Anatomical Study of the deep muscles of the sole

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# Anatomical Study of the Deep muscles of the Sole

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이 논문을 박사학위 논문으로 제출함

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# 박원진의 박사학위 논문을 인준함

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# 1. Introduction

The plantar muscle layers are arranged in four layers of thick skin, and the deep fascia of the foot protects the sole from injury and helps support the longitudinal arches of the foot. The second layer of the sole of the plantar foot contains the connections of the flexor hallucis longus (FHL) and flexor digitorum longus (FDL), which together travel with nerves and blood vessels in the tarsal tunnel of the ankle. The "Master Knot of Henry (MKH), equivalently Known as Henry's Knot" refers to the intersection territory, in which the FDL tendon crosses over the FHL tendon. Additionally, the plantar quadratus plantae (QP), which attaches to the flexor, crosses over the FHL tendon (1).

In this region, variations frequently occur, including variations of the connection between the FHL and FDL. Previous studies have classified the connection pattern between the FHL and FDL according to its direction and number; Type 1, one slip from the FHL to the FDL; Type 2, a crossed connection; Type 3, one slip from the FDL to the FHL; Type 4, no connection; Type 5, two slips from the FHL to the FDL; Type 6, two slips from the FHL to the FDL and one slip from the FDL to FHL; Type 7, two slips from the FDL to the FHL and one slip from the FHL to the FDL. Additionally, the location of the MKH where the FHL crosses the FDL has been studied for a long time (1).

The QP muscle is a flat shape muscle harboring two head, as lateral and medial heads. Its various origins have been reported frequently (2-4). Although many researchers have studied the QP variation, the topographies of the origin and insertion have not been confirmed. A previous study confirmed that the QP is composed of one (34%), two (57%), or three heads (9%) (5-8). However, the topographies of the

MKH and QP have not been confirmed in the Korean population.

Variations in these muscles may be related to vessel and nerve injury. For surgeons, knowledge of these variations is crucial for minimizing functional loss after the operation and understanding the functional mechanism in the toes (9). Mastery of the connections and locations of these variants requires anatomically accurate knowledge, which is also important from a clinical point of view (10).

Although many authors have described the pattern and variations of the MKH and QP, controversy still remains. Therefore, the present study examined the topographies and variations of the structures in the second layer of the sole. First, MKH and QP patterns were determined. Subsequently, quantitative data regarding the locations of important landmarks were calculated, and. differences in these locations according to the variation pattern were evaluated. These data will provide a basis for surgical and invasive techniques in this region and are also important for further imaging and biomechanical studies.

# 2. Materials and Methods

## 2.1. Identification of the muscles in the second layer:

A total of, 95 embalmed feet from 48 cadavers were dissected. Twenty cadavers were female and 28 were male; the cadavers had a mean age of 81.2 (range, 51 to 88) years. The skin, superficial fascia, and plantar aponeurosis, were removed, and the flexor digitorum brevis and abductor hallucis muscles were reflected inferiorly to expose the FHL and FDL tendons. Additionally, the neurovascular bundles, including the posterior tibial artery, tibial nerve and the medial and lateral platar arteries and nerves were retracted laterally (1). A detailed dissection was performed by focusing on the FDL and the FHL tendons for the all toes (Figure 1). Connections between the FHL and FDL tendons were identified when present and patterns were determined. The connection pattern was classified into 3 types (Figure 2). Type I was defined as no connection, Type II comprised a single connection from the FHL to the FDL tendon, and Type III had an additional connection originating from the QP, which was renamed as the QP tendon. Additionally, the QP pattern was defined according to the presence of the QP tendon.

## 2.2. Topography of the second layer of the sole:

The locations of the muscles in the second layer of the sole were analyzed. All length variables were calculated as percentiles form the height reference line, which was defined as the length from the calcaneus tuberosity to the distal phalanx in the great toe. A second reference line was defined as the line from the calcaneus notch to the distal phalanx in the great toe. The location of the MKH from the distal phalanx of the great and little toes was measured. The location of the insertion point of the FDL and FHL was also investigated. The lengths of the medial and lateral heads of the QP were then measured. (Figure 3).

All width variables were calculated as percentiles form the width reference line, which was defined as the line from the medial border of the 1st metatarsal bone to the lateral border of the 5th metatarsal bone. A second reference line was defined as the line between the tendons of FHL and FDL of the little toe. The locations of the MKH and QP were measured and calculated from the width reference line.

The locations of the structures in the second layer were measured by digital calipers (NA500-300S, Blue bird, Korea). Additionally, the angle between the FHL and FDL was measured by a protractor.

### 2.3. Differences in the topography of sole structures according to muscular variations:

The anatomical pattern of the sole muscles was classified according to the presence of a connection and additional muscle. Firstly, the differences in the topography of the sole muscles were analyzed according to the MKH pattern. Secondly, topography differences were examined according to the presence of the QP tendon.

## 2.4. Statistical analysis:

All statistical analyses were performed by SPSS (version 24.0, IBM SPSS®). The Mann-Whitney and Kruskal‑Wallis tests were used to analyze the differences in anatomical topography according to the variation pattern. Correlations among all variables were analyzed by the Pearson correlation test. Percentile data of the location or position of the structures were used in the correlational analysis. A P value $< 0.05$ was considered to indicate statistical significance.

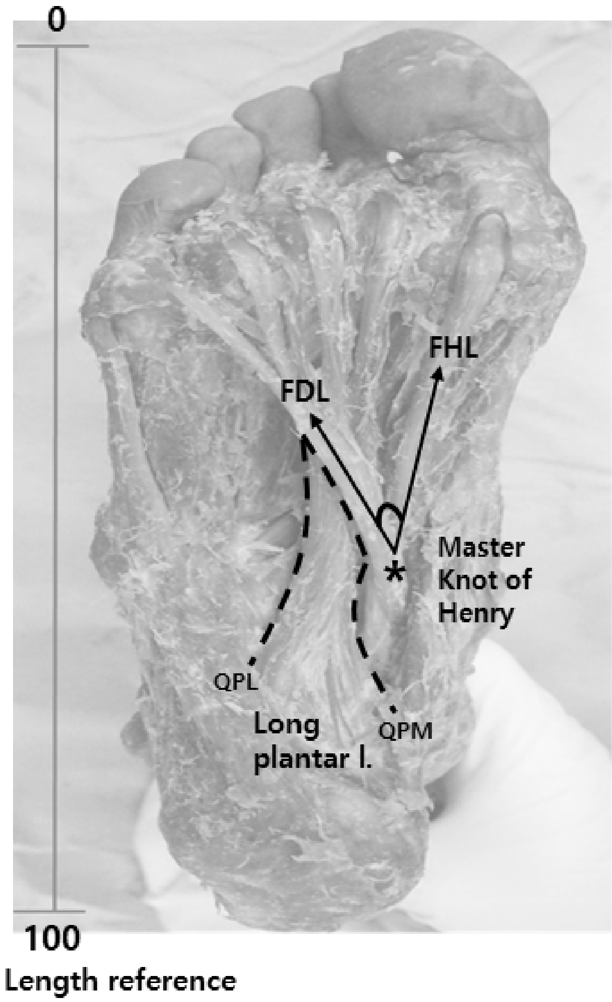


Figure 1. Representative picture showing the sole structures and measure point. FDL: Flexor digitorum longus; FHL: Flexor hallucis longus; Long plantar ligament; MKH: Master Knot of Henry; QPL: Quadratus plantae lateral head; QPM: Quadratus plantae medial head.

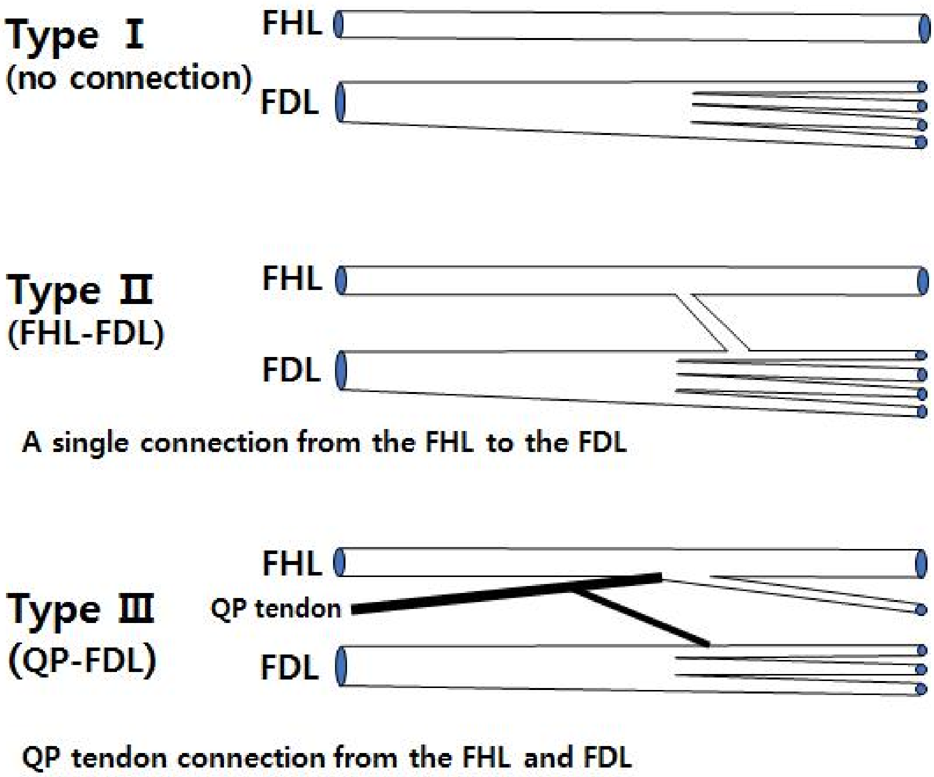


Figure 2. The pattern of connections between flexor digitorum longus and flexor hallucis longus. FDL: Flexor digitorum longus; FHL: Flexor hallucis longus; QP: Quadratus plantae.

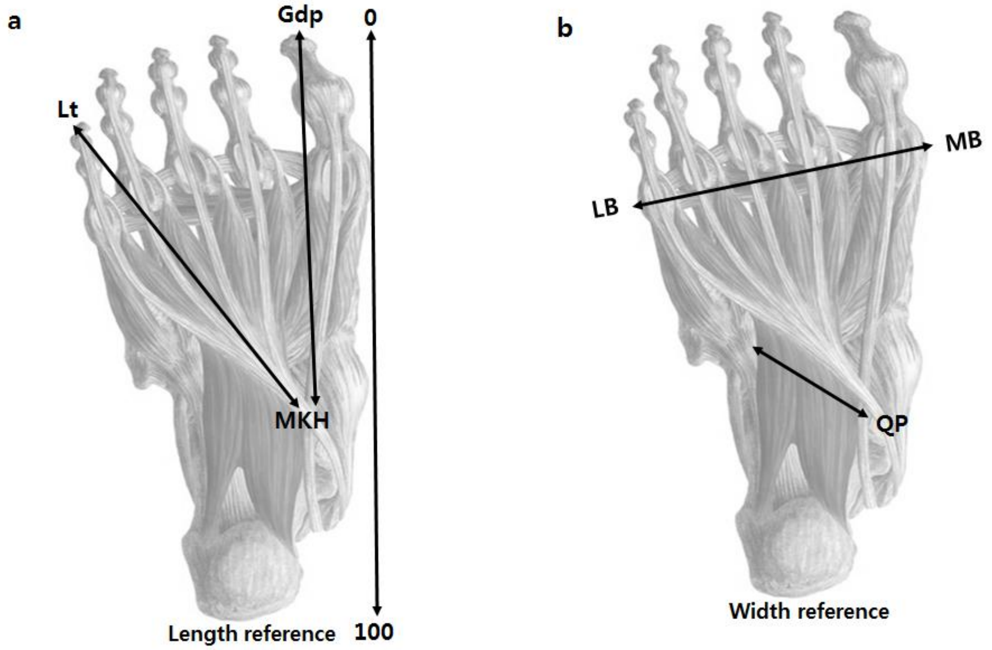


Figure 3. The reference lines of sole. Gdp: Great toe distal phalanx; LB: Lateral border of the foot; Lt: Little toe; MB: Medial border of the foot; MKH: Master Knot of Henry; QP: Quadratus plantae.

# 3. Results

## 3.1. Topography of the muscles in the second layer of the sole:

After the skin and superficial fascia were removed, a dense plantar aponeurosis supporting the plantae was observed. Under the aponeurosis, the abductor digiti minimi, abductor hallucis, and flexor digitorum brevis were exposed in the first layer. After these structures were removed, the FHL, FDL, QP, and lumbricals were identified in the second layer (Figure 4). The averages length of total foot (height reference line) and second reference line were 213.69 ± 17.54 mm and 180.88 ± 16.93 mm, respectively (Table 1). The second line was located at the 84th percentile relative to the total foot length and the total foot length was used as the vertical reference line. The MKH was located at the 65.61 percentile (140.16 ± 14.70 mm) and 56.59 percentile (121.79 ± 13.42 mm) from the great and little toes, respectively. The lateral and medical lengths of the QP were 72.80 ± 15.30 mm (34.01 percentile) and 51.70 ± 13.21 mm (24.21 percentile), respecitvely, from the distal end of the calcaneus.

The averages of the total foot width (width reference line) and second reference line were 79.49 ± 6.81 mm and 49.19 ± 5.86 mm, respectively (Table 2). The second line was located at the 61st percentile relative to the total width reference line. Therefore, the total foot width was selected as the reference line. The average width of the MKH was located at the 36.33 percentile (28.92 ± 6.58 mm) based on the medial side of the width reference line (Tables 1 and 2). The median of the angle between the FHL and FDL was 31.56 ± 5.75 °.

## 3.2. The patterns of connections between the flexor hallucis longus and flexor digitorum longus and related differences in the topography of the muscles:

The connections between the FHL and FDL tendons were divided as described in section 2.1. The connecion type was not clearly identified in 27 feet; thus, these samples were excluded from the present analysis. The presence of a connection between the FHL and FDL was observed in 55.88% of feet (38/68); accordingly, Type I (no connection) was observed in 44.12% of feet (30/68). Additionally, Type II (a single connection) was observed in 29.41% of feet (20/68), and Type III (QP tendon) was observed in 26.47% of feet (18/68).

Differences among connection types in the quantitative data for the evaluated structures are shown in (Table 3). The angle between the FHL and FDL significantly differed among connection types (P = 0.037); specifically, it was significantly larger. In feet with a connection (Type II, 32.18 ± 3.52; Type III, 35.57 ± 3.30) than in feet without a connection (Type I, 28.33 ± 7.69). The lengths of the QP and MKH differed somewhat among connection type; however, the differences failed to reach statistical significance. The lateral length of the QP was larger in feet with a connection although not statistically significant (Type II, 35.42 ± 3.76; Type III, 37.79 ± 4.59) than in feet without a connection (Type I, 33.10 ± 8.15; P = 0.055). The length from the MKH to the insertion point of the FDL of the little toe also differed among connection types, not statistically significant either (Type I, 48.19 ± 9.83; Type II, 53.13 ± 2.39; Type III, 51.94 ± 2.54, P = 0.071). No other variables differed significantly according to this classification.

## 3.3. The quadratus plantae pattern and related differences in the topography of the muscles:

Cadavers were classified into two groups according to the presence of the QP tendon. The QP tendon was observed in 25.3% of feet (24/95) and its presence was associated with its longer length.

Differences among connections types in the quantitative data for the evaluated structures are shown in Table 4. The lateral length of the QP was significantly longer in feet with an additional tendon (36.41 ± 4.34) than in feet without an additional tendon (33.18 ± 6.57, P = 0.031). The medial length of the QP also significantly differed according to the presence of the QP tendon (27.33 ± 4.72 vs. 23.11 ± 5.63; P = 0.001). No other variables differed significantly according to this classification.

## 3.4. Correlations:

The results of the correlational analyses are summarized in Table 5. The second length line (from the great toe distal phalanx to the calcaneus tuberosity) was positively correlated with the medial length from the MKH to the great toe distal phalanx ($R = 0.402$, $P < 0.001$) and FHL insertion ($R = 0.320$, $P = 0.002$). The second length line was also positively correlated with the lateral ($R = 0.428$, $P < 0.001$) and medial ($R = 0.262$, $P = 0.012$) lengths of the QP. The length from the MKH to the great toe distal phalanx was strongly correlated with the lengths of the lateral head of the QP ($R = 0.509$, $P < 0.001$) and QP tendon ($R = 0.440$, $P = 0.046$). The length from the MKH to the FHL insertion was correlated with the length of the medial head of the QP ($R = 0.249$, $P = 0.017$). The length from the MKH to the little toe distal phalanx was positively correlated with the length of the medial head of the QP ($R = 0.324$, $P = 0.003$) and negatively correlated with the lateral head of the QP ($R = -0.464$, $P < 0.001$). Furthermore, the lengths of the lateral and medial heads of the QP were correlated ($R = 0.294$, $P = 0.005$). The angle between the FHL and FDL tended to be correlated with the width length; however, statistical significance was not reached ($R = -0.222$, $P = 0.081$).

Table 1. Topography of the structures in second layer

| | Length | Percentile | Min-Max |
|---|---|---|---|
| Reference line (Gdp-Ct) | 213.69 ± 17.54 | 100 | 178.69-264.00 |
| Gdp-Cn | 180.88 ± 16.93 | 84.66 ± 3.88 | 146.59-242.64 |
| MKH-Gdp | 140.16 ± 14.70 | 65.61 ± 4.54 | 101.58-178.76 |
| MKH-FHLi | 124.56 ± 13.46 | 58.23 ± 4.31 | 91.43-164.10 |
| MKH-Lt | 121.79 ± 13.42 | 56.59 ± 5.51 | 96.00-181.79 |
| MKH-FDLi | 109.07 ± 14.17 | 50.63 ± 5.61 | 45.14-133.10 |
| QPM | 51.70 ± 13.21 | 24.21 ± 5.70 | 0.00-77.72 |
| QPL | 72.80 ± 15.30 | 34.01 ± 6.22 | 15.20-117.90 |

Gdp-Ct: Great toe distal phalanx-Calcaneus tuberosity; Gdp-Cn: Great toe distal phalanx-Calcaneus notch; MKH-Gdp: Master Knot of Henry-Great toe distal phalanx; MKH-FHLi: Master Knot of Henry-FHL insertion; MKH-Lt: Master Knot of Henry-Little toe; MKH-FDLi: Master Knot of Henry-FDL Little toe insertion; QPM: Quadratus plantae medial head; QPL: Quadratus plantae lateral head.

Table 2. The average width of sole

| | Width | Percentile | Min-Max |
|---|---|---|---|
| Width reference (LB-MB) | 79.49 ± 6.81 | 100 | 63.48-96.00 |
| LBt-MBt | 49.19 ± 5.86 | 61.85 ± 5.45 | 33.50-62.00 |
| QPw | 28.92 ± 6.58 | 36.33 ± 7.78 | 16.73-56.04 |

LB-MB: Lateral border of the foot from to Medial border of the foot; LBt-MBt: Lateral border of the foot tendon from to Medial border of the foot tendon; QPw: Quadratus plantae width.

Table 3. Topographic change of the sole structures according to the pattern of Master Knot of Henry (continued)

| | Type 1 (no connection) | Type 2 (FHL-FDL) | Type 3 (QP-FHL and FDL) | P-value |
|---|---|---|---|---|
| Gdp-Cn | 85.50 ± 3.01 | 85.35 ± 3.50 | 86.21 ± 4.51 | 0.535 |
| MKH-Gdp | 65.53 ± 6.50 | 67.92 ± 2.87 | 66.39 ± 2.29 | 0.305 |
| MKH-FHLi | 59.16 ± 5.55 | 59.89 ± 2.88 | 59.04 ± 2.64 | 0.613 |
| MKH-Lt | 59.03 ± 9.21 | 57.80 ± 2.53 | 55.62 ± 2.86 | 0.168 |
| MKH-FDLi | 48.19 ± 9.83 | 53.13 ± 2.39 | 51.94 ± 2.54 | 0.071 |
| LBt-MBt | 62.39 ± 6.47 | 61.64 ± 5.25 | 60.97 ± 3.95 | 0.861 |
| QPM | 24.48 ± 6.88 | 26.02 ± 4.18 | 27.44 ± 3.86 | 0.127 |
| QPL | 33.10 ± 8.15 | 35.42 ± 3.76 | 37.79 ± 4.59 | 0.055 |
| QPw | 37.00 ± 7.81 | 37.29 ± 9.46 | 35.22 ± 9.34 | 0.470 |
| QP tendon | 50.37 ± 9.03 | 58.79 ± 13.51 | 46.40 ± 19.61 | 0.436 |
| Angle* | 28.33 ± 7.69 | 32.18 ± 3.52 | 35.57 ± 3.30 | 0.037 |

*$P < 0.05$

Gdp-Cn: Great toe distal phalanx-Calcaneus notch; MKH-Gdp: Master Knot of Henry-Great toe distal phalanx; MKH-FHLi: Master Knot of

Henry-FHL insertion; MKH-Lt: Master Knot of Henry-Little toe; MKH-FDLi: Master Knot of Henry-FDL Little toe insertion; LBt-MBt: Lateral border of the foot tendon, Medial border of the foot tendon; QPM: Quadratus plantae medial head; QPL: Quadratus plantae lateral head; QPw: Quadratus plantae width.

Table 4. Topographic change of the sole structures according to the pattern of quadratus plantae

| | QP tendon(+) | QP tendon(-) | P-value |
|---|---|---|---|
| Gdp-Cn | 85.65 ± 4.29 | 84.33 ± 3.70 | 0.151 |
| MKH-Gdp | 66.48 ± 2.50 | 65.31 ± 5.02 | 0.278 |
| MKH-FHLi | 58.47 ± 2.86 | 58.15 ± 4.71 | 0.565 |
| MKH-Lt | 56.30 ± 2.98 | 56.68 ± 6.15 | 0.787 |
| MKH-FDLi | 52.19 ± 2.31 | 50.11 ± 6.27 | 0.142 |
| LBt-MBt | 61.90 ± 4.77 | 61.83 ± 5.69 | 0.957 |
| QPM** | 27.33 ± 4.72 | 23.11 ± 5.63 | 0.001 |
| QPL* | 36.41 ± 4.34 | 33.18 ± 6.57 | 0.031 |
| QPw | 34.91 ± 5.75 | 36.81 ± 8.35 | 0.347 |
| Angle | 35.30 ± 4.97 | 32.75 ± 5.42 | 0.171 |

*$P < 0.05$

**$P < 0.01$

Gdp-Cn: Great toe distal phalanx-Calcaneus notch; MKH-Gdp: Master Knot of Henry-Great toe distal phalanx; MKH-FHLi: Master Knot of Henry-FHL insertion; MKH-Lt: Master Knot of Henry-Little toe; MKH-FDLi: Master Knot of Henry-FDL Little toe insertion; LBt-MBt: Lateral border of the foot tendon, Medial border of the foot tendon; QPM: Quadratus plantae medial head; QPL: Quadratus plantae lateral head; QPw: Quadratus plantae width.

Table 5. Correlation analysis of sole structures (continued)

| | | Gdp-Cn | MKH-Gdp | MKH-FHLi | MKH-Lt | MKH-FDLi | LBt-MBt | QPM | QPL | QPw | QP tendon |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gdp-Cn | R | 1 | .402** | .320** | -.072 | .179 | -.072 | .262* | .418** | -.003 | .355 |
| | P | | .000 | .002 | .516 | .104 | .518 | .012 | .000 | .978 | .114 |
| MKH-Gdp | R | .402** | 1 | .381** | -.175 | .831** | .058 | -.115 | .509** | -.114 | .440* |
| | P | .000 | | .000 | .112 | .000 | .598 | .275 | .000 | .319 | .046 |
| MKH-FHLi | R | .320** | .381** | 1 | .608** | .133 | -.223* | .249* | -.007 | .003 | .378 |
| | P | .002 | .000 | | .000 | .229 | .041 | .017 | .950 | .977 | .091 |
| MKH-Lt | R | -.072 | -.175 | .608** | 1 | -.280** | -.136 | .324** | -.464** | -.048 | .029 |
| | P | .516 | .112 | .000 | | .010 | .219 | .003 | .000 | .675 | .902 |
| MKH-FDLi | R | .179 | .831** | .133 | -.280** | 1 | .104 | -.066 | .577** | -.073 | .107 |
| | P | .104 | .000 | .229 | .010 | | .348 | .560 | .000 | .522 | .644 |
| LB-MB | R | -.072 | .058 | -.223* | -.136 | .104 | 1 | -.004 | .150 | .212 | -.188 |
| | P | .518 | .598 | .041 | .219 | .348 | | .972 | .186 | .061 | .414 |
| LBt-MBt | R | .262* | -.115 | .249* | .324** | -.066 | -.004 | 1 | .294** | -.020 | .313 |
| | P | .012 | .275 | .017 | .003 | .560 | .972 | | .005 | .862 | .168 |
| QPM | R | .418** | .509** | -.007 | -.464** | .577** | .150 | .294** | 1 | .144 | .309 |
| | P | .000 | .000 | .950 | .000 | .000 | .186 | .005 | | .209 | .185 |
| QPL | R | -.003 | -.114 | .003 | -.048 | -.073 | .212 | -.020 | .144 | 1 | -.117 |
| | P | .978 | .319 | .977 | .675 | .522 | .061 | .862 | .209 | | .622 |
| QPw | R | .355 | .440* | .378 | .029 | .107 | -.188 | .313 | .309 | -.117 | 1 |
| | P | .114 | .046 | .091 | .902 | .644 | .414 | .168 | .185 | .622 | |
| Angle | R | -.110 | -.048 | .203 | -.084 | .147 | -.222 | -.101 | -.107 | -.086 | -.123 |
| | P | .392 | .710 | .111 | .513 | .251 | .081 | .443 | .416 | .518 | .735 |

Gdp-Cn: Great toe distal phalanx-Calcaneus notch; MKH-Gdp: Master Knot of Henry-Great toe distal phalanx; MKH-FHLi: Master Knot of Henry-FHL insertion; MKH-Lt: Master Knot of Henry-Little toe; MKH-FDLi: Master Knot of Henry-FDL Little toe insertion; LB-MB: Lateral border of the foot, Medial border of the foot; LBt-MBt: Lateral border of the foot tendon, Medial border of the foot tendon; QPM: Quadratus plantae medial head; QPL: Quadratus plantae lateral head; QPw: Quadratus plantae width.

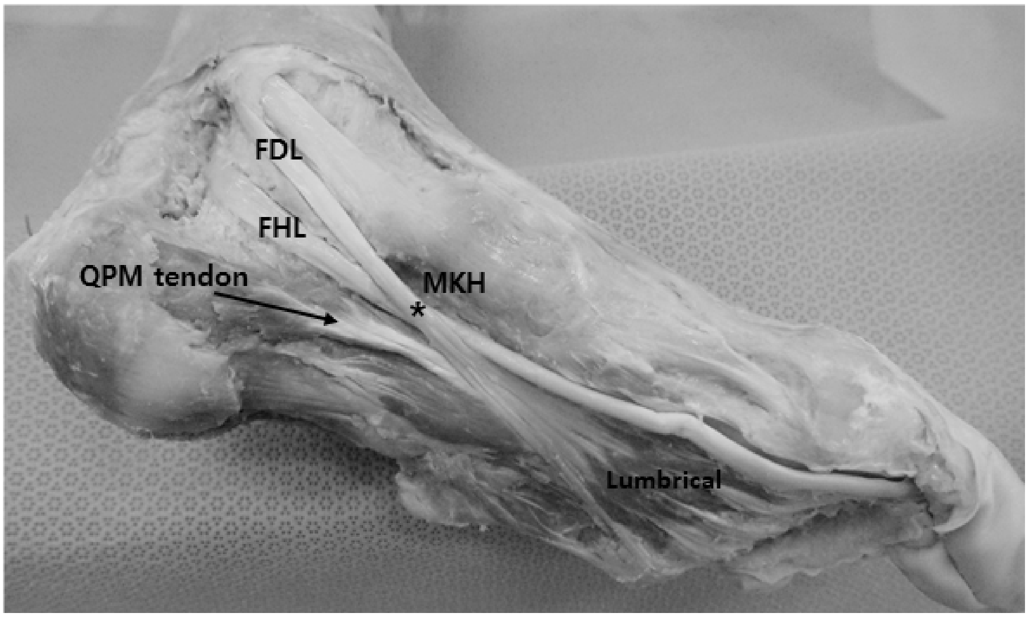


Figure 4. Representative result of measured data showing Master Knot of Henry and quadratus plantae tendon. FDL: Flexor digitorum longus; FHL: Flexor hallucis longus; MKH: Master Knot of Henry; QPM: Quadratus plantae medial head.

# 4. Discussion

In my study, the lengths of the structures in the second layer of the foot were measured and then analyzed using objective numerical data, with a focus on the tendons and muscles. The measured values and statistical analysis indicated that the lengths of the sole structures could vary depending on the anatomical variation and pattern of connection between the FHL and FDL.

There are many muscle and tendons in the sole and neurovascular structures are also located in its second layer. The FHL muscle is located in the posterior compartment of the leg and inserted to the distal phalanx of the great toe. The other muscles located in the this compartment are the FDL and tibialis posterior. These three muscles are innervated by the tibial nerve, which is the branch of the sciatic nerve.

The FDL muscle is the long flexor muscles in the posterior compartment of leg. It originates from below the soleal line in the posterior surface of the tibia, just medial to the tibialis posterior muscle. The muscle curves behind the medial malleolus and crosses superficially to the FHL tendon in the plantar aspect of the foot. And it inserts to base of the distal phalanges of the four lesser toes. At the crossing point known as Master knot of Henry (MKH), FDL receives a few tendinous connecting slips from the FHL (11,12). The FDL and FHL play an central role for stabilizing the foot arch and supporting the gait. As the MKH is the most commonly used landmark for foot and ankle surgeries, surgeons should recognize its location (13-15). For lack of knowledge about the MKH, a smaller skin incision in this region was performed during surgery. It can reduce wound morbidity by preserving the plantar nerves and vessels. The FHL and FDL cross each other with different types of communicating slips between them. Therefore, the exact anatomy of this important area is still controversial (1,9,11,16).

In the present study, the locational relationships of the cross point of the FHL and FDL (i.e. the MKH) were analyzed. The topographical relationships and variations of the FHL and FDL connections were examined, and the features of the MKH were divided into three types, which were compared in terms of the measured values of adjacent structures.

Previous studies classified the pattern of the connection between the FHL and FDL tendons into four types (6,16-20); Type I, a tendinous slip from the FHL to the FDL tendon, which was observed in 41.7-97% of feet; Type II, a tendinous slip from the FHL to the FDL and an additional slip from the FDL to the FHL (a crossed connection), which was observed in 1-41.7% of feet; Type III, a tendinous slip from the FDL to the FHL, which was observed in 0-30% of feet; and Type IV, no connection between the FHL and FDL, which occurred in 0-16.7% of feet (12). The present study classified the connection pattern by direction and an additional slip, which represents a new classification system. Type I was defined as no connection, Type II was defined as a single connection from the FHL to the FDL tendon, and Type III had an additional connection originated from the QP, (the QP tendon). Additionally, the QP pattern was defined according to the presence of the QP tendon. The frequency of this classification was similar to that described by Plaasss et al (9) and Edama et al (20).

The presence of tendon connection (Types II and III) was found in 55.88% of feet (38/68). Interestingly, the angle between the FHL and FDL was significantly larger in feet with a connections (Type II, III), than in feet without connections (Type I). Additionally, the lateral length of the QP was significantly larger in feet with a connections (Type II, and III) than in feet without a connections (Type I). Although the lengths of the QP and MKH differed to some extent, the differences were not statistically significant. There results indicate that the presence of a connection may influence the morphology of the sole muscles.

The QP muscle was first named as the massa carnae by Jacque DuBois, who is better known by his Latinized name of Jacobus Sylvius (21). Anatomists later named the muscle as the caro plantae pedis, then as the caro quadrato, and finally as the QP. The long plantar ligament separates the two heads from each other. It was originally thought that the QP fibers sent slips to the FDL tendons that pass to digits two through five in the foot, but it is now known that there is much variability in the connection pattern. Especially, there was no bony insertion for QP, and it is distally attached to FHL tendon or a tendinous slip connecting between FHL and FDL. The QP is variably involved in the attachments to the tendons of the FDL (16). The QP has a great role for stabilizing the foot during standing and walking. Various functions have been attributed to the QP, such as supporting foot arch, plantar flexion of the lesser toes, and eversion of the foot (19-20,22-24). Despite the wide range of functional study about QP, topography of this muscle has not been identified (12).

A number of studies of the existence of the QP have highlighted some important variations with regards to its functional attributes (25,26). Investigations have shown that, in some cases, the size of QP may be reduced. In other cases, the heads may be duplicated in size or divided into superficial and deep parts, or have a high origin from the low part of the fibula. The medial head may contribute to the flexion for two digital tendon, two and three tendons, or two to four tendons. It may partly attach to the lateral border of the FDL tendon, especially if there is no lateral head. The lateral head may cross superficially to the medial head, which is the most common arrangement, or it may merge with the lateral border of the medial head or be absent (21).

Another study provided qualitative and quantitative data about the number of heads, points of origin, and type of insertion of the QP. The authors demonstrated its origin, as all points of origin of the QP were specified. If an accessory tendon was found to insert into the QP, chiasma plantare, or calcaneus, its origin was additionally determined. According to the origin point, the heads were defined as the medial, middle, and lateral heads. The QP was composed of one (34%), two (57%), or three heads (9%). Interestingly, three heads was shown only in men. Additionally, the lateral head was absent in 31 of 50 feet, and the medial head alone was observed in one right foot of a man. The medial head, amongst others, arose from the medial calcaneal surface in all cases, from the long plantar ligament in 93% of case, and from the plantar calcaneocuboid ligament in 80% of cases. The lateral head, amongst others, arose from the long plantar ligament in 90% of cases and from the lateral process of the calcaneal tuberosity in 64% of the examined feet. The insertion type was a mixture of at least two of three types; muscular (84%), tendinous (89%), and aponeurotic (45%). As additional findings, the flexor digitorum accessorius longus and the peroneocalcaneus internus were observed in 12% of all individuals and in 20% of men. Although the QP may be classified according to the number of heads, no classification can be given for its points of origin or type of insertion (5). According to its origins, the middle and lateral heads are divided from the long plantar ligament. In the present study, the QP tendon was observed in 25.3% of feet. Additionally, the lateral and medial lengths of the QP were significantly longer in feet with an additional tendon than in feet without an additional tendon. These results suggest that the presence of the QP tendon may affect the size of the QP.

Interestingly, the correlational analysis in the present study revealed novel data regarding the associations among sole structures. The length from the MKH to the little toe distal phalanx has a paradoxical association with the medial and lateral heads of the QP, even though the medial and lateral heads of the QP have a positive association with each other. This result indicates that the form of the MKH toward the little toe may affect the size of the QP. The QP is named by its morphology; however, this could be changed by the MKH form to a rhomboid or round form. This result should be confirmed in other species.

The present study has a limitation that should be acknowledged. Although attempts were made, it was difficult to observe the major nerves and vessels due to. The state of cadavers; the cadavers were not intact because of previous dissections in other studies. Further research should be performed to obtain more information regarding the structures of the second layer of the sole that includes the nerves and vessels. Based on the present study data and this additional research, clinical applications of the anatomy of the second layer can be expected.

# 5. Summary

In this article, the anatomical structure of the second layer of the sole and its variations were investigated. In the second layer of the sole, FHL and FDL have a connection each other. And, the locational relationship of the cross point of FHL and FDL known as MKH was analyzed. The location of MKH was longitudinally at 2/3 of length reference from distal end and horizontally at 1/3 of the full width of the foot from medial border. I examined their topographical relationships and variations, divided features of MKH into three types and compared measured values of adjacent structures. Also, I verified QP which helps FDL to flex toes. As a variation related with QP, medially attached tendon to QP the tendon could be seen. In my study, the length of the second layer structure of the sole were measured and analyzed with objective numerical data and through these analyses it could be proved that the length of structures would be different depending on their variations and patterns. With this study, I am trying to provide important informations about the second layer of the sole to anatomical researchers and clinicians.

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# Anatomical Study of the muscles of the sole

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(Abstract)

The plantar muscle layers are arranged in four layers. I studied the topography and variation of the structures in this region. I dissected 95 feet of donated cadavers and analyzed the topography and variation of muscular structures. The average length of sole was 213.69 ± 17.5 mm, used as height reference line. Based on this line, Master Knot of Henry (MKH) was located at 63.57 percentile (140.16 ± 14.70 mm) and 56.59 percentile (121.79 ± 13.42 mm) from great toe and little toe, respectively. The median of the angle between flexor digitorum longus (FDL) and flexor hallucis longus (FHL), was 31.56 ± 5.75 °. The average width was 79.49 ± 6.8 mm, as width reference line. The average width of the quadratus plantae (QP) was 36.33 ± 7.78 percentile (28.92 ± 6.58 mm) based on width reference line. Quadratus plantae(QP) was found in 25.3% (24/95) and its presence was associated with its longer length

And the presence of the connection was found in 55.88% (38/68) and it had a relation with longer length of QP and increased angle. The information of the patterns and variations in this region may be helpful for accurate diagnosis and treatment of the plantar injury.

# 발바닥의 깊은 근육에 대한 해부학적 연구

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(초록)

발은 서 있을 때 체중을 지탱하는 기반이 되며, 움직임에 있어서 중요한 역할을 한다. 발바닥근육은 발바닥 쪽에서 보았을 때, 네 개의 층으로 배열되어 있다. 발바닥 두 번째 층의 교차지점에 관련된 위치관계와 형태 및 변이에 대한 연구가 부족하여 본 연구에서 발바닥 둘째 층의 형태 및 변이를 연구하였다. 50구의 기증된 시신에서 발바닥 둘째 층의 형태를 연구 하였다. 이 근육은 교차지점의 분지된 형태에 따라 바닥의 구조적 차이가 발견되었다. 발바닥의 평균 길이는 높이를 기준선으로 213.69 ± 17.5 mm 정의하였다. 이 선을 기준으로 하여 “Master Knot of Herny” 는 엄지발가락과 새끼발가락에서 각각 63.57 퍼센타일 (140.16 ± 14.70 mm), 56.59 퍼센타일 (121.79 ± 13.42 mm)에 위치하였다. FHL과 FDL 사이의 각도 중앙값은 31.56 ± 5.75 ° 였다. 폭의 평균 길이는 79.49 ± 6.8 mm이고, 기준으로 하여 측정되었다. 발바닥네모근의 평균 폭은 폭 기준선을 기준으로 36.33 ± 7.78 퍼센타일 (28.92 ± 6.58 mm)이었다. 발바닥네모근의 힘줄은 25.3%

(24/95)에서 발견되었으며, 있는 경우 발바닥네모근 중 더 긴 길이와 관련이 있다. 그리고 FHL과 FDL 사이의 교차지점에 대해서는 55.88% (38/68)에서 발견되었으며, 긴 길이의 발바닥네모근은 FHL과 FDL 사이의 각도도 함께 증가되었다. 발바닥 둘째 층의 교차지점에서 다양한 형태 및 변이는 발바닥의 부상의 정확한 진단과 치료에 도움이 될 것으로 예상된다.

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