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Surface localization of Master knot of Henry, in situ and ex vivo length of flexor hallucis longus tendon: pertinent data for tendon harvesting and transfer

Running head: Flexor hallucis longus

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Abstract

Background: Length of flexor hallucis longus (FHL), localization of master knot of Henry (MKH) and relationship between MKH and neurovascular bundle are essential for the achievement of FHL tendon transfer. The purpose of this study is to define the localization of MKH in reference to bony landmarks of the foot, its relationship to plantar neurovascular bundle and to investigate in situ and ex vivo length of FHL tendon in single incision, double incision and minimally invasive techniques.

Materials and methods: Foot length was examined in sixty-two feet of thirty-one soft cadavers (9 males, 22 females). Various parameters including the relationship between MKH and neurovascular bundle, the distances from MKH to medial malleolus (MM), navicular tuberosity (NT) and the first interphalangeal joint of great toe (IP) were measured. Surface localization of MKH in relation to a line joining the medial end of plantar flexion crease at the base of great toes (MC) to NT (MC-NT line) was determined. Lengths of FHL tendon graft from three surgical techniques were examined. In situ length was measured in the plantar surface of foot and ex vivo length was measured after tendon was cut from its insertion.

Results: The mean length of foot was 230.98±15.35 mm with a statistically significant difference between genders in both sides ($p<0.05$). No distance was found between medial plantar neurovascular bundle (MPNVB) and MKH. Mean distance of 17.13±3.55 mm was found between lateral plantar neurovascular bundle (LPNVB) and MKH. MKH was located at a mean distance of 117.11±1.00 mm proximal to IP, 26.28±4.75 mm under NT and 59.58±7.51mm distal to MM with a statistically significant difference of MKH-IP distance between genders in both sides and MKH-NT in right side. MKH was located anterior to NT (66.1 %), at NT (27.4%) and posterior to NT (6.5%) on the MC-NT line. Surface localization of MKH was 94.75±8.43% of MC-NT line from MC with a perpendicular distance of 25.11±5.37mm below MC-NT line. The in situ and ex vivo tendon lengths from MTJ to ST, to MKH and to IP were 39.05±10.88 mm and 34.43±10.23 mm, 73.45±9.91 mm and 68.63±9.43 mm, 197.98±13.89 and 191.79±14.00 mm, respectively. A statistically significant difference between genders was found in MTJ-IP of in situ and ex vivo length of both sides ($p < 0.05$). The mean length of tendon between in situ and ex vivo was significantly different in all techniques ($p < 0.05$). A moderate positive correlation between foot length and tendon length was found in MTJ-IP of both in situ and ex vivo tendon length.

Conclusions: A statistically significant difference between in situ and ex vivo tendon length was shown in all harvesting techniques. Surface location of MKH was approximately at 95%of MC-NT line from MC with a perpendicular distance of 25 mm from MC-NT line.

Key words: flexor hallucis longus, master knot of Henry, tendon transfer

INTRODUCTION

Flexor hallucis longus (FHL) tendon transfer is a widely used technique for reconstruction of the Achilles tendinopathies[17, 20]. This technique proposes to repair the length, to strengthen the injured tendon with additional tendon, and to corporate more muscle force to the plantarflexor[6]. FHL is appropriate for transfer because of its strength, axis and amplitude of contraction, and its concomitant action with triceps surae muscles [32].

Moreover, FHL transfer can also reduce the pain by normalizing vascularity [6, 1]. FHL transfer is also used for the treatment of posterior tibial insufficiency with a good to excellent clinical outcome [19, 8].

There are many techniques for harvesting FHL tendon grafts including single incision, double incision, and minimally invasive techniques [13]. The differences among these techniques are the indication and sites of incision. Importantly, the length of harvested tendon from each technique is vastly different [13]. The single incision approach is used to harvest the FHL within the tarsal tunnel. Although, this technique yields a shorter graft but it is long enough to be inserted on the calcaneus. When the additional length is required, the double incision technique at the medial aspect of foot near Master Knot of Henry (MKH) is considered. The added 3 cm of tendon length is obtained from this technique if the FHL is cut at MKH [4,27,29]. The minimally invasive technique provides the longest length [17]. Although, previous reports revealed good results following FHL transfer, complications such as serious injury of the distal branches of the posterior tibial artery and nerve, cock-up deformity, and functional loss of toe have been reported [1, 7, 13, 26].

Anatomically, medial and lateral plantar neurovascular bundles (MPNVB, LPNVB) reside near the incision line. In consequence, they might be at risk during harvesting. The other structure which affects tendon harvesting is MKH. MKH is where the tendon of flexor digitorum longus (FDL) crosses over the tendon of FHL. It has been used as a surgical landmark for the tendon graft harvesting [2, 17]. Therefore, the precise location of the MKH is crucial for better results [2].

Knowledge of the length of FHL tendon available for harvesting, the relationship between tendon and neurovascular bundle, and the anatomical locations of MKH are essential for guiding the surgeon during operation and decreasing potential morbidity [13]. The length of FHL tendon after cutting for harvesting, which might be different from the length of attached tendon, should be elucidated. This anatomical study aims to clarify these issues in soft cadavers.

MATERIALS AND METHODS

This study was performed in 62 legs from 31 Thai soft cadavers (9 male and 22 female) supported by the Chula Soft Cadaver Surgical Training Center, Faculty of Medicine, Chulalongkorn University. The average age of the cadavers was 78.39 ±10.60 years (age range 53-100). All cadaveric ankles and feet had no deformities, damage and history of previous surgery.

Foot length measurement and surface marking

The foot was aligned to neutral position by fixing with a supporting frame. The foot length was measured from the most posterior portion of the calcaneus to the end of the longest toe [30]. The line joining the medial end of plantar flexion crease at the base of the great toes (MC) and the most prominent point of navicular tuberosity (NT) by palpation was created to be a reference line for locating the MKH surface landmark (Figure 1A).

Cadaveric dissection

The skin incision along the dotted line as shown in figure 1A was performed. The skin was dissected. Subcutaneous fatty tissue, flexor digitorum brevis and abductor hallucis muscle were removed to expose FHL tendon, FDL tendon and MKH in the plantar surface of foot (Figure 1B). FHL was dissected further to its musculotendinous junction (MTJ) proximally and its insertion distally. The skin flab was turned down to cover the plantar surface of the foot and the location of MKH was marked on the skin surface. The perpendicular line from MKH to MC-NT line (MKH-A) was created (Figure 1A). Point A might be located at NT, anterior to NT or posterior to NT on MC-NT line (Figure 2). The most prominent point of medial malleolus (MM), sustentaculum tali (ST) and the midpoint of first interphalangeal joint of great toe (IP) were marked (Figure 1B, 4A).

Observations and measurements

Surface landmark and location of MKH, its relationship to the neurovascular bundle

The surface landmark of MKH was determined by measuring the length of MC-NT, MKH-A and MC-A lines (Figure1A). The MC-A length was calculated into percentage of MC-NT length. To determine the location of MKH in the dissected specimen, the distances from MKH to MM, to NT and to IP was measured (Figure1B). The anatomical relationship between MKH and neurovascular bundle, including MPNVB and LPNVB were evaluated and the distance between their midpoints were recorded (Figure 3). All distances were measured by standardized digital Vernier caliper (Mitutoyo ® 0-150 mm; range 150 mm, resolution 0.01 mm).

In situ and ex vivo lengths of FHL tendon

To determine the in situ length of FHL tendon, the lengths from MTJ to ST, MTJ to MKH and MTJ to IP represent the length harvested through a single incision, double-incision and the minimally invasive technique, respectively (Figure 4A).

To define the ex vivo length of FHL tendon, three points were marked on the FHL tendon at the level of ST, MKH and IP. FHL tendon was cut at its insertion. Ex vivo length was measured from MTJ to those three points on FHL tendon by using a measuring tape (Butterfly ® 0-150 cm; range 150 cm, resolution 1 mm) (Figure 4B).

Each parameter was measured twice. The same digital Vernier caliper and measuring tape were used to ensure the consistency. All measurements were done by the same investigator.

Statistical analysis

Statistical analysis was performed by SPSS software version 22.0. All data from measurements were statistically analyzed to demonstrate range, mean and SD. To compare between genders, unpaired t-test (for parametric test) or Mann-Whitney U test (for nonparametric test) was used. The difference between in situ and ex vivo tendon length was examined with paired t-test (for parametric test) or Wilcoxon signed-rank test (for nonparametric test). A p-value of less than 0.05 was statistically significant. Pearson correlation test was used to assess the associative relationship between the foot length and the tendon length.

Ethical consideration

This cadaveric study has been approved by the Institutional Review Board (IRB) of the Faculty of Medicine, Chulalongkorn University (IRB NO. 636/62).

RESULTS

Foot length

Results and analyses of the foot length are illustrated in Table 1. The mean length of foot in male and female was 246.50±12.02 and 224.64±11.63 mm, respectively. A statistically significant difference was found between genders in both sides.

Surface landmark and location of MKH

MKH location and surface landmark results and analyses are shown on Table 2-3. The location of MKH was identified at 117.11±1.00 mm proximal to IP, 26.28±4.75 mm under NT and 59.58±7.51 mm distal to MM. A statistically significant difference between genders was observed in MKH-IP of both sides and MKH-NT on right side.

Point A could be resided anterior to NT (66.1 %), at NT (27.4%) and posterior to NT (6.5%) (Table 3).The mean length of MC-NT and MC-A line were 107.36±8.60 and 101.72±12.01 mm, respectively. Point A was located at 94.75±8.43 % of MC-NT line from MC (Table 2). The mean perpendicular length from MKH to A (MKH-A) was 25.11+5.37 mm (Table 2). A statistically significant difference between genders was present in MC-A on both sides and MKH-A on right side.

Relationship between MKH and plantar neurovascular bundle

The MPNVB lied very closely to MKH in all cases; therefore, no distance could be measured. In contrast, a mean distance of 17.13±3.55 mm was observed between LPNVB and MKH without a statistically significant difference between genders (Table 2).

Length of FHL tendon

The mean in situ and ex vivo length of FHL tendon graft, harvested by three different incision techniques, are shown on Table 4. A statistically significant difference was found between genders in MTJ-IP of in situ and ex vivo length of both sides ($p < 0.05$). The mean length of tendon between in situ and ex vivo was significantly different in all techniques ($p < 0.05$). Moreover, a moderate positive correlation between foot length and tendon length was found in MTJ-IP of both in situ and ex vivo tendon length (r=0.52 and 0.56 respectively).

The length of FHL tendon was calculated in term of percentage of foot length as shown in Table 5. In situ and ex vivo tendon lengths were 16.96±4.84 and 14.96±4.53%, 31.88±4.43 and 29.79±4.16%, 85.63±3.70 and 83.09±3.90% of foot length in single incision, double incision, and minimally invasive techniques, respectively.

DISCUSSION

Achilles tendinopathy is a painful condition that can occur in both active and inactive people [11]. Despite of noninvasive treatments such as physical therapy, orthotics and drugs, surgical intervention might be necessary when clinical outcome remained disappointing [6, 12]. FHL tendon is a common tendon used in the augmentation of the Achilles tendon because it is easy to harvest and provides good to excellent functional outcomes and pain relief regardless of the technique used to harvest the tendon [4, 6, 29].

The shape and morphology of the foot vary among ethnicities, genders, and individuals [10, 15, 21, 24, 31]. Foot length was used in this study to anticipate anatomical data which is significant for FHL tendon transfer. Asian foot length is shorter than that of North American and European. In Asians, the most frequent length was 255 mm for male and 235 mm for female [9]. In this study, the mean foot lengths were 246 mm and 225 mm in male and female respectively. A significant difference between genders was found similar to the previous reports [3, 22]

MKH has been widely utilized as a surgical landmark for the FHL tendon graft harvesting especially in double incision technique [2]. The first IP joint and NT were used to localize MKH by Mao et al., in Asian embalmed cadavers [13]. Moreover, Beger et al. and Vasudha et al. further investigated the precise location of the MKH from MM, NT and first IP joint in Turkish and Indian formalin fixed cadavers, respectively [2, 28]. According to the results of this study, the location of MKH resided proximal to the first IP joint, inferior to NT and distal to MM which resembled findings of previous reports [2, 28] (Table 6).

Although there were several reports about the location of the MKH, they did not take surface landmarks for localizing MKH into account. Medial end of plantar flexion crease at the base of great toe (MC) and navicular tuberosity (NT), which could be clearly identified and palpated, were used to determine the surface localization of MKH in this study. For accuracy and easy application in clinical practice, MC-NT line and A which is the perpendicular point of MKH on MC-NT line were defined. Approximately, MKH located at 95 % of MC-NT line from MC with a perpendicular distance of 25 mm from MC-NT line. However, our results revealed that point A could be located anterior, posterior and at the NT on MC-NT line. Nevertheless, MKH was located posterior to NT in only 6.5 % of cases.

Medial and lateral plantar nerves (MPN and LPN) are the branches of posterior tibial nerve which supply skin and intrinsic muscle of the sole. Anatomically, MPN travels along the plantar surface of FDL tendon and passes through MKH [16]. LPN passes obliquely between flexor digitorum brevis and quadratus plantae to the lateral side of the foot. The anatomical relationship between plantar nerves and MKH was reported by Mao and colleague in embalmed cadavers [14]. They found a mean distance of 5.26 mm between MPN and MKH, and 15.50 mm between LPN and MKH which was different from the result of this study. In all specimens of this study, there was no distance between MPNVB and MKH and a longer distance of 17.13±3.55 mm was observed between LPNVB and MKH. This might be due to the different methods of cadaveric fixation. In embalmed cadaver, most tissues are rigid and joints cannot be moved freely which may affect the location of anatomical structures [23]. The proximity of MKH and MPNVB might lead to neurovascular bundle injury. The injuries of the distal branches of the posterior tibial nerve and artery were reported previously [7, 13, 14, 18]. The transection of tendon that was performed near MKH in double incision technique may cause MPN or LPN injury [13]. In the literature, it was hypothesized that difficult harvesting might be the cause of nerve injury [16].Nerve injury might be partial but not significant enough to cause clinical symptoms and long periods of casting after surgery could prohibit the detection of symptoms[16]. Nevertheless, caution is required to preserve this neurovascular bundle especially when distal transection is performed blindly [25, 27]. Moreover, tendon disease in the region of MKH may lead to the entrapment of MPN[5].

In this study, the length of tendon graft with three different incision techniques (single incision, double incision and minimally invasive technique) was quantified. Previous researches reported that the in situ length of harvested FHL tendon were different between techniques [2, 13, 27] (Table 6). The length of tendon graft from single incision technique in this study was shorter than previous studies. In double incision technique, our result was longer when compared to those of Mao et al. and Beger et al., but shorter than that of Tashjian et al. Furthermore, the length of tendon graft from minimally invasive technique was found to be longer when compares with Moa et al. Nevertheless, it was shorter than the mean length from Beger et al. These differences might be caused by the different ethnic backgrounds, cadaveric preservation technique and position of foot and ankle during measurement.

Ex vivo length of tendon graft has never been reported previously. Ex vivo length refers to the length of tendon after it is cut from the insertion point, which may be more similar to the length of harvested tendon for transfer. Our results revealed significant differences between in situ and ex vivo length of tendon from all techniques. Ex vivo tendon length was shorter than in situ tendon length by about 4.5 mm in single incision and double incision techniques and 6.0 mm in minimally invasive technique. The shorter tendon might result from loss of tension after it was cut from the insertion site in the foot. The correlation between tendon length and foot length was analyzed for clinical benefit. Our results showed a moderate positive correlation between them. The lengths of harvested tendon from single incision, double incision and minimally invasive technique were about 15%, 30%, and 85% of foot length, respectively. Thus, it might be possible to estimate the length of harvested tendon from the foot length.

This study offers some benefits as it identifies the precise surface location of MKH which will make it easier to identify the incision site and improve the clinical efficacy of the surgery. Understanding the relation between MKH and neurovascular bundle can assist the clinician to avoid iatrogenic injury. The in situ and ex vivo length of FHL tendon could guide surgeons to designs personalized operation techniques that are appropriate for each patient. Therefore, the knowledge of this investigation can enhance the clinical efficacy of foot and ankle surgery and help minimize potential complications.

CONCLUSIONS

MKH resides distal to MM, under NT and proximal to IP with MPNVB residing closely to MKH. Surface localization of MKH can be located at 95% of MC-NT line from MC with a perpendicular distance of 25 mm from MC-NT line. The ex vivo lengths of tendon graft in all techniques were significantly shorter than in situ length. Foot length, MKH-IP, MKH-NT, MC-A, MKH-A and the lengths of FHL tendon graft from minimally invasive technique had statistically significant differences between genders.

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Table 1. The mean foot length in male and female

Gender/Side	**Foot length (mm) — Mean ± SD (min-max)**			**p-value**
	Left	**Right**	**Total**	
Male	(n=9) 246.44±12.22 (225.00-268.00)	(n=9) 246.56±12.54 (228.00-270.00)	(n=18) 246.50±12.02 (225.00-270.00)	0.937
Female	(n=22) 223.77±12.18 (200.00-250.00)	(n=22) 225.50±11.27 (203.00-248.00)	(n=44) 224.64±11.63 (200.00-250.00)	0.026
Total	(n=31) 230.35±15.91 (20.00-26.80)	(n=31) 231.61±15.01 (203.00-270.00)	(n=62) 230.98±15.35 (200.00-270.00)	-
p-value	0.00	0.00	-	

Table 2. Location of MKH from IP, NT and MM, surface landmark of MKH, distances between MKH and NVB, location of MKH in term of percentage of the length of MC-NT line

Parameters	Male — Mean ± SD (min-max)			Female — Mean ± SD (min-max)			Total
	Left	Right	Total	Left	Right	Total	
Location of MKH(mm)							
MKH-IP	124.69±9.04 (106.56–137.88)	126.39±12.39 (110.24–151.27)	125.54±10.55 (106.56–151.27)	113.30±8.11 (93.14–129.50)	114.03±6.95 (100.27–128.20)	113.66±7.47 (93.14–129.50)	117.11±1.00 (93.14–151.27)
MKH-NT	29.45±7.06 (21.38–40.91)	27.88±4.15 (19.53–33.16)	28.67±5.68 (19.53–40.91)	26.21±3.51 (17.93–33.73)	24.40±4.32 (18.30–35.87)	25.31±3.99 (17.93–35.87)	26.28±4.75 (17.93–40.91)
MKH-MM	63.32±9.80 (47.02–78.71)	60.02±11.02 (34.59–75.27)	61.67±10.26 (34.59–78.71)	60.36±6.49 (48.91–78.07)	57.10±5.06 (44.43–67.05)	58.72±5.98 (44.43–78.07)	59.58±7.51 (34.59–78.71)
Surface landmark of MKH(mm)							
MC-NT	113.11±10.21 (91.75–124.12)	113.13±7.44 (101.49–122.19)	113.12±8.67 (91.75–123.37)	102.57±8.09 (87.18–116.74)	107.45±6.01 97.26–117.65)	105.01±7.46 (87.18–117.65)	107.36±8.60 (87.18–124.12)
MKH-A	29.10±8.83 (19.39–41.85)	27.89±4.86 (25.11–35.53)	28.49±6.94 (19.39–41.85)	24.18±3.33 (17.26–32.27)	23.26±4.39 (16.89–34.15)	23.72±3.88 (16.89–34.15)	25.11±5.37 (16.89–41.85)
MC-A	111.59±11.01 (90.62–126.71)	110.87±15.39 (87.26–139.77)	111.23±12.99 (87.26–139.77)	95.92±10.55 (76.05–116.74)	99.75±7.40 86.91–115.63)	97.83±9.21 (76.05–116.74)	101.72±12.01 (76.05–139.77)
Distance between MKH and NVB(mm)							
MKH-LPNVB	17.98±6.09 (9.59–30.29)	19.91±5.32 (13.05–28.85)	18.94±5.64 (9.59–30.29)	15.17±3.84 (8.44–22.05)	17.61±3.56 (7.11–24.38)	16.39±3.86 (7.11–24.38)	17.13±3.55 (7.11–30.29)
MKH-MPNVB	0	0	0	0	0	0	0
Location of MKH in term of percentage of MC-NT length (%)	98.84±7.77 (87.77–110.28)	98.34±15.90 (82.21–137.72)	98.56±11.98 (82.21–137.72)	93.47±6.36 (75.83–107.16)	92.89±5.65 (79.82–100.00)	93.18±5.95 (75.83–107.16)	94.75±8.43 (75.83–137.72)

A= perpendicular point of MKH on MC-NT line, IP= first interphalangeal joint of great toe,LPNVB= lateral plantar neurovascular bundles,MC= medial end of plantar flexion crease at the base of great toes, MKH=Master knot of Henry, MM=medial malleolus, MPNVB= medial plantar neurovascular bundles, NT=navicular tuberosity

Table 3. Prevalence of MKH location on MC-NT line

Location of MKH	Male — N (%)			Female — N (%)			Total (N=62)
	Left (N=9)	Right (N=9)	Total (N=18)	Left (N=22)	Right (N=22)	Total (N=44)	
At NT	4 (44.4)	3 (33.3)	7 (38.9)	4 (18.2)	6 (27.3)	10 (22.7)	17 (27.4)
Anterior to NT	3 (33.33)	5 (55.6)	8 (44.4)	17 (77.3)	16 (72.7)	33 (75.0)	41 (66.1)
Posterior to NT	2 (22.22)	1 (11.1)	3 (16.7)	1 (4.5)	0 (0)	1 (2.3)	4 (6.5)

MC= medial end of plantar flexion crease at the base of great toes, MKH=Master knot of Henry, MM=medial malleolus, NT= navicular tuberosity

Table 4. In situ and ex vivo length of harvested FHL tendon from single incision (MTJ-ST), double incision (MTJ-MKH) and minimally invasive techniques (MTJ-IP)

Techniques / Genders	Male — mean ± SD (min-max) (mm)			Female— mean ± SD (min-max) (mm)			Total (n=62)
	Left (n=9)	Right(n=9)	Total (n=18)	Left(n=22)	Right(n=22)	Total (n=44)	
• **In situ length**							
MTJ-ST	43.22±12.14 (21.00–60.00)	41.56±8.35 (30.00–55.00)	42.39±10.15 (21.00–60.00)	37.50±10.15 (15.00–62.00)	37.86±12.01 (19.00–71.00)	37.68±11.00 (15.00–71.00)	39.05±10.88 (15.00–71.00)
MTJ-MKH	76.78±9.55 (67.00–95.00)	75.78±10.19 (60.00–91.00)	76.28±9.60 (60.00–95.00)	71.00±8.09 (59.00–92.00)	73.59±11.51 (54.00–95.00)	72.29±9.92 (54.00–95.00)	73.45±9.91 (54.00–95.00)
MTJ-IP	209.44±17.67 (181.00–240.00)	209.56±15.32 (188.00–240.00)	209.50±16.00 (181.00–240.00)	192.22±9.12 (174.00–215.00)	194.32±10.33 (179.00–215.00)	193.27±9.68 (174.00–215.00)	197.98±13.89 (174.00–240.00)
• **Ex vivo length**							
MTJ-ST	38.33±10.22 (19.00–50.00)	36.67±7.36 (25.00–46.00)	37.50±8.68 (19.00–50.00)	33.00±10.64 (11.00–57.00)	33.36±10.88 (15.00–58.00)	33.18±10.63 (11.00–58.00)	34.43±10.23 (11.00–58.00)
MTJ-MKH	71.67±8.90 (64.00–90.00)	70.44±9.36 (57.00–87.00)	71.06±8.88 (57.00–90.00)	66.45±8.73 (54.00–89.00)	68.82±10.40 (51.00–84.00)	67.64±9.56 (51.00–89.00)	68.63±9.43 (51.00–90.00)
MTJ-IP	203.56±18.77 (174.00–236.00)	203.78±14.94 (184.00–235.00)	203.67±16.46 (174.00–236.00)	186.36±9.21 (167.00–209.00)	187.50±9.69 (173.00–205.00)	186.93±9.36 (167.00–209.00)	191.79±14.00 (167.00–236.00)

FHL= flexor hallucis longus, IP= first interphalangeal joint of great toe,MKH=Master knot of Henry, MTJ= musculotendinous junction, NT= navicular tuberosity, ST= sustentaculumtali

Table 5. Length of harvested FHL tendon in term of percentage of the foot length

Techniques / Genders	Male — mean ± SD (min-max) (mm)			Female — mean ± SD (min-max) (mm)			Total (n=62)
	Left (n=9)	Right (n=9)	Total (n=18)	Left(n=22)	Right(n=22)	Total (n=44)	
• **In situ length**							
MTJ-ST	17.45±4.64 (9.33–24.29)	16.84±3.27 (12.24–22.82)	17.14±3.90 (9.33–24.29)	16.84±4.72 (6.38–28.84)	16.92±5.77 (8.19–33.81)	16.88±5.21 (6.38–33.81)	16.96±4.84 (6.38–33.81)
MTJ-MKH	31.18±3.69 (27.31–35.56)	30.76±2.91 (26.15–36.93)	30.97±3.79 (26.15–36.93)	31.81±3.89 (25.11–39.07)	32.70±5.36 (23.40–45.24)	32.26±4.65 (23.40–45.24)	31.88±4.43 (23.40–45.24)
MTJ-IP	84.89±3.89 (74.58–88.06)	84.97±3.90 (80.77–93.36)	84.93±3.78 (78.75–93.36)	86.02±3.91 (75.74–92.09)	85.83±3.51 (79.91–93.75)	85.92±3.67 (75.74–93.75)	85.63±3.70 (75.74–93.75)
• **Ex vivo length**							
MTJ-ST	15.47±3.85 (8.44–20.24)	14.87±2.91 (12.24–18.67)	15.17±3.33 (8.44–20.24)	14.83±4.91 (4.78–26.51)	14.91±5.15 (6.47–27.62)	14.87±4.97 (4.78–27.62)	14.96±4.53 (4.78–27.62)
MTJ-MKH	29.09±3.31 (25.77–33.58)	28.59±3.70 (24.23–34.80)	28.84±3.41 (24.23–34.80)	29.77±4.07 (23.20–37.21)	30.57±4.78 (23.18–40.00)	32.26±4.65 (23.18–40.00)	29.79±4.16 (23.18–40.00)
MTJ-IP	82.48±4.49 (74.58–88.06)	82.61±3.34 (79.62–89.21)	82.55±3.84 (74.58–89.21)	83.38±3.71 (74.89–90.23)	83.38±3.71 (74.89–90.23)	83.31±3.95 (74.89–94.76)	83.09±3.90 (74.58–94.76)

FHL= Flexor hallucis longus,IP= first interphalangeal joint of great toe,MKH=Master knot of Henry, MTJ= musculotendinous junction, NT= navicular tuberosity, ST= sustentaculumtali

Table 6. Comparison of the distances from MKH to anatomical landmarks and in situ FHL tendon length

	This study, 2020	**Vasudha et al., 2019[28]**	**Beger et al., 2018[2]**	**Mao et al., 2015 [13]**	**Tashjian et al., 2003 [27]**
Ethnic	Thai	Indian	Turkish	Asian	US
Cadaveric type	Soft	Formalin fixed	Formalin fixed	Embalmed	Fresh frozen
Number of specimen	62	L: 36 R: 36	20	64	14
Distances from MKH to landmarks (cm)					
MM	5.96 ± 0.75 (3.46–7.87)	L: 6.07 ± 1.25 (4.03–9.00) R: 6.10 ± 1.17 (4.26–8.50)	5.93± 0.74 (4.72–7.35)	-	-
NT	2.63 ± 0.48 (1.79–4.09)	L: 2.99 ± 0.96 (1.50-5.50) R: 3.24 ± 0.93 (1.64–5.00)	1.75 ± 0.39 (1.11–2.44)	2.21± 0.34 (1.59–3.04)	-
IP	11.71 ± 1.00 (9.31–15.13)	L: 11.97 ± 1.11 (9.32–14.2) R: 12.50 ± 0.89 (9.77–14.46)	12.61 ± 1.11 (10.33–14.09)	10.89 ±1.08 (13.04–9.22)	-
Tendon length (cm)					
Single incision technique	3.90 ± 1.09 (1.50–7.10)	-	5.75 ± 0.63 (4.52–6.86)	5.08 ± 1.09 (3.32–10.35)	5.16 ± 1.29 (3.4–6.9)
Double incision technique	7.34 ± 0.99 (5.40–9.50)	-	7.03 ± 0.86 (5.77–8.80)	6.72 ± 1.02 (4.69–12.09)	8.09 ± 1.63 (5.1–11.1)
Minimally invasive technique	19.80 ± 1.39 (17.40–24.00)	-	20.22 ± 1.32 (16.82–21.97)	17.49 ± 1.80 (13.51–20.52)	-

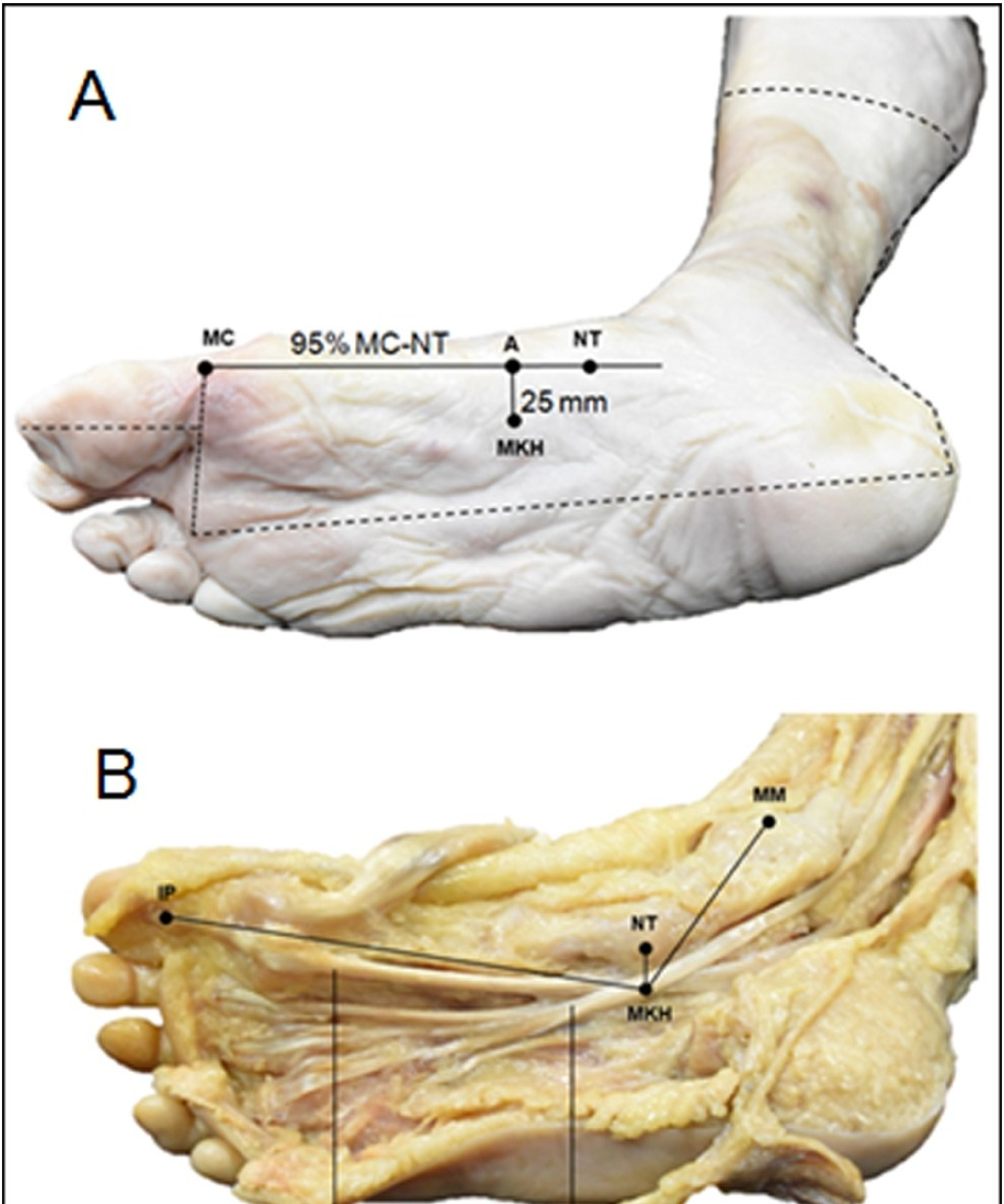
FHL= Flexor hallucis longus, IP= first interphalangeal joint of great toe,L= left, MKH= Master knot of Henry, MM=medial malleolus,NT= navicular tuberosity, R= right

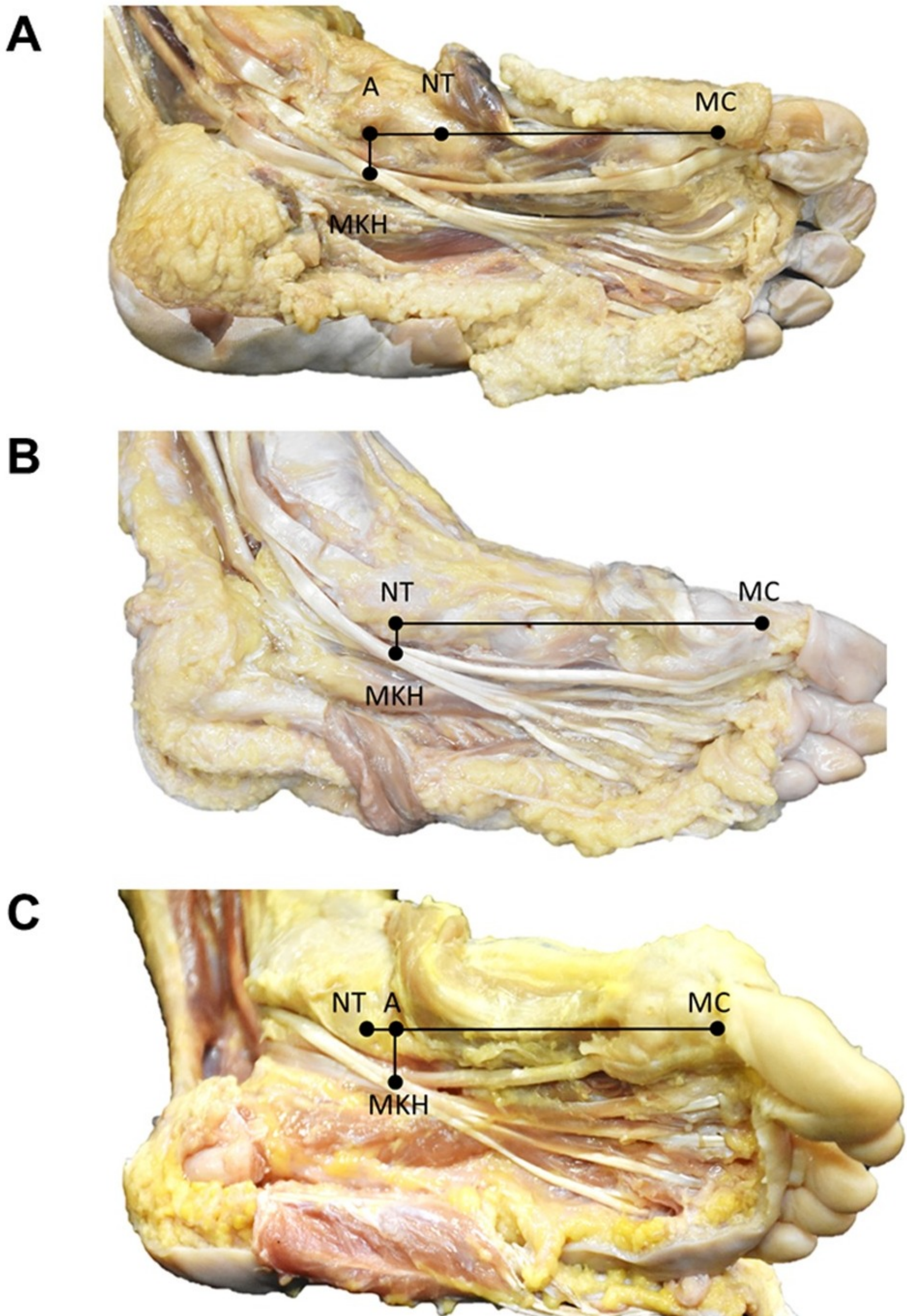
Figure 1. Photographs of plantar surface of right foot showing the skin incision and surface landmark of MKH; A. Skin incision line (dot line), the line joining between the medial end of plantar flexion crease at the base of the great toes (MC) and the most prominent point of navicular tuberosity (NT) (MC-NT line), the surface location of MKH on MC-NT line**;** B. The distance from MKH to the most prominent point of medial malleolus (MM), navicular tuberosity (NT) and first interphalangeal joint (IP); A= the perpendicular point of MKH on MC-NT line; FDL=flexor digitorum longus; FHL=flexor hallucis longus; MKH= master knot of Henry.

Figure 2. Photographs of plantar surface of left feet showing the surface location of MKH on MC-NT line (point A); A. Posterior to NT; B. At NT; C. Anterior to NT; A = the perpendicular point of MKH on MC-NT line; MC=medial end of plantar flexor crease at the base of great toe; MKH= master knot of Henry, NT= navicular tuberosity.

Figure 3. Photograph of plantar surface right foot showing the distance between MKH and the midpoint of LPNVB; LPNVB=lateral plantar neurovascular bundle; MKH= master knot of Henry; MNVB= medial plantar neurovascular bundle.

Figure 4. Photographs of plantar surface right foot showing the distances between MTJ of FHL and IP, MKH, ST; A. In situ tendon length; B. Ex vivo tendon length; MKH=master knot of Henry; MTJ= musculotendinous junction; IP= first interphalangeal joint; ST=sustentaculum tali.


A
MC
95% MC-NT
A
NT
25 mm
MKH
B
MM
IP
NT
MKH
FHL tendon
FDL tendon


A
A
NT
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MKH
B
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C
NT
A
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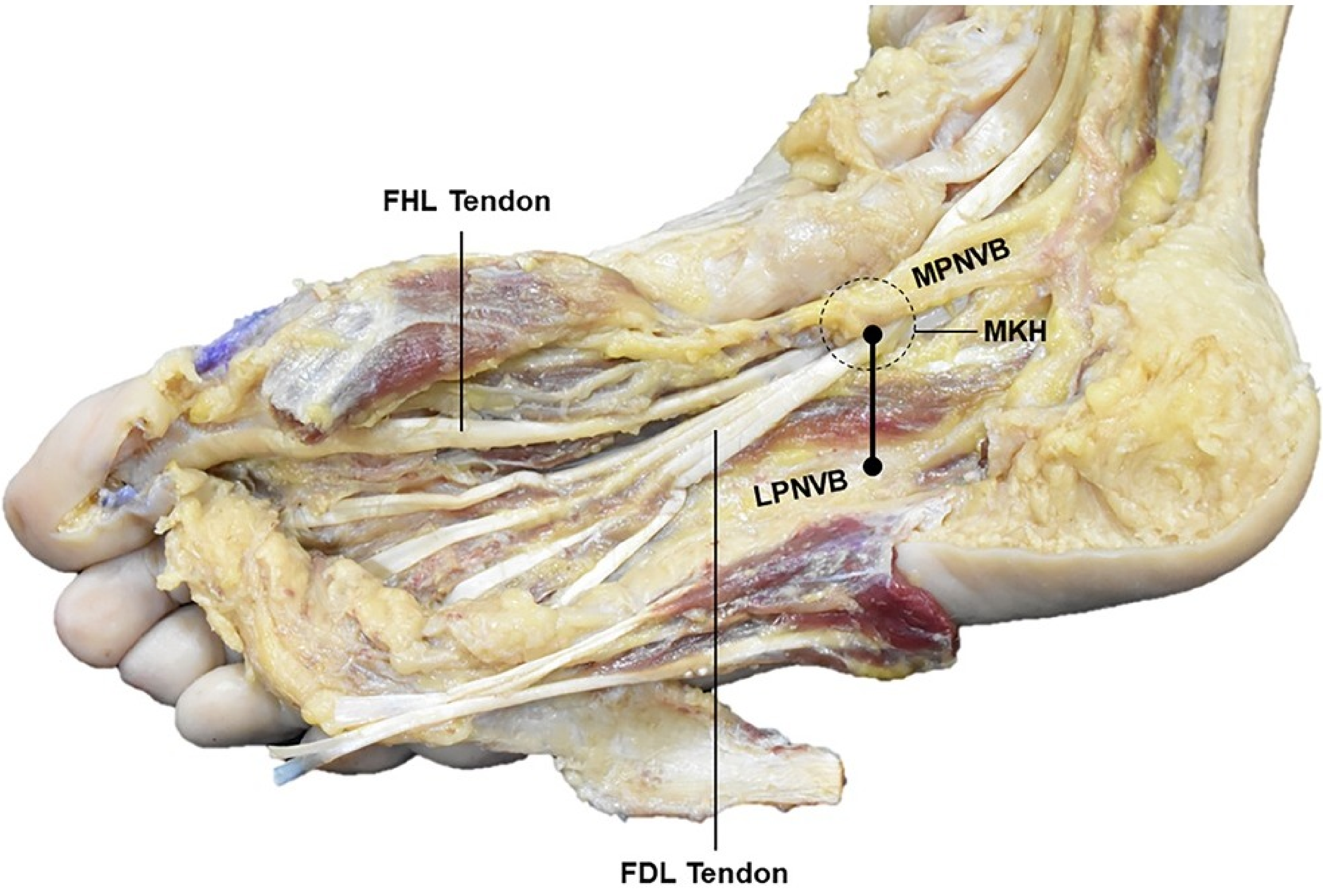
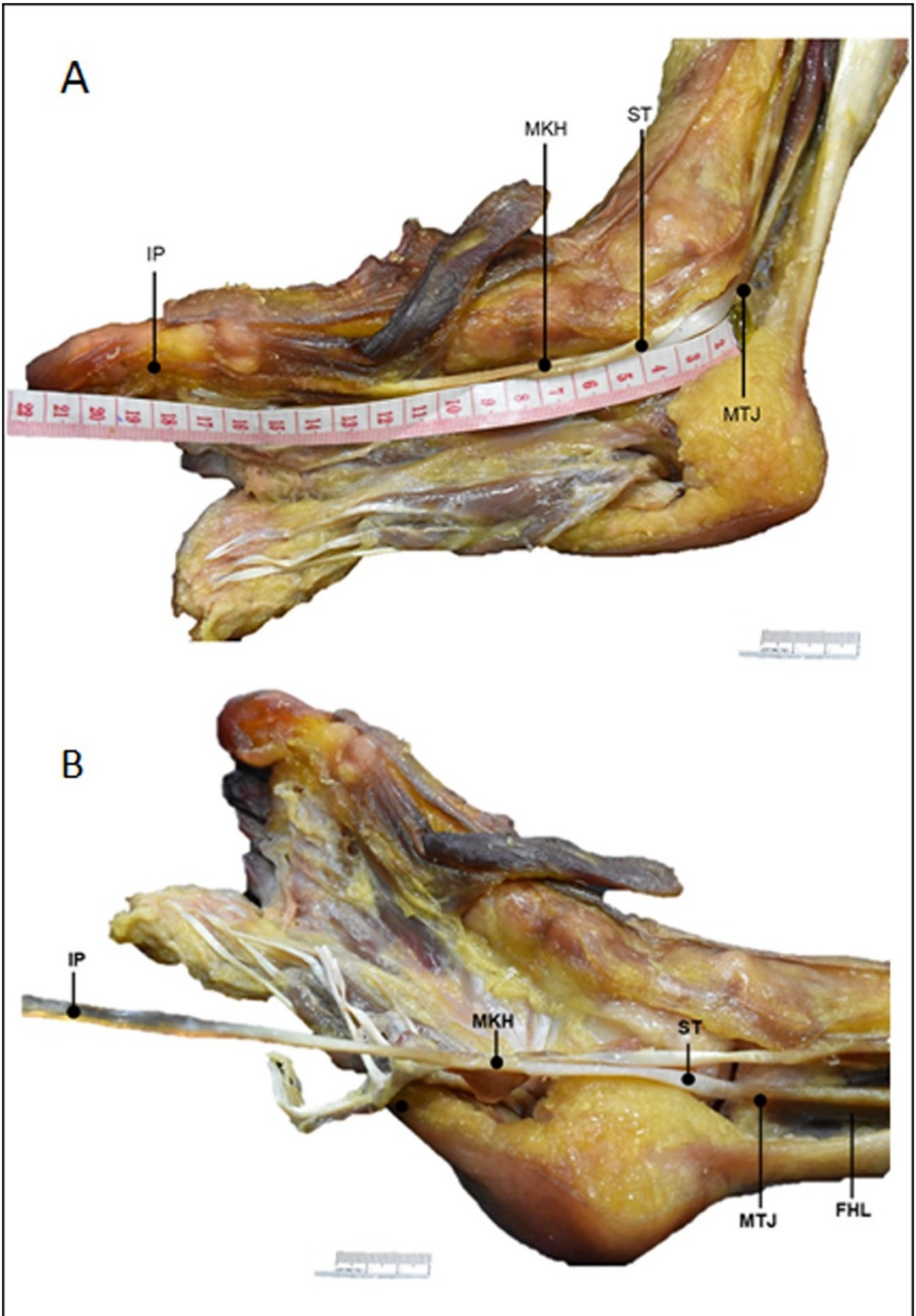
MKH


FHL Tendon
MPNVB
MKH
LPNVB
FDL Tendon


A
MKH
ST
IP
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B
IP
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ST
MTJ
FHL