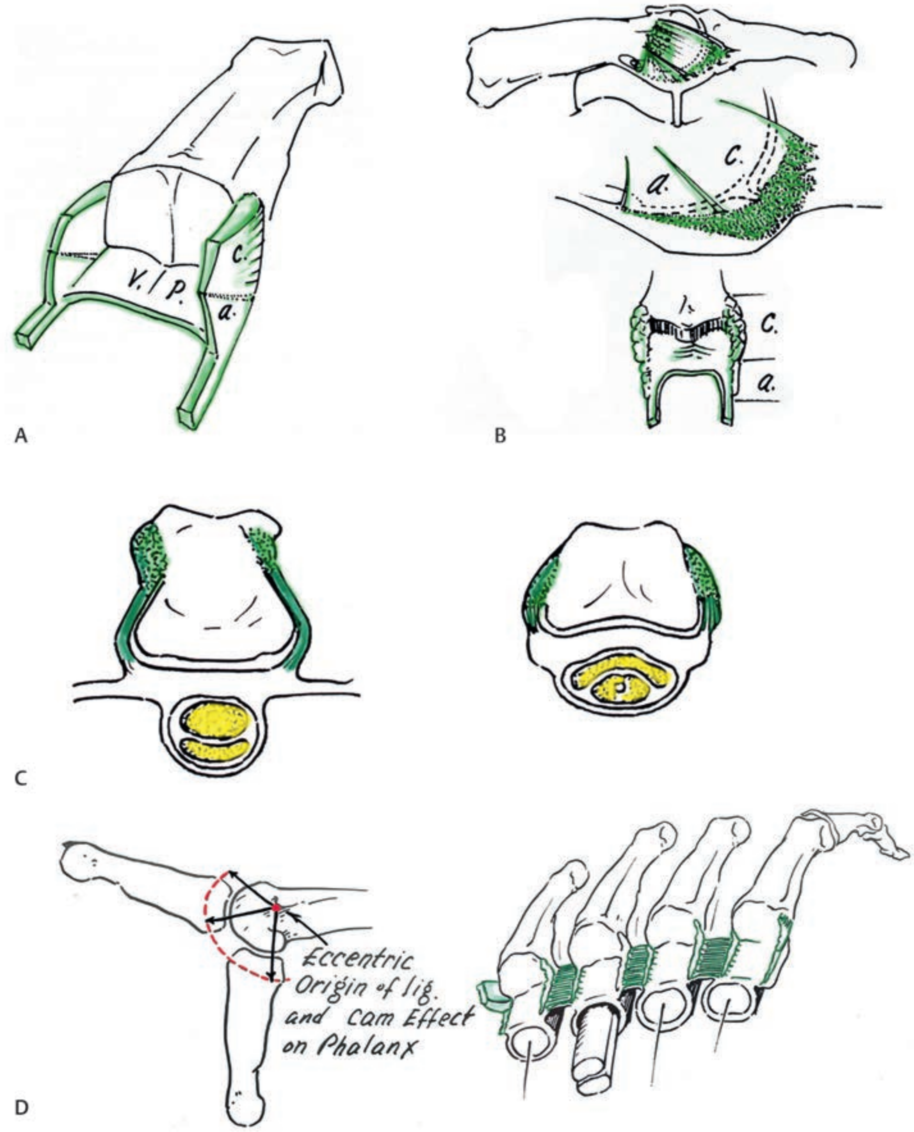

Fig. 1.4 Ligament support. **(A)** The ligamentous support of the PIP joint shows a box configuration. The thickest portion of the collateral ligament is where these two portions overlap and reinforce the insertion of the volar (palmar) into the base of the middle phalanx. This creates a very strong support system. Displacement of the joint cannot occur unless two sides of the box are disrupted. The accessory portion (a) narrows as it converges proximally to form the strong "check ligament". **(B)** The quadrangular or cord (c) portion and accessory (a) portion are seen from the lateral view. The flexor sheath adds additional support. The central portion of the volar plate thins and is membranous proximally, allowing this portion to fold upon itself and provide room for the base of the middle phalanx with flexion. **(C)** The collateral ligaments of the metacarpophalangeal (MP) joint (left) originate dorsal to the axis of rotation of the joint and diverge distally and insert onto the proximal phalanx and volar plate. Unlike the concentric condyles of the middle and proximal phalanges, the metacarpal head is asymmetrical and longer from the axis of rotation volar, creating the CAM effect, which contributes to tightening of the ligament with flexion. The proximal interphalangeal (PIP) joint axis is centered and tension on the ligament is the same in flexion and extension. Cross-sectional views show that the lateral flare of the metacarpal head (left) also increases tension with MP flexion. The flare of the proximal phalanx (right) plays a minor role. **(D)** The eccentric origin of the collateral ligament and CAM effect upon joint stability are seen on lateral view (left). Diagram of the intervolar plate linkage with the metacarpal heads removed (right). These ligaments into both the collateral ligament complex and the proximal phalanx add three-dimensional stability. The central two rays (long and ring) have bilateral support. Consequently, these joints are rarely dislocated. (With permission from Eaton RG, Joints and their Ligaments, Chapter 2, In Symposium on reconstructive hand surgery. Vol.9, Littler JW, Cramer LM, and Smith JW (eds.) St. Louis, C.V. Mosby, 1974).

One important observation worthy of sharing is that there are two levels of voluntary wrist extension and flexion. During examination, when the patient is asked to extend the wrist, he or she would extend the wrist to a relatively relaxed state of 40 to 45 degrees depending on the laxity of the individual's ligaments. When the examinee is asked to maximally extend the wrist, he or she is likely to extend an additional 15 to 20 to 55 to 60 degrees. When the wrist is passively extended to a maximal range measuring 70 to 75 degrees, there is often discomfort. Similarly, relaxed flexion of the wrist is often in the 40- to 45-degree range. Maximal voluntary flexion is 55 to 60 degrees. Forced flexion is also likely to yield another 10 to 15 degrees,

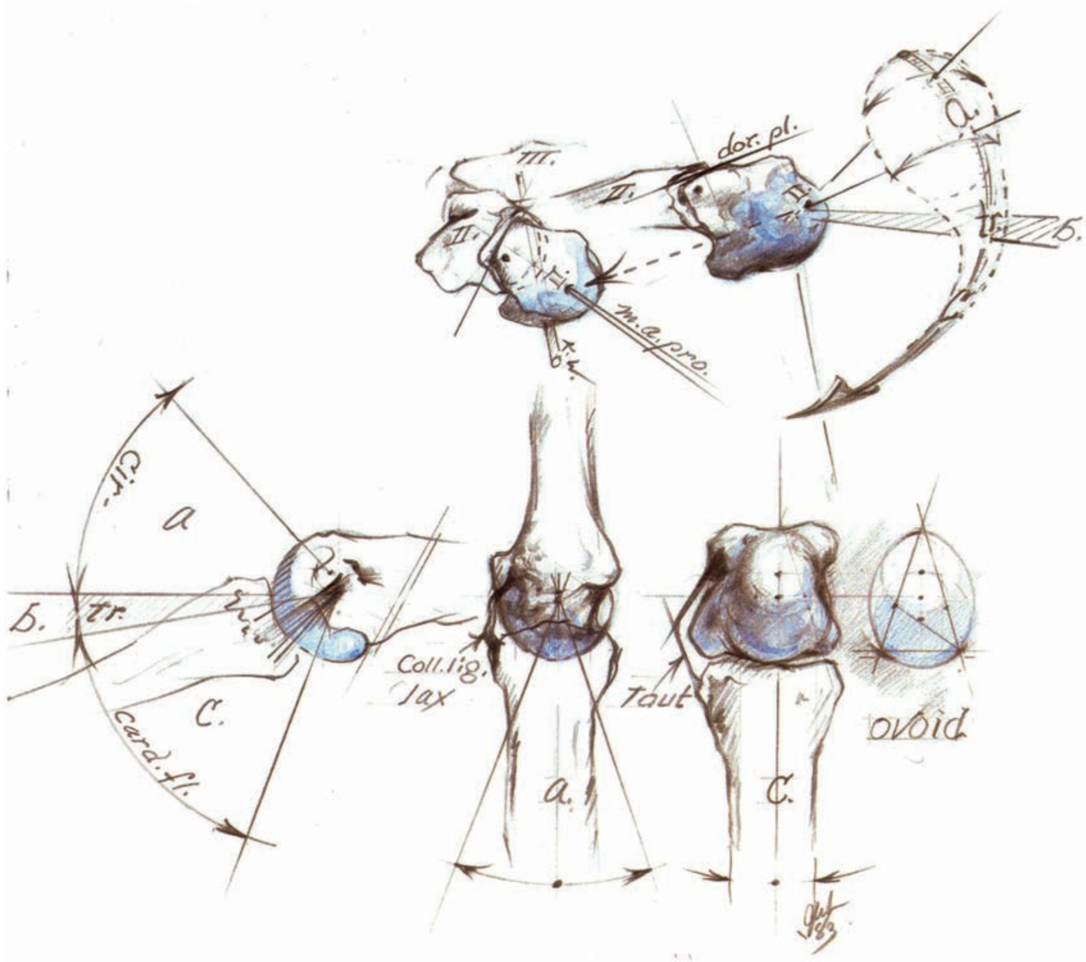

Fig. 1.5 Metacarpal head configuration and CAM effect. A classic pencil sketch by Dr. Littler demonstrates the ovoid configuration of the index metacarpal head and the collateral ligaments. When the finger is in the neutral position in the cardinal plane of flexion/extension, there is trace of side-to-side motion (b.) or abduction/adduction. Hyperextension of the metacarpophalangeal joint (MPJ) will decrease the lever arm and position the collateral ligaments in laxity, which then permit much greater motion (a.). In full flexion, the lever arm is longer and the metacarpal head and collateral ligaments taut permitting no motion. From the frontal view, the metacarpal head is ovoid (not circular).
(III, long metacarpal; II, index metacarpal; a., motion parameter in hyperextension; b., in neutral position; c., full flexion; Coll.lig.lax., laxity in ligament in hyperextension; taut, opposite position in full flexion; cir. card.fl., the single cardinal plane of flexion and extension; dor.pl., dorsal plane; taut, collateral ligament tight in flexion; ovoid, shape of the articulating portion of the metacarpal head; m.a.pro., medial axis pronation; x., dorsal-palmar axis of metacarpal head.) (With permission from Littler JW Archives at New York Academy of Medicine (NYAM) (original drawing)).

again depending on the examinee's internal ligamentous laxity. Such a phenomenon is critically important while utilizing the tenodesis effect as a guide for tension setting during extensor or flexion tendon reconstruction.

General pattern: Marginal projections in a bone indicate points of attachment of ligaments or retinacular structures; a ridge for membranous structures; and tubercle for muscle, tendon, or ligament.

Ligaments are organized collagen bundles with bone-to-bone attachment. Their function is to provide support and restraint, and their flexibility defines joint mobility (▶ Fig. 1.6, ▶ Fig. 1.11). The volar (palmar) plate of a thumb IP joint provides both side-to-side stability and restraint from hyperextension. The accordionlike accommodation of the thin membranous proximal portion allows flexion (▶ Fig. 1.4A, B). The support and restraint of the arcuate ligament of the radial head defines the limitation of forearm motion in pronation and supination. More specialized are the intraosseous ligaments on either side of the distal phalanx.

Retinacular structures are thin, fascial structures with bone-to-bone attachments and serve to prevent tendon bowstringing. The mesothelial lining facilitates gliding. Examples are the six dorsal compartments of the wrist and the fibro-osseous pulley system, which contains the flexor mechanism on the palmar surface of the digits (▶ Fig. 1.14).

The marginal projections of carpal bones indicate points of attachment for ligaments or retinacula. A good example is the

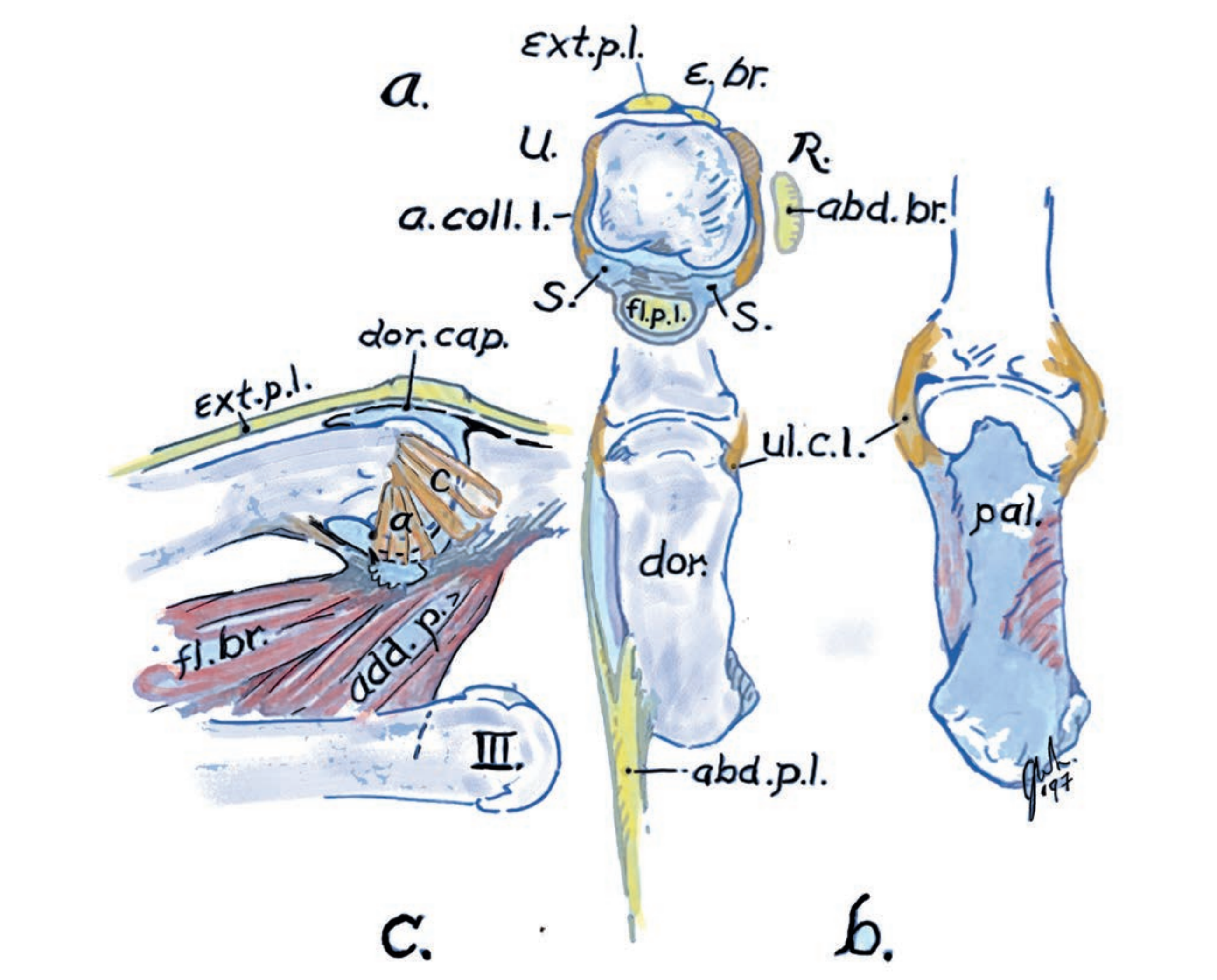

Fig. 1.6 Structures around the thumb metacarpophalangeal (MP) joint. **(A)** A coronal view at the level of the thumb metacarpal head shows that the bone is ensheathed by extensor tendons, intrinsic muscle insertions, collateral ligaments, and volar plate with sesamoid bones. **(B)** Dorsal and palmar views show the collateral ligaments. **(C)** Lateral view shows the relationship between the collateral ligament with its accessory (a) and cord (c) portions and the mesial short flexor inserting into the ulnar sesamoid bone and the adductor pollicis onto the base of the proximal phalanx. (U., ulnar; ext.p.l., extensor pollicis longus tendon; e.br., extensor pollicis brevis intrinsic muscle tendon; R., radial; abd.br., abductor pollicis intrinsic muscle; S., sesamoid bone; fl.p.l., flexor pollicis brevis longus tendon; dor.cap., dorsal capsule of the MP joint; fl.br., flexor pollicis brevis intrinsic muscle; III., long metacarpal giving origin to the two intrinsic muscles; dor., dorsal; pal., palmar; ul.c.l., ulnar collateral ligament of the MP joint.) (Reprinted with permission of Steven Z. Glickel, MD (original drawing)).

beaklike extension at the ulnar side of the base of the first metacarpal, onto which a strong volar (anterior) ligament arises (► Fig. 1.10). Reinforcing the radial side of this joint is the relatively thin lateral ligament. The capsule circumscribing the periphery of the trapezium is attached to the ridge of the base of the first metacarpal, which surrounds the articular surface at about 1.5 mm. Such unique anatomical arrangement creates a joint that is strong yet flexible (► Fig. 1.11). Over the past few centuries, this joint has attracted considerable interest from both anatomists and mathematicians. The surface relationships and movement between the trapezium and metacarpal have been subjected to analysis far beyond the comprehension and need of most hand surgeons. This is undoubtedly the most versatile joint in the hand (► Fig. 1.7, ► Fig. 1.10, ► Fig. 1.11).

Characteristic muscle attachments to bone prominences could be found in the opponens pollicis (OP) origin from the tubercle of the trapezium radial border of the thumb metacarpal and the abductor pollicis brevis (AbPB) to the tubercle of the scaphoid (► Fig. 1.10, ► Fig. 1.11B). The dorsal retinaculum of the wrist has a strong, unyielding attachment to the radial styloid process, Lister's tubercle, and the ulnar styloid. The radial wrist extensors attach to prominent dorsal tubercles at the bases of the second and third metacarpals (► Fig. 1.8), which, when hypertrophied, are designated as a metacarpal boss. Lateral and volar ridges of the proximal and middle phalanges represent the attachment of the digital theca. The dorsal tubercles on the proximal portions of the middle and distal phalanges provide the interface for the attachment of the extensor mechanism onto the cortical bone.

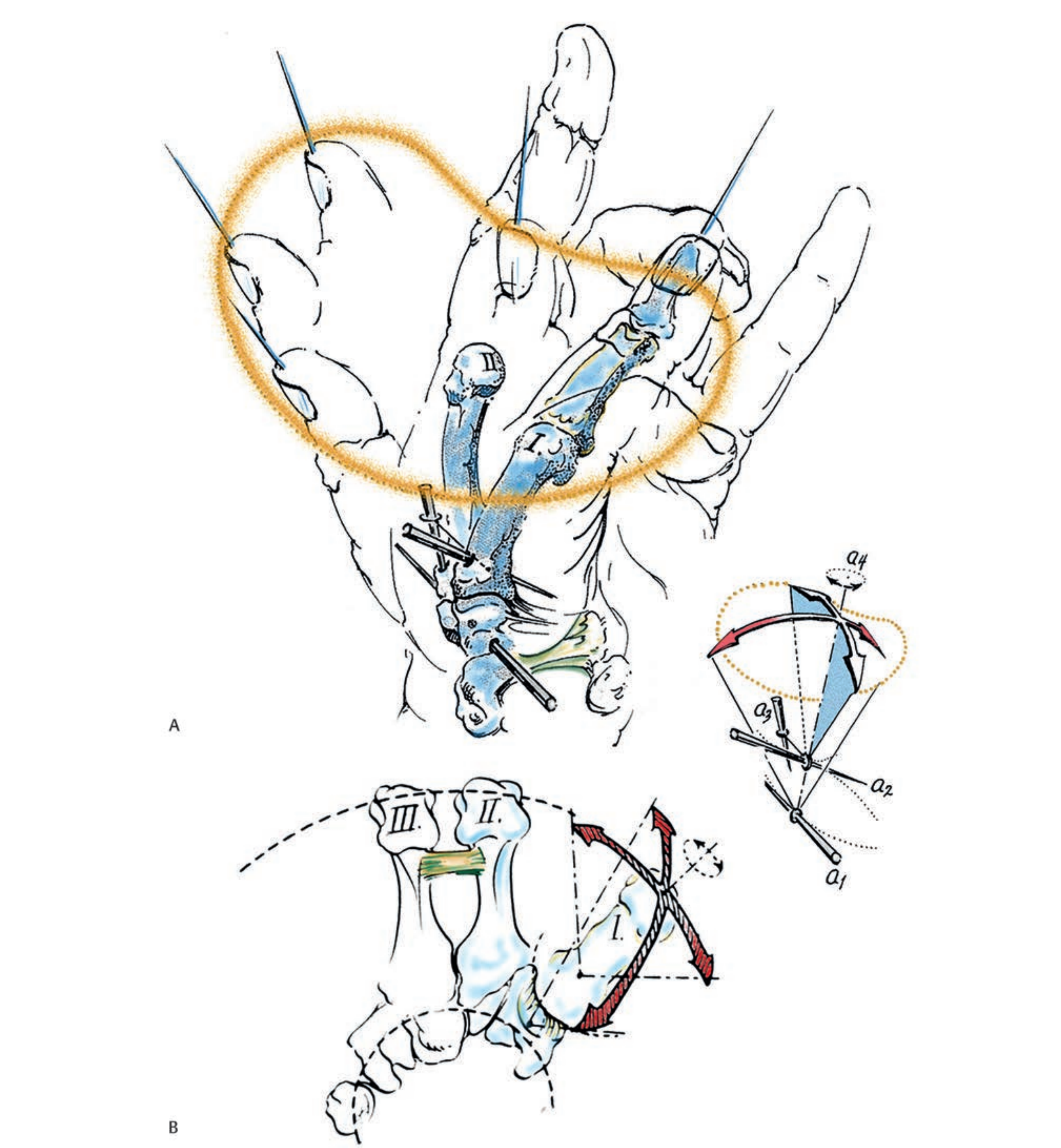

Fig. 1.7 Thumb basal (carpometacarpal [CMC]) joint mechanics. **(A)** During circumduction the thumb tip traverses a reniform (kidney-shaped) orbit (*gold*). The volume within this region is conical and can be conceptualized as the contemporary summation of motion in multiple planes. The motion of this unique joint is the result of the configuration of the joint surfaces (CMC, MP, IP) and the harnessing effect of the collateral ligaments and joint capsule.
There are four major axes (a1–a4) of rotation of these cardinal planes of movement summarized as (1) oblique: flexion/adduction and extension/abduction (a1); (2) vertical: flexion/adduction and extension/abduction (a2); (3) internal rotation: pronation by opponens pollicis and abductor pollicis muscles) and supination by adductor pollicis and extensor pollicis longus muscles (a3); and (4) internal rotation: by the laxity of the CMC joint as well as the surface contours (a4). Ligament support on the radial side of the CMC joint is weaker in comparison to the tighter structures on the dorsal surface, especially the volar (anterior) oblique side. These structures help lock the joint in place with internal or external rotation. When the thumb is fully pronated and abducted during power pinching or gripping, a stable, joint configuration, tight ligament support, and powerful thenar intrinsic muscles maintain "locked" position. **(B)** The movement of the CMC joint through these four planes are determined by both the configuration of the joint surface and the soft-tissue (ligament and capsule) support. A flat joint contour, often seen in young middle-aged women, coupled with a lax dorsal ligament support will predispose to much greater mobility (especially with rotation) across the joint.
The end result will be arthrosis. The opposite may be seen in males who have a saddle-shaped articular surface, which will restrict intrinsic hypermobility. (II, index metacarpal head; I, thumb metacarpal; III, long metacarpal head; a1–a4, four different axes of rotation.) (With permission from Littler JW, Chapt. 1, Hand Structure and Function, Littler JW. 1974a:10-11).

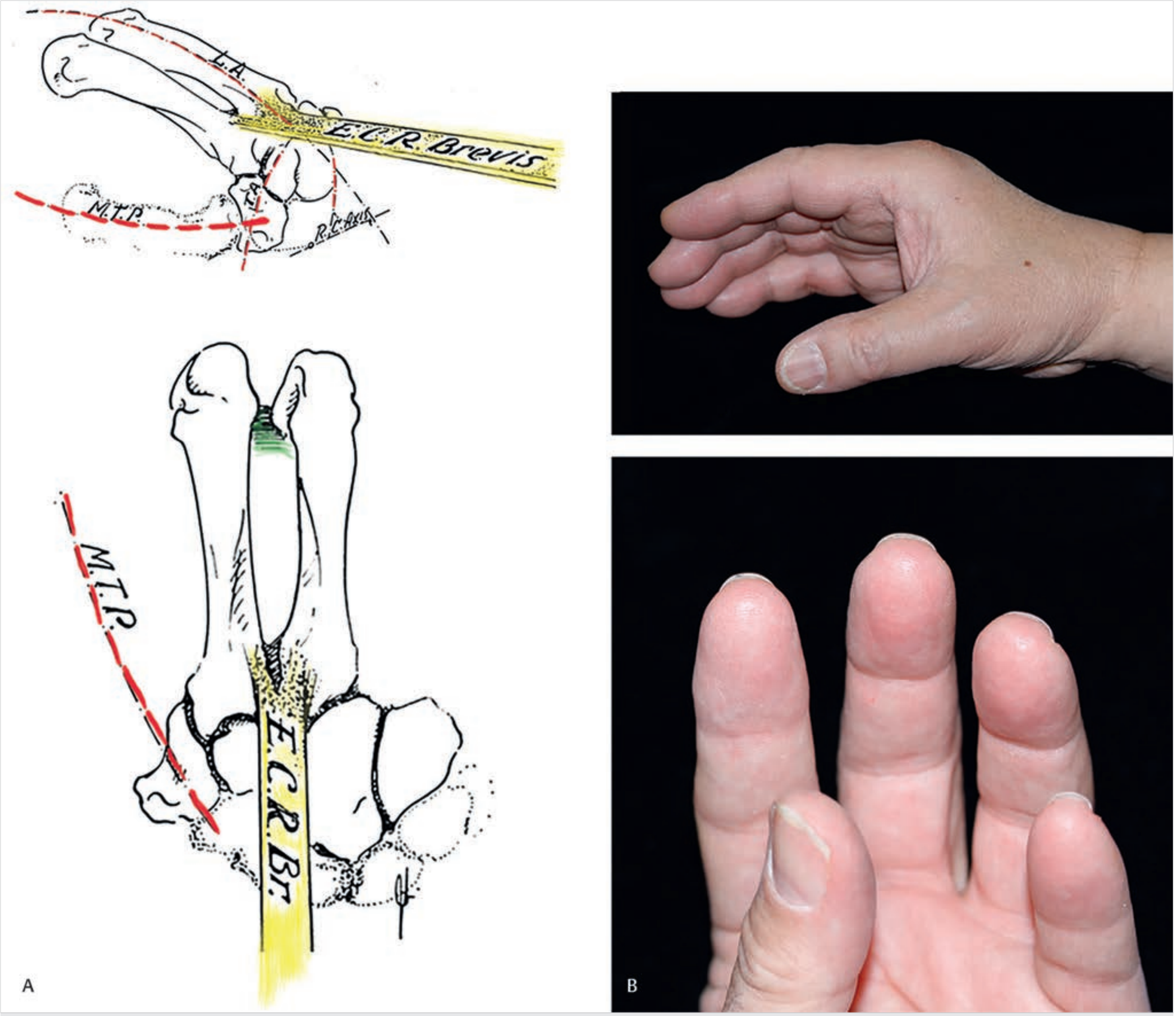

Fig. 1.8 Longitudinal arch and fixed unit. **(A)** From the lateral perspective, the fixed unit of the hand forms the proximal portion of the longitudinal arch of the hand, also maintained in resting posture by the intrinsic musculature. The wrist is supported by the strong extensor carpi radialis brevis (ECRB), which attaches to the dorsal base of the index and long metacarpals. The carpometacarpal (CMC) joint configuration renders this portion of the carpal arch immobile or fixed. Of the three wrist extensors, the ECRB has the best mechanical advantage due to its proximity to the axis of rotation within the capitate. *Ridges* along the metacarpal designate retinacular or muscular attachments; *tubercles* represent tendon attachments. **(B)** The photograph of the hand in optimal "position of function" shows the fixed portion in a dorsiflexed position at 30 degrees and the thumb parallel to the radius and in 45 degrees of palmar abduction. The digits should be semi-flexed, and the fingertips should be at equal distances from the pulp surface of the thumb. Due to its unique CMC joint, the thumb can be positioned in direct opposition to any finger.
(ECRBr, extensor carpi radialis brevis tendon; TA, transverse carpal arch; LA, longitudinal arch; MTP, metacarpophalangeal; RC axis, radiocarpal axis.)
(**A**: With permission from Littler JW, Chapt. 73. Principles of Reconstructive Surgery of the Hand, 1977e:3108; **B**: © David T. W. Chiu M.D).

General pattern: Wrist mobility along the plane of motion and lateral stability at the plane 90 degrees to the former predetermines effective prehension. The stability of the proximal joint predetermines the mobility of the distal joint.

General pattern: Ultimate motion within the hand is the balance of the activation (i.e., contraction) of one motor and reciprocal accommodation (i.e., relaxation) of the opposing muscle groups.

In this intercalated system, movement of one joint is provided by the stability of another. In addition, through dynamic tenodeses, the movement at one joint can be used to transmit power to the next or more distal joint (▶ Fig. 1.15). Synergistic contraction of the acromion stabilizes the elbow with wrist flexion and extension. Similarly, at the thumb metacarpal level the extensor pollicis brevis (EPB) stabilizes the MPJ and facilitates IP flexion and extension. The radiocarpal joint, which mobilizes through a ball bearing–like mechanism, connects the radius to the fixed unit of the hand through the proximal carpal row consisting of three bones: scaphoid, lunate, and triquetrum. Of the three strong extensor muscles, the extensor carpi radialis brevis (ECRB) is the prime mover due to its apical insertion on the