Hammertoe Deformity: Anatomy of the Lesser Toes, Pathophysiology, and Etiology

Part 1

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Hammertoe deformity is a prevalent disorder of the lesser toes, particularly in older adults and populations in which constricting footwear is popular. The PIP joint is the only joint affected by flexible hammertoe deformity causing abnormal flexion of the joint. A rigid hammertoe is distinguished by abnormal flexion of the PIP joint and extension at the MTP joint.[1]

Leonardo Da Vinci is credited with one of the first descriptions of the interaction between the intrinsic muscles of the foot with the extrinsic muscles of the lateral aspect of the lower leg.[1] During the winter season from 1510-1511, Leonardo was working at the University of Pavia Medical school located south of Milan, Italy, and had switched his scientific research to focus on the bones and muscles of the human body. This provided the opportunity for the Renaissance physician and anatomist Marcantonio della Torre, who worked at the university as a professor, to meet and collaborate with Leonardo. This gave Leonardo access to corpses to dissect and study; he may have dissected up to 20 bodies during this time. It is thought that Leonardo and della Torre were intending to co-publish a book, but this did not come to fruition with della Torre's unfortunate death due to the plague in 1511. However, it did lead to Leonardo producing 18 sheets of detailed drawings known as the *Anatomical Manuscript A* (Figure 1).

Figure 1 *Bones of the Foot and Shoulder (Drawings by Leonardo Da Vinci)*

LEARNING OBJECTIVES

- Describe in detail the anatomy of the lesser toes
- Discuss the role the lesser toes play in the biomechanics of movement
- Explain how the pathophysiology of the toes is responsible for the hammertoe deformity
- Discuss the etiological factors of hammertoe deformity

KEYWORDS

distal interphalangeal joint, extensor digitorum longus, flexor digitorum brevis, flexor digitorum longus, hammertoe, metatarsophalangeal joint, plantar plate, proximal interphalangeal joint,

DEFINITIONS

Attenuated: Weakened.

Bipennate muscle: A muscle with fibers that attach obliquely to both sides of a central tendon, resembling a feather. The fibers run at an angle to the tendon, providing strong contractions and force generation but with a smaller range of motion.

Lesser toes: Second through the fifth toes.

Slip: A branch of a larger ligament or tendon.

Subluxate: Incomplete or partial dislocation.

Unipennate muscle: A muscle with fibers that are arranged obliquely only on one side and inserts into a tendon, resembling half of a feather. The muscle is designed for strength and endurance rather than contributing to a wide range of motion.

ABBREVIATIONS

DIP: Distal interphalangeal (DIP) joint
EDB: Extensor digitorum brevis
EDL: Extensor digitorum longus
FDB: Flexor digitorum brevis
FDL: Flexor digitorum longus
MTP: Metatarsophalangeal (MTP) joint
PIP: Proximal interphalangeal (PIP) joint

"The cause of hammertoe deformity is considered to be caused by a weakening of the plantar plate and collateral ligaments that are the stabilizing structures in conjunction with an imbalance between the extrinsic and intrinsic muscles."

In 1863, Guillaume Benjamin Amand Duchenne (Duchenne de Boulogne), famous French neurologist in the early to mid-1800s, is credited with his excellent description of toe deformities, including claw toe and hammertoe as both resulting from a dynamic muscular imbalance.[2] He determined that the deformity was not due to a localized joint defect, but the result of atrophy or functional failure of the intrinsic foot muscles.

The imbalance leads to continuing deformity and dysfunction of the toe that also can cause the patient chronic pain. Patients with a hammertoe deformity often complain of pain because of the formation of a callus on the dorsal PIP joint, plantar callus on the posterior of the metatarsal heads, or the tip of the toe that is pressing against the front of the footwear.[3]

LESSER TOE ANATOMY AND KINESIOLOGY OF TOE ALIGNMENT AND FUNCTION

Several anatomical structures of the toes interact to properly distribute the body's weight and sustain correct toe alignment to provide the person with the ability to walk normally. These structures include bones and their joints, extrinsic and intrinsic muscles, tendons, and ligaments (Figure 2).

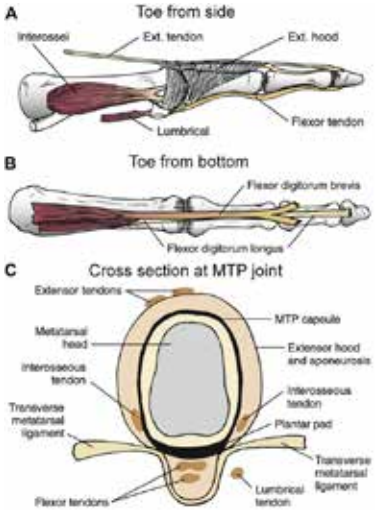

Figure 2 *Anatomy of the MTP Joint and Lesser Toe*

Beginning with the dorsal side of the toe, situated down the middle of the bone, is the EDL that divides into three slips at the joint of the proximal phalanx. Two slips are positioned dorsolaterally over the middle phalanx and merge together to form a single tendon inserted onto the base of the distal phalanx.[1] The middle slip inserts into the base of the middle phalanx. The entire tendon is held in place by the extensor hood that positions the EDL to the plantar portion of the MTP joint and to the base of the proximal phalanx. The EDB originates at the dorsal surface of the calcaneus and inserts on the dorsal base of the middle phalanx and is also held in place by the extensor hood.[4] The EDB facilitates toe extension.

Positioned on the plantar aspect of the toe are the FDB and FDL. The FDB originates from the plantar surface of the calcaneus and inserts onto the middle phalanx.[4] The FDB primarily supports flexion of the PIP joint.[5] The FDL originates from the deep posterior compartment of the leg, crosses the ankle medially, and inserts onto the distal phalanx and flexes all three joints of the toes.[4] The lumbricals originate from the adjacent FDL tendons, run plantarly to the MTP, and extend dorsally to merge with the lateral bands.[4] The primary role of the lumbricals are to flex the MTP joint and extend the DIP and PIP joints (Figure 3).

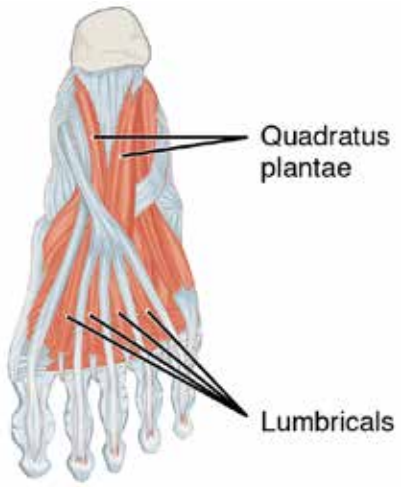

Figure 3 *Lumbricals*

To further understand the anatomy of the MTP joint, the anatomy of the plantar plate needs to be described. The plantar plate is a thick fibrocartilaginous ligament that runs along the ball of the foot and attaches to the joints that also acts as an attachment site for the plantar fascia. It extends from the periosteum of the inferior metatarsal neck to the inferior aspect of the base of the proximal phalanx.[6] The two primary functions of the plate are to safeguard the metatarsal head from excess pressure and stabilize the MTP joint of the lesser toes.[6] This is achieved because of the fibrocartilaginous structure of the plate that provides resistance to tension and compression forces at the MTP joints.

The two collateral ligaments of the MTP joint are the phalangeal collateral ligament that attaches to the proximal phalanx base and the accessory collateral ligament that attaches to the plantar plate.[5] The third ligament, the transverse metatarsal ligament, attaches to the lateral and medial edges of the plantar plate.

The intrinsic muscles are involved in the normal function of the toes as well as the abnormal development of hammertoe deformity. The plantar interossei are a group of three small muscles that, along with the dorsal interossei, form the deepest layer of plantar muscles and have a unipennate shape. The three muscles originate from the medial metatarsals of toes three to five and attach to the medial sides of the phalanges. The dorsal interossei are four muscles that have a bipennate shape. The muscles originate from the lateral aspect of the metatarsals. The first muscle attaches to the medial side of the proximal phalanx of the second toe. The second to fourth interossei attach to the lateral sides of the proximal phalanxes of the second through fourth toes.

The arterial blood supply to the toes are branches from the anterior and posterior tibial arteries consisting of the:

- arcuate artery,
- deep plantar artery,
- plantar arch artery,
- dorsal digital arteries (including the 1st dorsal metatarsal artery)
- plantar metatarsal, and
- plantar digitals.[5]

The interdigital artery is prone to traction injury in the presence of hammertoe deformity.[4]

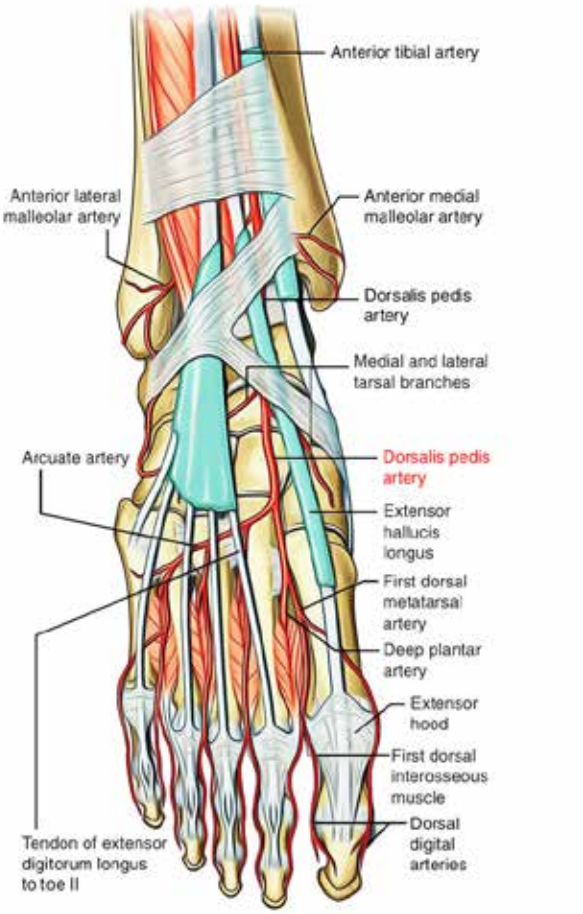

Figure 4 *Arterial supply to the foot*

The nerve supply is multiple branches of the lateral and medial plantar nerves including laterally the adductor hallucis, all interossei, lateral 3 lumbricals and medially, the medial lumbrical, flexor hallucis brevis, adductor hallucis, and medial plantar nerve.[5]

The lesser toes have an important function towards normal gait and balance. During movement, such as running or walking, the body weight is shifted to the foot and heel. The force of the movement is transferred to the toes by the intrinsic muscles of the foot and the structures of the arch that includes the plantar fascia.[1] The normal toe alignment is maintained by a balance between the extrinsic muscles, the EDL and FDL, with the extrinsic muscles, the interossei, lumbricals, and quadratus plantae. The intrinsic muscles counteract the extrinsic muscles flexion of the MTP joints and extension across the DIP and PIP joints.[1] Dysfunction of the extrinsic or intrinsic muscles contributes to the development of hammertoe deformity.

During normal movement, the MTP joints extend and the DIP and PIP joints flex to facilitate foot contact with the ground. When the toes are moving off the ground, the FDB and FDL muscles push the body forward over the foot. The plantar plate contributes to stabilizing the MTP joint. Through its connections to the intrinsic muscles, the MTP joint prevents excessive dorsiflexion. The next section on pathophysiology provides additional details as to how abnormalities of the joints and ligaments contribute to hammertoe deformity.

The plantar plate's role is to stabilize the MTP joint. The plate provides active and passive resistance to dorsiflexion through its connections with the intrinsic muscles of the foot that prevents excessive dorsiflexion.[1] Lastly, the collateral ligaments help maintain the alignment of the toe in both the sagittal and transverse planes.[1]

PATHOPHYSIOLOGY

The cause of hammertoe deformity is considered to be caused by a weakening of the plantar plate and collateral ligaments that are the stabilizing structures in conjunction with an imbalance between the extrinsic and intrinsic muscles. This imbalance can be caused by atrophy of the intrinsic muscles, over extension of the extrinsic muscles, and chronic extension of the MTP joint, such as the constant wearing of high heeled shoes.[1] Chronic extension of the MTP joint causes the plantar structures to weaken leading to extension of the proximal phalanx at the MTP joint. Over time, the EDL no longer exerts its extension on the interphalangeal joints that allows the phalanges distal to the PIP joint to move into flexion. Upon dorsiflexion by the MTP joint, the extrinsic muscles undergo tension at rest, thus further contributing to the flexion deformity at the PIP joint. The following provides additional details that contribute to the pathophysiology of hammertoe deformity (Figure 5).

The position of the proximal phalanx and the function of the EDL must be understood in relation to the development of hammertoe deformity. The main function of the EDL is to dorsiflex the toes.[1] Normally, the EDL functions to extend the PIP joint when the proximal phalanx is in a flexed or neutral position at the MTP joint. However, in the presence of hammertoe deformity and the MTP joint is extended, the EDL cannot extend the PIP joint that causes a flexion contracture at that joint.[1] Additionally, during normal movement, the MTP joint is moved from a neutral position to a dorsiflexion position. When the EDL cannot extend the PIP joint with the MTP joint dorsiflexed, the DIP and PIP joints flex because of unopposed flexion. This extrinsic muscle movement also contributes to hammertoe deformity.

When the plantar plate is improperly functioning, the proximal phalanx subluxates dorsally onto the metatarsal head. This also causes the

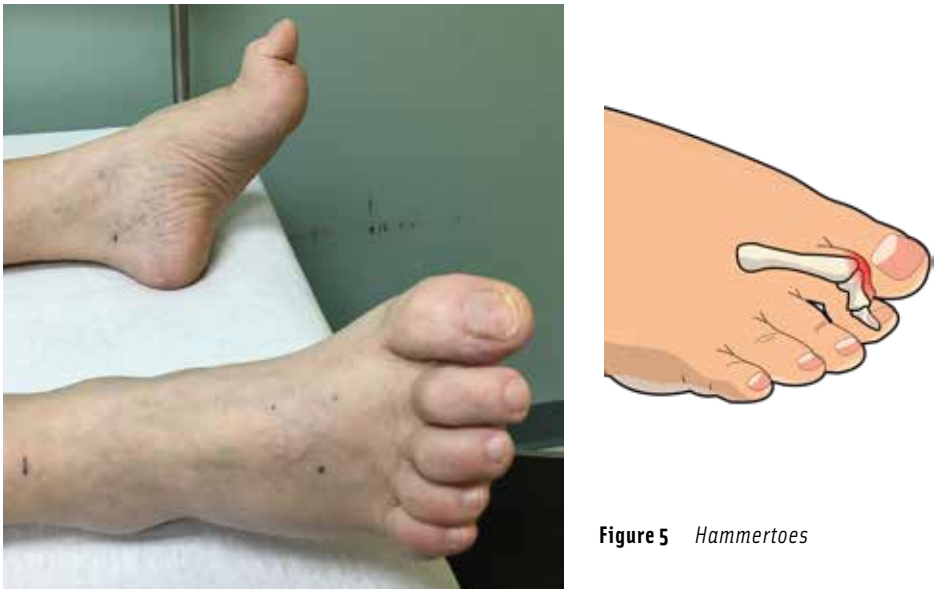

Figure 5 *Hammertoes*

interossei muscles to function as dorsiflexors instead of plantar flexors, further contributing to the severity of the hammertoe deformity. The lumbrical muscle also contributes to hammertoe deformity because of its insertion on the medial side of the MTP joint. It can place an unwanted adduction force vector on the toe (pulling the toe inward toward the other toes).

ETIOLOGY

Hammertoe deformity occurs more often in women than men, with a female-to-male ration of approximately 4:1 and 85% of patients being women.[7] The incidence of hammertoe deformity increases with age with the highest rate between the ages of 50-70 years of age.[8] Multiple toes are affected in 70% of cases with the second toe most frequently involved, possibly due to its increased length as compared to the lengths of the other toes.[7] Additionally, patients with hallux valgus (bunion) or a long second toe (Morton's toe) are susceptible to developing hammertoe deformity because of mechanical overload and the individual compensating when walking (Figure 6).

Figure 6 *Morton's toe*

A primary contributing factor to the development of a hammertoe deformity is restrictive footwear, including high heels that place an abnormal force upon the structures of the foot. Hammertoe deformity is often a secondary result of a disease or injury including:

- compartment syndrome,
- degenerative disk disease,
- diabetes,
- hallux valgus,
- psoriatic arthritis, and
- rheumatoid arthritis (causes hammertoe deformity by progressive MTP joint destruction that leads to MTP joint subluxation).[3,4]

Part 2 will discuss the methods used for diagnosing hammertoe deformity and its extent, nonsurgical treatment options, and common surgery procedures.

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1. Which of the following refers to muscles that are arranged obliquely on only one side of a toe?
a. Ray
b. Bipennate
c. Slip
d. Unipennate

2. What anatomical structure holds the EDB and EDL in position?
a. Plantar plate
b. Lumbricals
c. Extensor hood
d. Ligaments

3. Which of the following is a role of the lumbrical muscles?
a. Protect the metatarsal head
b. Resist tension at the PIP joint
c. Flex the DIP joint
d. Flex the MTP joint

4. Which anatomical structure is located along the ball of the foot?
a. Plantar plate
b. Collateral ligaments
c. Intrinsic muscles
d. Interossei muscles

5. Which of the following anatomical structures forms the deepest layer of plantar muscles?
a. Lumbricals
b. Plantars
c. Interossei
d. Extrinsic

6. Which artery is prone to traction injury caused by hammertoe deformity?
a. Arcuate
b. Interdigital
c. Plantar metatarsal
d. Dorsal metatarsal

7. Which of the following is a nerve that provides multiple branches that innervate the toes?
a. Lateral plantar
b. Adductor hallicus
c. Medial lumbrical
d. Flexor hallicus brevis

8. What causes a flexion contracture of the PIP joint that contributes to the pathology of hammertoe deformity?
a. MTP is preventing excessive dorsiflexion
b. Instrinsic muscles counteract extrinsic muscles
c. FDB muscles are pushing the body over the foot
d. EDL cannot extend the PIP joint

9. Which toe is most frequently affected by hammertoe deformity?
a. First
b. Second
c. Third
d. Fourth

10. Which of the following is not a secondary cause of hammertoe deformity?
a. Diabetes
b. Hallux valgus
c. Osteosarcoma
d. Psoriatic arthritis

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