Two Sides of the Same Coin: Tendoligamentous Similarities and Dissimilarities of Great Toe and Thumb Anatomy on MRI

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Abstract

Evolution and functional necessities have compelled the great toe of the foot and its embryological kin, thumb, to have some tendoligamentous differences with a similar basic anatomical structure. This provides biomechanical advantage to these joints: the thumb is apposable and more mobile, ensuring hand dexterity and tool-handling, whereas the great toe is less mobile and more stable, ensuring weight bearing, strength, and stability for bipedal locomotion. This pictorial review will methodically illustrate the similarities and dissimilarities of the joint morphology and its tendoligamentous attachments at the level of carpometacarpal joint, metacarpophalangeal joint, and interphalangeal joints of thumb compared with tarsometatarsal joint, metatarsophalangeal joint, and interphalangeal joints of great toe. It intends to provide a comprehensive understanding of the normal anatomy of great toe and thumb to the radiologists, enabling better interpretation of the pathologies.

Keywords

► MRI
► great toe
► thumb
► hallucis
► pollicis

Introduction

With evolution, quadrupeds progressed to develop two hands and two feet. Driven by functional necessity, thumb evolved to become opposable for maintaining hand dexterity, and great toe evolved to optimize weight bearing, balance, and bipedal locomotion. Therefore, there are anatomical tendoligamentous modifications at the level of carpometacarpal (CM) joint and metacarpophalangeal (MCP) of thumb compared with tarsometatarsal (TM) joint, and metatarsophalangeal (MTP) joint of great toe. Understanding the anatomical modifications is essential to analyze the anatomy and biomechanics of these joint on magnetic resonance imaging (MRI) that will aid in comprehensive evaluation of the patterns of injury in these joints.

In addition to limited range of movements in the joints of great toe, another major difference between great toe and thumb is that the coronal plane of thumb is nearly at right angle to that of the rest of the fingers and rotated medially, whereas the great toe lies in the same coronal plane as the rest of the toes2 (►Fig. 1).

In the current pictorial review, we will illustrate the radiological anatomy of thumb and great toe on 3T MRI. The capsuloligamentous anatomy and tendinous attachments will be described at the level of TM/CM joint, MTP/MCP, and interphalangeal (IP) joints highlighting similarities and dissimilarities at each level.

For the great toe MRI, the patient is placed in supine position, the plantar surface of foot flat against bottom of foot coil, and the foot at 90 degrees to leg. The sequences,
planes, and scan parameters are summarized in Table 1 and the planning is summarized in Fig. 2. For the thumb MRI, patient is placed in prone position with elevated arm (supera-

Table 1 Scan sequences and parameters of great toe

| Sequence | Plane | Slice thickness | FOV (cm x cm) |
|----------|-------|-----------------|---------------|
| PDFS     | Axial | 2–3             | 8 x 8         |
| PDFS     | Coronal | 2–3             | 10 x 12       |
| PDFS     | Sagittal | 2–3             | 10 x 12       |
| T1W      | Sagittal | 2–3             | 10 x 12       |
| T2W      | Coronal | 2–3             | 10 x 12       |

Abbreviations: FOV, field of view; PDFS, fat suppressed proton density; T1W, T1-weighted.

Table 2 Scan sequences and parameters of thumb

| Sequence | Plane | Slice thickness | FOV (cm x cm) |
|----------|-------|-----------------|---------------|
| PDFS     | Axial | 2–3             | 8 x 8         |
| PDFS     | Coronal | 2–3             | 10 x 12       |
| PDFS     | Sagittal | 2–3             | 10 x 12       |
| T1W      | Sagittal | 2–3             | 10 x 12       |
| T2W      | Coronal | 2–3             | 10 x 12       |

Abbreviations: FOV, field of view; PDFS, fat suppressed proton density; T1W, T1-weighted.

Tarsometatarsal/Carpometacarpal Joints

Great Toe

The first TM joint of foot forms the medial column of the Lisfranc’s joint that provides stability to the mid foot and forefoot. It is an arthrodial joint between the distal articular surface of the medial cuneiform and the base of first metatarsal, allowing flexion and extension with limited abduction and rotation. The dorsomedial ligament connects the dorsal surface of the medial cuneiform to that of base of first metatarsal, the dorsal Lisfranc’s ligament extends from the dorsolateral side of medial cuneiform to the medial surface of base of second metatarsal, and the dorsal intercuneiform ligament connects the medial and intermediate cuneiforms. The plantar TM ligament and the plantar Lisfranc’s complex connects plantar surface of medial cuneiform to plantar surface of base of first, second, and third metatarsal, respectively. The tendon of tibialis anterior attaches on the medioplantar aspect of the base of first metatarsal and the distal end of medial cuneiform, whereas the peroneus longus attaches on the lateral aspect of the same.A (Fig. 4).

The Lisfranc’s ligament is responsible for anterolateral stabilization of midfoot and forefoot. As

Fig. 2 Planning of magnetic resonance imaging great toe. (A) First, the localizer was used to plan axial images perpendicular to the long axis of the metatarsal and proximal phalanx. (B) The coronal slices were planned on the sagittal plane, parallel to the long axis of the metatarsal and proximal phalanx. (C) Using axial images, sagittal scan was planned perpendicular to the line joining the two sesamoids.
**Fig. 3** Planning of magnetic resonance imaging thumb. (A) First, localizer was used to plan axial images perpendicular to the long axis of the proximal phalanx. (B) Using axial images, coronal scan was planned parallel to the line joining the two sesamoids (outlined with yellow circle). (C) Using axial images, sagittal scan was planned perpendicular to the line joining the two sesamoids.

**Fig. 4** Ligaments around first tarsometatarsal joint. (A) Diagrammatic representation of the three dorsal ligaments: dorsomedial ligament (dC1-M1) that is between dorsal surface of medial cuneiform (C1) and the dorsal surface of the base of first metatarsal (M1), proper Lisfranc’s ligament (dC1-M2) between the dorsal surface of medial cuneiform (C1) and base of second metatarsal (M2) and the intercuneiform ligament (dC1-C2) between the dorsal surfaces of the medial (C1) and intermediate cuneiform (C2). (B) Diagrammatic representation of the three plantar ligaments: plantar tarsometatarsal ligament (pC1-M1) between plantar surface of medial cuneiform (C1) to base of first metatarsal (M1) and the proper plantar Lisfranc’s ligament’s complex (pC1-M2/M3) extending between medial cuneiform and plantar surface of base of second (M2) and third metatarsal (M3). (C) Sagittal fat suppressed proton density (PDFS) weighted magnetic resonance image shows dorsomedial ligament (thin green arrow) and plantar tarsometatarsal ligament (thin yellow arrow). (D–G) Serial axial PDFS image from dorsal to plantar aspect shows proper dorsal ligament (thick green arrows, D) and intercuneiform ligament (green arrow heads, D), pC1-M2 (thick yellow arrow, E) and pC1-M3 (yellow arrow heads, F) components of proper plantar Lisfranc ligament. The tendon of tibialis anterior (white arrows, F) can be seen attaching to the base of distal phalanx and the adjacent proximal aspect of medial cuneiform. The tendon of the peroneus longus (black arrows, G) can be seen attaching to the lateral aspect of base of the first metatarsal.
anterolateral stabilization is not required in thumb, the corresponding Lisfranc’s akin ligament is not seen in the thumb.5

**Thumb**
The first CM joint is an incongruous saddle joint between trapezium and first metacarpal with a wide range of motion, including flexion, extension, abduction, adduction, and circumduction, contributing to the apposable and prehensile capability of the human thumb. There are five main ligaments around this joint, divided into dorsal and volar group. The ligaments of the dorsal group include dorsoradial ligament (DRL), posterior oblique ligament (POL), collectively called dorsal carpometacarpal ligament complex as well-as intermetatarsal ligament (IML). They are best visualized in the sagittal plane, except IML that is seen on oblique coronal reformatted image across the first web space. DRL is a capsular ligament that extends from the dorsoradial tubercle of trapezium to the dorsolateral surface of base of first metacarpal, attaching deep to the attachment of abductor pollicis longus (APL) tendon. POL is also a capsular ligament, attached more ulnar to the DRL. IML connects the base of the first and second metacarpals. The volar trapeziometacarpal ligament includes the anterior oblique ligament (AOL—superficial capsular and deep intracapsular components) extending from the volar tubercle of trapezium to the volar tubercle of the base of first metacarpal and the ulnar collateral ligament, a thin ligament on the ulnar aspect of AOL that is often difficult to appreciate, separately from AOL, on MRI.6 The tendon of APL attaches to the radial aspect of base of the first metacarpal3 (►Fig. 5 and ►Table 3).

**Metatarsophalangeal/Metacarpophalangeal Joints**

**Great Toe**
The first MTP joint is an ellipsoid joint between the head of first metatarsal and base of first proximal phalanx that allows flexion, extension, limited adduction, abduction, rotation, and circumduction. There exists a “plantar plate complex” that stabilizes and protects the joint, aiding in propulsion while walking and maintaining balance. It comprises the sesamoido-capsulo-ligamentous complex and a musculo-tendinous complex.8

There are two sesamoid bones, medial and lateral, articulating in the respective grooves present on the plantar surface of the first metatarsal head. They function as a pulley system, providing attachment and smooth movement of tendons as well as protection to the underlying joint. The sesamoids are connected to each other by the intersesamoid ligament (ISL), to the base of proximal phalanx by the paired sesamoidophalangeal ligaments (SPL) and to the plantar aspect of first metatarsal neck by the paired metatarsosesamoid ligaments. The SPLs are thicker and serve as the main stabilizer against hyperextension. There is a fibrocartilaginous pad, visible between the two SPLs that invest the sesamoid bones and is inseparable from the plantar capsule and above-described ligaments. The ligaments between the lateral and medial aspect of the proximal phalanx and the head of metatarsal are the lateral and medial collateral ligaments, respectively, that typically are not considered part of the “plantar plate complex” and protect against varus and valgus forces, respectively3,8 (►Figs. 6 and 7).

The musculo-tendinous complex provides dynamic stabilization to the joint. The flexor hallucis longus (FHL)
Table 3 Comparative analysis of the tarsometatarsal joint and the carpometacarpal joint

| Ligaments                                      | Great toe: Tarsometatarsal joint | Thumb: Carpometacarpal joint |
|------------------------------------------------|----------------------------------|------------------------------|
| Dorsomedial ligament                           | Dorsal carpal-pedal ligament complex--DRL and POL | Dorsal carpal-pedal ligament complex--DRL and POL |
| (dC1-M1)                                       | Dorsal Lisfranc’s ligament       | Intermetatarsal ligament     |
| (dC1-M2)                                       | Dorsal intersosseous ligament    | UCL-AOL                      |
| (dC1-C2)                                       | Planter tarsometatarsal ligament |                              |
| (pC1-M1)                                       | Planter Lisfranc’s ligament complex (pC1-M2/M3) |                              |
| Tendons                                        | At distal end of medial cuneiform: | At trapezium: Nil            |
| Peroneus longus                                | At base of first metatarsal:     | At base of first metacarpal: |
| Tibialis anterior                              | Peroneus longus                  | APL                          |
|                                                | Tibialis anterior                |                              |

Abbreviations: AOL, anterior oblique ligament; APL, abductor pollicis longus; DRL, dorsoradial ligament; POL, posterior oblique ligament; UCL, ulnar collateral ligament.

Fig. 6 Ligamentous attachments around the first metatarsophalangeal (MTP) joint representing the plantar plate complex. (A) Diagrammatic representation of the first MTP joint shows the medial (M) and lateral (L) sesamoids and their paired attachments to the plantar surface of the base of proximal phalanx—the sesamoidophalangeal ligaments (SPL), paired metatarsosseal ligaments (MSL) between the respective sesamoid and neck of first metatarsal. Medial (M) and lateral (L) collateral ligaments are obliquely oriented, from the head of metatarsal on each side to the plantar surface of the base of proximal phalanx. The intersesamoid ligament (ISL) is between the two sesamoids. (B) Axial fat suppressed proton density weighted (PDFS) magnetic resonance (MR) image and (D) sagittal T2-weighted imaging (T2WI) shows the lateral SPL (yellow arrow heads) as thick ligament extending from the lateral (L)sesamoid to the base of proximal phalanx, deep to the conjoint tendon of the adductor hallucis (yellow arrow). Similarly, (B) axial PDFS and (E) sagittal T2WI show the medial SPL (green arrow heads) as thick ligament extending from the medial (M) sesamoid to the base of proximal phalanx. (C) The subsequent T1W axial image shows the abductor hallucis (green arrow), which is superficial to the medial SPL. (F and G) Sequential PDFS axial MR image shows the medial collateral ligament (MCL) (bent green arrow) and lateral collateral ligament (LCL) (bent yellow arrow) extending from the base of proximal phalanx to the head of first metatarsal on each side. Note the discontinuity and preligamentous edema at the metatarsal attachment of MCL suggestive of a tear.
tendon runs beneath ISL, in the groove between the two sesamoids and finally attaches to the base of the distal phalanx. The paired flexor hallucis brevis attaches to the respective sesamoid bones. On the medial aspect, abductor hallucis tendon attaches to the medial sesamoid with extensions to the capsule-ligamentous complex and medial aspect of the base of the proximal phalanx. Similarly, on the lateral aspect, conjoint tendon of the oblique and transverse heads of adductor hallucis attach to the lateral sesamoid with extensions to the capsule-ligamentous complex and lateral aspect of the base of the proximal phalanx.\(^3,8\) (→ Figs. 8 and 9).

On the dorsal aspect of the MTP joint, the extensor hallucis brevis and extensor hallucis longus (EHL) pass over the dorsal plate to finally attach on the dorsal aspect of the base of the proximal and distal phalanx, respectively. The extensor tendons are anchored to the underlying bones by the medial and lateral sagittal bands.\(^3,8\) (→ Fig. 10).

**Thumb**

The first MCP joint is also an ellipsoid joint that allows flexion, extension, limited adduction, abduction, rotation, and circumduction. Analogous to the plantar plate complex, there exists a similar “volar plate complex” comprising the radial and ulnar sesamoids, embedded within the fibrocartilaginous volar plate with a gamut of ligamentous and musculo-tendinous attachments. Its ligamentous support is less robust, allowing more mobility and less stability compared with the MTP joint that plays a pivotal role in weight bearing and walking.

The radial and ulnar collateral ligaments attach proximally on the volar aspect of the metacarpal head laterally and distally to the dorsolateral aspect of the base of the proximal phalanx. The accessory collateral ligaments attach proximally to the volar aspect of the metacarpal head and distally to the dorsal aspect of the base of the proximal phalanx. The accessory collateral ligaments attach to the
metacarpal head (volar to proper collateral ligaments), connecting it to the respective sesamoids and the volar plate\(^6,9\) (\(\text{\small Figs. 11 and 12}\)).

The radial and ulnar sesamoids provide attachments to flexor pollicis brevis (FPB) and adductor pollicis, respectively. The aponeurosis of adductor pollicis extends further to attach on the ulnar aspect of the base of the proximal phalanx. The tendon of abductor pollicis brevis is however attached only to the radial aspect of base of proximal phalanx\(^6,9\) (\(\text{\small Figs. 11 and 12}\)).

The flexor pollicis longus (FPL) tendon passes over the volar plate in the groove between the sesamoid bones to finally attach to the base of the distal phalanx (\(\text{\small Fig. 13}\)). FPL is anchored to the underlying bones by the annular pulley system that prevents bow-stringing of the tendon during flexion. The pulley system of the thumb differs from the rest of the digits as there are no transverse pulleys, but only annular pulleys as described in \(\text{\small Figs. 14}\)\(^6,9\).

Similar to the MTP joint, extensor pollicis brevis (EPB) and extensor pollicis longus (EPL) tendons pass over the dorsal plate of the MCP joint and finally attach to the dorsal aspect of the base of the proximal and distal phalanx, respectively (\(\text{\small Fig. 13}\)). EPB, being a muscle of the first extensor compartment of the forearm, is visualized more radial to the EPL, a muscle of the third compartment. The extensor tendons are anchored to the underlying bones by the medial and lateral sagittal bands\(^6,9\) (\(\text{\small Figs. 15 and Table 4}\)).
Interphalangeal Joints

The IP joint in both great toe and thumb is a hinge joint, allowing only flexion and extension movement.

Paired collateral ligaments are present on the medial and lateral aspect of the joint extending between the two sesamoid bones, the flexor pollicis brevis (FPB) attaches on the radial sesamoid (R). The abductor pollicis brevis (AbPB) attaches directly to the base of radial aspect of proximal phalanx. (B–E) Serial coronal fat-supppressed proton density magnetic resonance imaging showing the radial (R) and ulnar (U) sesamoid bones and FPL tendon (long green arrow) in (B). FHB tendon (short green arrows; c) is seen attaching on the radial sesamoid and base of proximal phalanx. The RCL (blue arrow heads; D–E) lies deep to the AbPB (blue arrows; D), whereas the UCL (yellow arrow heads; D–E) lies deep to the AdP aponeurosis (yellow arrows; D–E), attaching distally to the base of proximal phalanx on its radial and ulnar aspect, respectively.

Conclusion

The evolutionary development of human limbs facilitated their feet and hands to assume functional roles of stability and mobility, respectively, and hence they have many similarities with few dissimilarities in their anatomy. Evaluating their MRI anatomy in correlation allows a comprehensive understanding to a radiologist, enabling them to develop a systematic approach to read the MRI scans thereof.
Fig. 13  Muscles of the flexor and extensor compartment of the great toe. (A) Sagittal schematic diagram and (B, C) serial sagittal fat suppressed proton density (PDFS) shows that the flexor pollicis longus (FPL; green arrows) attaches to the base of the distal phalanx on the volar aspect, passing over the volar plates (white asterisks) at the level of metacarpophalangeal (MCP) and distal interphalangeal (DIP) joints. The extensor pollicis brevis (EPB; short white arrow) attaches to the dorsal aspect of the base of the proximal phalanx and the extensor pollicis longus (EPL) (long white arrow) goes on to attach on the dorsal aspect of the base of the distal phalanx, passing over the dorsal plates (yellow asterisks) at the level of intervening joints. Note that there is a synovial recess (yellow arrow, B) at the proximal attachment of the volar plate, which should not be misinterpreted as a tear. (D) Sagittal schematic diagram and (E) serial sagittal PDFS shows the attachment of the flexor pollicis brevis (FPB; short green arrows) on the radial sesamoid (R) and volar aspect of the base of proximal phalanx.

Fig. 14  Pulley system around the flexor pollicis longus (FPL) tendon. (A) Coronal schematic diagram showing the positions of annular pulleys (shaded in green): A1 and A2 are along the metacarpophalangeal (MCP) and distal interphalangeal (DIP) joints, respectively. The oblique pulley (Ao) is along the diaphysis of proximal phalanx and oriented obliquely. The variable pulley (Av) is between the A1 and A2. (B) Axial schematic diagram showing the position of annular pulleys in relation to the FPL tendon. The pulleys (green line) surround the FPL tendon, attaching to the palmer aspect of the phalanges, preventing bowstringing of FPL. (C–F) Corresponding axial magnetic resonance T1-weighted images are shown in the panel on the right with the pulleys marked with green arrows. To merge either A1 and A2 pulleys are seen to merge with the underlying volar plates.

Fig. 15  Extensor muscles of the thumb. (A) Coronal and (C) axial schematic diagram, (B) coronal fat suppressed proton density magnetic resonance (MR) images and (D) axial T1-weighted MR images at the level of first metacarpal bone show that the extensor shows that the extensor pollicis brevis (EPB, short white arrow) lies radial to the extensor pollicis longus (EPL, long white arrow). Note that even at the level of distal forearm and wrist, the EPB is more on the radial aspect as it belongs to the first compartment and EPL belongs to the third compartment of the extensor group of muscle. The tendons are held in central position by the sagittal bands (shaded in gray in a, black arrows in C–D), in and around the metacarpophalangeal (MCP) joint, whereas more distally, it is supported by a faint triangular expansion (shaded in purple), which is not well appreciated on imaging.
Table 4 Comparative analysis of the first metatarsophalangeal (MTP) joint of foot and metacarpophalangeal (MCP) joint of thumb

| Great Toe: First MTP joint | Thumb: First MCP joint |
|----------------------------|------------------------|
| **Ligaments**              |                        |
| Plantar plate—fibrocartilage pad* | Volar plate |
| Medial and lateral SPL*     | Intersesamoid ligament |
| Intersesamoid ligament*     | RCL                    |
| MCL                        | UCL supported by adductor aponeurosis |
| LCL                        | Accessory UCL and RCL  |
| Medial and lateral MTSL*    | Dorsal plate           |
| Dorsal plate               | Radial and ulnar sagittal bands |
| Medial and lateral sagittal bands | Pulleys |
|                           |                        |
| **Tendons**                |                        |
| Lateral sesamoid: FHB (lateral head), adductor hallucis | Ulnar sesamoid: adductor pollicis |
| Medial sesamoid: FHB (medial head), abductor hallucis | Radial sesamoid: FPL |
| FHL                        | Base of first metacarpal radial aspect: abductor pollicis brevis |
| EHL                        | FPL                    |
| EHB                        | EPL                    |
|                           | EPB                    |

Abbreviations: EHB, extensor hallucis brevis; EHL, extensor hallucis longus; EPB, extensor pollicis brevis; EPL, extensor pollicis longus; FHB, flexor hallucis brevis; FHL, flexor hallucis longus; FPL, flexor pollicis longus; LCL, lateral collateral ligament; MCL, medial collateral ligament; MTSL, metatarsosesamoid ligament; RCL, radial collateral ligament; SPL, sesamoidophalangeal ligament; UCL, ulnar collateral ligament.

*Forms part of the “planter plate complex.”

Fig. 16 Ligamentous and tendinous attachments near the distal interphalangeal (DIP) joint of the great toe. (A) Coronal schematic diagram and (B) coronal fat suppressed proton density (PDFS) magnetic resonance (MR) image at the level of DIP joint show the lateral (LCL) and medial (MCL) collateral ligaments (blue arrows) extending from the lateral and medial aspects of distal end of proximal phalanx to the proximal end of distal phalanx, respectively. (C) Coronal schematic diagram and (D) axial PDFS MR image at the level of base of distal phalanx show LCL and MCL (blue arrows), extensor hallucis longus (EHL; long white arrow) and flexor hallucis longus (FHL; long green arrow) attached to the dorsal aspect and volar aspect respectively. The prominent volar plate is deep to the FHL tendon and is marked with white asterisk. The dorsal plate (yellow asterisk) is small.

Fig. 17 Ligamentous and tendinous attachments near the distal interphalangeal (DIP) joint of the thumb. (A) Coronal schematic diagram and (B) coronal fat suppressed proton density (PDFS) MR image at the level of DIP joint show the radial (RCL) and ulnar (UCL) collateral ligaments (blue arrows) extending from the radial and ulnar aspects of distal end of proximal phalanx to the proximal end of distal phalanx, respectively. (C) Axial schematic diagram and the (D) axial PDFS MR image at the level of base of distal phalanx show the radial and ulnar collateral ligaments (blue arrow) attached laterally, extensor pollicis longus (EPL; long white arrow) and flexor pollicis longus (FPL; long green arrow) attached to the dorsal aspect and volar aspect, respectively. The prominent volar plate is deep to the FPL tendon and is marked with white asterisk, while the A2 (small green arrows) pulley covers the FPL on its superficial aspect. The sagittal bands (small white arrow) are thin linear bands that secure the EPL tendon.
Conflits of Interest
None declared.

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Table 5 Comparative analysis of interphalangeal (IP) joints of great toe and thumb

|                | Great toe: IP joint       | Thumb: IP joint     |
|----------------|---------------------------|---------------------|
| Ligaments      | MCL                       | RCL                 |
|                | LCL                       | UCL                 |
|                | Plantar plate             | Volar plate         |
|                | Dorsal plate              | Dorsal plate        |
| Tendons        | FHL                       | FPL                 |
|                | EHL                       | EPL                 |

Abbreviations: EHL, extensor hallucis longus; EPL, extensor pollicis longus; FHL, flexor hallucis longus; FPL, flexor pollicis longus; LCL, lateral collateral ligament; MCL, medial collateral ligament; RCL, radial collateral ligament; UCL, ulnar collateral ligament.