Int. J. Morphol.,
44(2):414-419, 2026.

Applied Anatomy and Sex- and Side-Related Differences of the Flexor Hallucis Longus Tendon: A Cadaveric Study

Anatomía Aplicada y Diferencias Relacionadas con el Sexo y el Lado del Tendón del Músculo Flexor Largo del Hálux: Un Estudio Cadavérico

Truong Thanh Dinh[1] & Thi Cao[2]

THANH DINH, T. & CAO, T. Applied anatomy and sex- and side-related differences of the flexor hallucis longus tendon: A cadaveric study. *Int. J. Morphol., 44(2)*:414-419, 2026.

SUMMARY: The purpose of this study was to describe the applied anatomy of the flexor hallucis longus tendon and evaluate differences between sexes and sides, as well as the influence of foot length. Thirty lower limbs from fifteen Vietnamese cadavers were dissected. Measurements included distances from the master knot of Henry to anatomical landmarks, tendon dimensions, intertendinous slips, branching patterns, and tendon length obtained using different harvesting techniques. The master knot of Henry was located 5.8 cm from the medial malleolus, 2.6 cm from the navicular tuberosity, and 11.8 cm from the interphalangeal joint. The mean distance to the medial plantar neurovascular bundle was 3.8 mm. Slips between the flexor hallucis longus and flexor digitorum longus tendons were Type 1 in 83.3 % and Type 5 in 16.7 % of specimens, and branching patterns were Type 2 in 60 %. Tendon length was 3.8 cm with the single-incision technique, 5.9 cm with the double-incision technique, and 18.0 cm with the minimally invasive technique. Tendon length was significantly greater in males than in females, except for the segment from the musculotendinous junction to the interphalangeal joint, and no differences were observed between sides. The flexor hallucis longus tendon showed consistent anatomical relationships with surrounding landmarks and neurovascular structures, with sex-related differences in tendon length and no significant effect of laterality.

KEY WORDS: Flexor hallucis longus; Tendon transfer; Foot; Flexor digitorum longus; Cadaver.

INTRODUCTION

Flexor hallucis longus tendon (FHLt) transfer is a valuable procedure in the management of chronic calcaneal tendon (Achilles tendon) rupture, calcaneal tendinopathy, and adult acquired flatfoot deformity (Den Hartog, 2003; Tashjian *et al*., 2003; Lui, 2015). Anatomical studies highlight the consistent intertendinous slips between FHLt and the flexor digitorum longus tendon (FDLt) at the master knot of Henry (MKH), first described by Henry (1957). These slips preserve residual toe flexion after harvest. Tendon length is crucial for surgical success. Insufficient length may compromise fixation, whereas excessive harvesting may cause donor morbidity (Wong & Ng, 2005). Previous reports demonstrate population-specific variations, yet sex- and side-related differences remain underexplored, and data from Vietnamese cadavers are lacking. This study aimed to (1) describe the applied anatomy of the FHLt, including morphometric parameters, anatomical relationships, and tendon morphology, (2) evaluate sex- and side-related differences, and (3) assess the effect of foot length on tendon length.

MATERIAL AND METHOD

Thirty lower limbs from fifteen cadavers, including seven male and eight female cadavers, were dissected, yielding 14 male limbs and 16 female limbs. The research project was approved by the Bioethics Commission of the University of Medicine and Pharmacy at Ho Chi Minh City, Vietnam, under approval number 122/HDDD-DHYD dated 17 February 2021. After dissection revealed the master knot of Henry (MKH), its location was determined by measuring the distances from the MKH to the following anatomical landmarks, namely the medial malleolus (MM), navicular tuberosity (NT), and first interphalangeal joint

[1] Thu Duc General Hospital, Ho Chi Minh City, Vietnam.
[2] Department of Orthopaedics and Rehabilitation, School of Medicine, University of Medicine and Pharmacy at Ho Chi Minh City, Ho Chi Minh City, Vietnam.

Received: 2025-10-15 Accepted: 2026-02-12

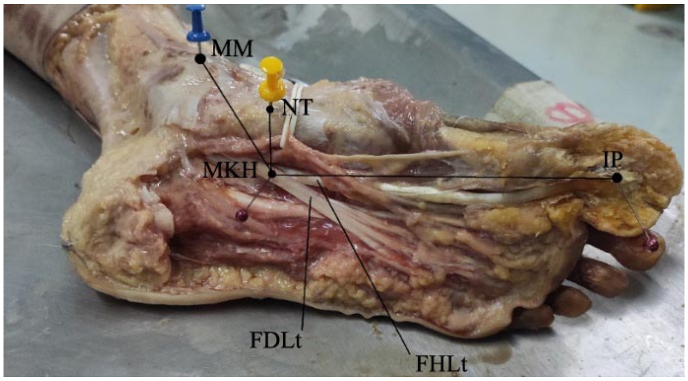

Fig. 1. Distance from the master knot of Henry (MKH) to anatomical landmarks. MKH: master knot of Henry; FHLt: flexor hallucis longus tendon; FDLt: flexor digitorum longus tendon; MM: medial malleolus; NT: navicular tuberosity; IP: interphalangeal joint of the hallux.

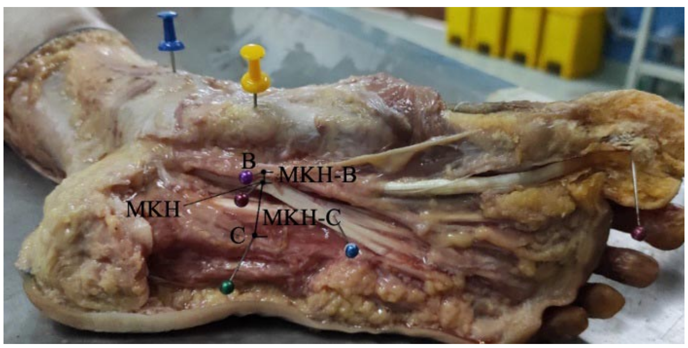

Fig. 2. Distance from the master knot of Henry (MKH) to the medial plantar neurovascular bundle (MKH–B) and to the lateral plantar neurovascular bundle (MKH–C). MKH: master knot of Henry; B: medial plantar neurovascular bundle; C: lateral plantar neurovascular bundle.

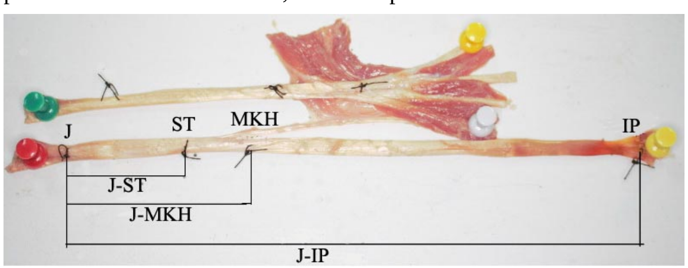

Fig. 3. Measurement of distances and dimensions on the flexor hallucis longus tendon (FHLt). J: musculotendinous junction; ST: sustentaculum tali; MKH: master knot of Henry; IP: interphalangeal joint of the hallux; J–ST: distance from J to ST; J–MKH: distance from J to MKH; J–IP: distance from J to IP.

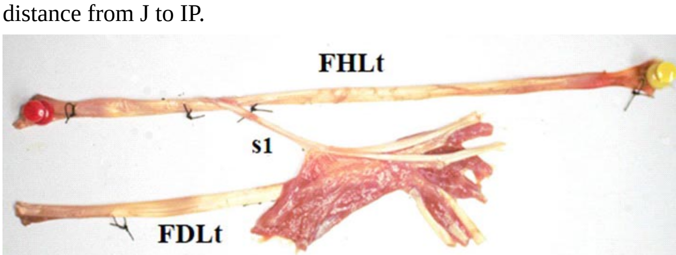

Fig. 4. Intertendinous slip from the flexor hallucis longus tendon (FHLt) to the flexor digitorum longus tendon (FDLt) (Type 1). S1: slip from FHLt to FDLt.

(IP) (Fig. 1) The distance from the MKH to the medial plantar neurovascular bundle (MPNVB) was recorded as MKH–B, and the distance from the MKH to the lateral plantar neurovascular bundle (LPNVB) was recorded as MKH–C (Fig. 2). The distance from the MKH to the medial plantar neurovascular bundle (MPNVB) was recorded as MKH–B, and the distance from the MKH to the lateral plantar neurovascular bundle (LPNVB) was recorded as MKH–C (Fig. 2).

The landmarks on the FHLt were marked, after which the tendon was sectioned, fixed to a plastic board, and its length was measured according to each tendon-harvesting technique. In the single-incision technique, one incision was made at the posterior ankle, and the harvested tendon reached the sustentaculum tali (ST). Tendon length in this technique was measured from the musculotendinous junction (J) to the ST. In the double-incision technique, one incision was made at the posterior ankle and another on the plantar aspect of the foot, allowing the tendon to be harvested to the region of the crossing point. The tendon length in this technique was measured from J to the MKH. In the minimally invasive technique, an incision was made at the posterior ankle together with a small incision at the interphalangeal joint, and the tendon length was measured from J to the IP. The width and thickness of the tendon were measured at the level of the sustentaculum tali (Fig. 3).

Finally, the characteristics of the intertendinous slips were determined according to Beger's classification (Beger *et al*., 2018), and the slip characteristics were recorded (Fig. 4). Thirty lower limbs from fifteen cadavers, including seven male and eight female cadavers, were dissected, yielding 14 male limbs and 16 female limbs.

The research project was approved by the Bioethics Commission of the University of Medicine and Pharmacy at Ho Chi Minh City, Vietnam, under approval number 122/HDDD-DHYD. After dissection revealed the master knot of Henry (MKH), its location was determined by measuring the distances from the MKH to the following anatomical landmarks, namely the medial malleolus (MM), navicular tuberosity (NT), and first interphalangeal joint (IP) (Fig. 1). The distance from the MKH to the medial plantar neurovascular bundle (MPNVB) was recorded as MKH–B, and the distance from the MKH to the lateral plantar neurovascular bundle (LPNVB) was recorded as MKH–C (Fig. 2).

The landmarks on the FHLt were marked, after which the tendon was sectioned, fixed to a plastic board, and its length was measured according to each tendon-harvesting technique. In the single-incision technique, one incision was made at the posterior ankle, and the harvested tendon reached the sustentaculum tali (ST). Tendon length in this technique was measured from the musculotendinous junction (J) to the ST. In the double-incision technique, one incision was made at the posterior ankle and another on the plantar aspect of the foot, allowing the tendon to be harvested to the region of the crossing point. The tendon length in this technique was measured from J to the MKH. In the minimally invasive technique, an incision was made at the posterior ankle together with a small incision at the interphalangeal joint, and the tendon length was measured from J to the IP. The width and thickness of the tendon were measured at the level of the sustentaculum tali (Fig. 3). Finally, the characteristics of the intertendinous slips were determined according to Beger's classification (Beger *et al*., 2018), and the slip characteristics were recorded (Fig. 4).

Descriptive statistics were calculated for all variables. Independent t-tests were used to compare male and female specimens as well as left and right limbs. Pearson correlation analysis assessed the relationships between foot length and tendon length. Analysis of covariance was performed to evaluate the independent effect of sex after adjustment for foot length. A p-value less than 0.05 was considered statistically significant.

RESULTS

A total of 30 lower limb specimens from 15 fresh frozen cadavers were analyzed, including 14 male limbs and 16 female limbs. The mean age was 72.9 ± 13.6 years.

- The average foot length of the study sample was 20.5 ± 1.1 cm and the differences between men and women and between right and left limbs were not statistically significant (p > 0.05).

- Distances from the MKH to anatomical landmarks and to the medial and lateral plantar neurovascular bundles were presented in Table I.

Table I. Distances from MKH to anatomical landmarks and neurovascular bundles.

Distance	Mean ± SD	Min	Max
MKH – MM (cm)	5.8 ± 0.6	4.8	7.1
MKH – NT (cm)	2.6 ± 0.3	2.1	3.3
MKH – IP (cm)	11.8 ± 0.7	10.5	13.0
MKH – MPNVB (mm)	3.8 ± 1.7	0	8.4
MKH – LPNVB (mm)	15.8 ± 3.1	10.4	22.1

Table II. FHL tendon dimensions and morphology.

Measurement	Mean ± SD	Range
J–ST (cm)	3.8 ± 1.0	2.2 – 5.8
J–MKH (cm)	5.9 ± 1.0	4.1 – 7.9
J–IP (cm)	18.0 ± 1.5	15.1 – 20.5
Width at ST (mm)	5.7 ± 0.7	4.1 – 7.2
Thickness at ST (mm)	2.4 ± 0.5	1.2 – 3.2

- The distances from the J point to ST, MKH, and IP, as well as the width and thickness of the FHLt, were presented in Table II.

- The relation between the FHLt and the FDLt at the sole of the foot showed Type 1 in 83.3 % (25/30) and Type 5 in 16.7 % (5/30), while Types 2, 3, 4, 6, and 7 were not observed (Fig. 5).

- Slips from the FHLt were distributed as Type 1 to the second toe only in 30 % (9/30), Type 2 to the second and third toes in 60 % (18/30), and Type 3 to the second, third, and fourth toes in 10 % (3/30) (Fig. 6), while no specimens showed Type 4.

- The distribution of slip Types between males and females was as follows: in males, Type 1 accounted for 71.4 % (10/14) and Type 5 for 28.6 % (4/14), whereas in females, Type 1 accounted for 93.8 % (15/16) and Type 5 for 6.3 % (1/16).

- In right limbs, Type 1 accounted for 86.7 % (13/15) and Type 5 for 13.3 % (2/15), whereas in left limbs, Type 1 accounted for 80 % (12/15) and Type 5 for 20 % (3/15).

- Tendon length by sex, side, and ANCOVA analysis are shown in Table III.

Table III. Comparison of tendon length by sex, side, and ANCOVA analysis

Variable	Male (cm)	Female (cm)	p (Sex)	p (Side)	ANCOVA (Sex/Foot length)
Foot length	20.7 ± 1.0	20.4 ± 0.8	0.60	0.74	-
J–ST	4.2± 1.0	3.4 ± 0.8	0.03*	0.79	Sex p=0.036, Foot p=0.24
J–MKH	6.4 ± 1.0	5.5 ± 0.8	0.01*	0.79	Sex p=0.013, Foot p=0.21
J–IP	18.8 ± 1.3	17.3 ± 1.2	0.003*	0.86	Sex p=0.0008, Foot p=0.0001*

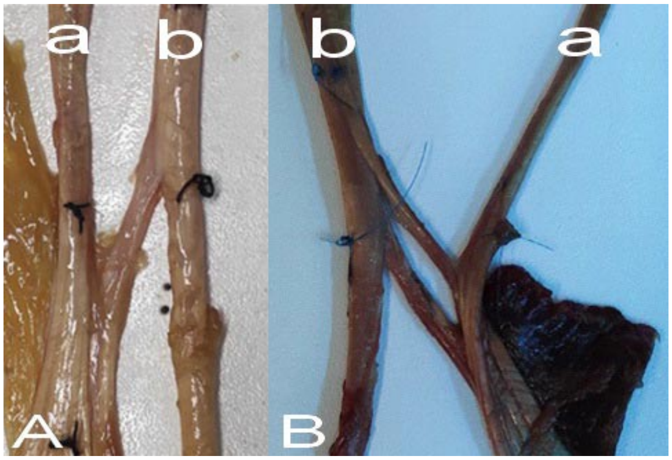

Fig. 5. Two Types of intertendinous slips observed in the study: Type 1 (A) and Type 5 (B). a: flexor digitorum longus tendon (FDLt); b: flexor hallucis longus tendon (FHLt).

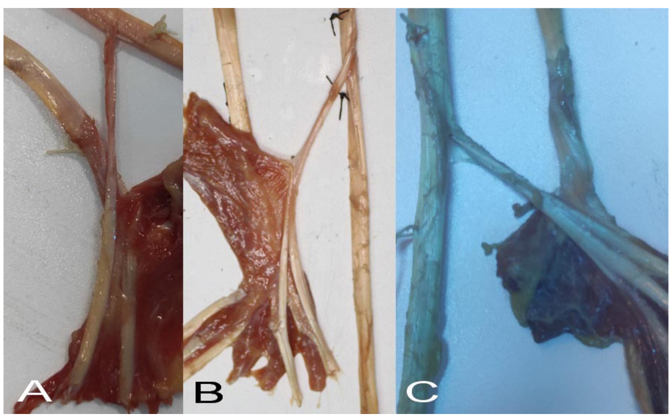

Fig. 6. Three types of slips from FHLt: Type 1 (A) (30 %), Type 2 (B) (60 %), and Type 3 (C) (10 %).

DISCUSSION

This cadaveric study provides a comprehensive anatomical description of the FHLt and its clinical implications. The MKH was consistently identified relative to bony landmarks and close to the medial plantar neurovascular bundle, underscoring surgical risks.

Our findings on MKH localization and its proximity to the medial plantar neurovascular bundle are consistent with those reported by Wan-Ae-Loh *et al*. (2021). Currently, when harvesting tendons around the MKH, surgeons usually use two incisions: a direct plantar incision or an internal incision along the medial midfoot (Tashjian *et al*., 2003; Amlang *et al*., 2012). Because the medial plantar neurovascular bundle is located near, and sometimes coincides with, the MKH point, a direct plantar incision offers a clearer view for protecting the bundle, whereas a medial incision provides easier access to the FHLt and FDLt when the MPNVB is retracted downward. The direct plantar approach allows a wider field for visualizing the FHLt to obtain optimal length.

Several authors have reported the presence of connections between the FHLt and FDLt. Mulier *et al*. (2007), LaRue & Anctil (2006) and Vasudha *et al*. (2019) found rare cases lacking intertendinous connections (Type 4), while Mulier *et al*. (2007), LaRue & Anctil (2006) and Plaass *et al*. (2013) described frequent bidirectional slips (Type 2). O'Sullivan *et al*. (2005) also noted slips from FDLt to FHLt (Type 3). Based on these findings, some authors hypothesized that preserving these slips could maintain great toe flexion even without suturing the distal FHLt to the FDLt (Edama *et al*., 2016). In contrast, in our series, all specimens exhibited unidirectional slips from FHLt to FDLt only. These findings suggest that suturing the distal end of the FHLt to the FDLt to preserve great toe flexion and prevent imbalance of the forefoot after tendon harvest.

In this study, slips from the FHLt to the second and third toes accounted for the highest proportion, followed by those to the second toe, and then to the second through fourth toes. No cases of slips extending to all four lesser toes were observed in our dissections. These findings indicate that distal flexion of the second and third toes are commonly supported by the FHLt slip. Consequently, during FDLt harvesting, flexion of toes 2 and 3 may be preserved through this branch, whereas FHLt harvesting without preserving the slip could reduce flexion force in these toes. Our unadjusted analysis showed that males had significantly longer FHLt than females at all levels (Table II). However, ANCOVA demonstrated that tendon length in the distal segment (J–IP) was influenced by both sex and foot length, whereas sex independently affected the proximal and mid-segments (J–ST and J–MKH) (Table III). No side-to-side differences were observed, suggesting that either limb can be safely selected for tendon harvest. In the present study, the mean tendon width and thickness at the level of the sustentaculum tali were 5.7 mm and 2.4 mm, respectively. These dimensions indicate that the FHLt provides sufficient graft size for reconstructive procedures.

The mean tendon lengths increased progressively with more distal harvesting techniques, consistent with the findings of Beger *et al*. (2018), and Wan-Ae-Loh *et al*. (2021). This confirms the importance of selecting the harvesting method according to the required graft length andclinical indication. Furthermore, the predominance of slip Type 1 (83.3 %) over Type 5 (16.7 %) reinforces the anatomical basis that the FHLt contributes to flexion of the second toe through a unidirectional slip to the FDLt. This pattern helps preserve partial digital flexion after tendon harvest and explains the low risk of postoperative weakness reported in clinical series using distal FHLt transfers. These findings align with Park *et al*. (2022), who reported that absolute tendon lengths were greater in males but normalized when adjusted for foot length, and no laterality differences were observed. This suggests that larger foot size in males partly explains the longer distal tendon lengths, whereas intrinsic sex-related morphological factors may contribute to the proximal tendon length differences. The lack of laterality difference supports the assumption that either limb can be harvested safely, consistent with Park *et al*. (2022) and Mao *et al*. (2017). These data strengthen the anatomical rationale for graft planning and preoperative estimation of tendon length, especially in female patients with smaller feet. Compared with Turkish (Beger *et al*., 2018), Thai (Wan-Ae-Loh *et al*., 2021), and Indian (Vasudha *et al*., 2019) populations, our results demonstrate consistent anatomy but highlight the importance of considering sex-related variations. Clinically, surgeons should anticipate shorter grafts in female patients, particularly when distal tendon length is required.

This study has some limitations. The sample size was small and limited to elderly Vietnamese cadavers, which may not represent younger or other populations. Measurements on cadaveric tissue may differ from in vivo conditions due to loss of elasticity and altered spatial relations. In addition, the study lacked radiological and intraoperative validation.

CONCLUSION

The flexor hallucis longus tendon shows consistent anatomical dimensions and predictable relations to neighboring structures. Males have longer tendons than females, independent of foot length proximally but dependent on foot length distally. No differences are found between left and right sides. These findings provide valuable anatomical data to guide safe and effective FHLt transfer.

ACKNOWLEDGMENTS

The authors would like to thank the Department of Anatomy, University of Medicine and Pharmacy at Ho Chi Minh City, for providing facilities and cadaveric specimens for this study. The authors also gratefully acknowledge the body donors and their families for their invaluable contribution to anatomical research and education.

Conflicts of interest. The authors declare no conflicts of interest.

THANH DINH, T. & CAO, T. Anatomía aplicada y diferencias relacionadas con el sexo y el lado del tendón del músculo flexor largo del hálux: Un estudio cadavérico. *Int. J. Morphol., 44(2)*:414-419, 2026.

RESUMEN: El objetivo de este estudio fue describir la anatomía aplicada del tendón flexor largo del hálux y evaluar las diferencias entre sexos y lados, así como la influencia de la longitud del pie. Se disecaron 30 miembros inferiores de 15 cadáveres de individuos vietnamitas. Las mediciones incluyeron distancias desde el cruzamiento en la planta del pie de los tendones de los músculos flexores largos del hálux y de los dedos (nudo maestro de Henry) hasta puntos de referencia anatómicos, dimensiones del tendón, fascículos intertendinosos, patrones de ramificación y longitud del tendón obtenida mediante diferentes técnicas de extracción. El cruzamiento de los tendones de los músculos flexores largos del hálux y de los dedos se localizó a 5,8 cm del maléolo medial, a 2,6 cm de la tuberosidad del hueso navicular y a 11,8 cm de la articulación interfalángica. La distancia media al fascículo neurovascular plantar medial fue de 3,8 mm. Los deslizamientos entre los tendones del músculo flexor largo del hálux y del músculo flexor largo de los dedos fueron de tipo 1 en el 83,3 % y de tipo 5 en el 16,7 % de las muestras, y los patrones de ramificación fueron de tipo 2 en el 60 %. La longitud del tendón fue de 3,8 cm con la técnica de incisión única, de 5,9 cm con la técnica de doble incisión y de 18,0 cm con la técnica mínimamente invasiva. La longitud del tendón fue significativamente mayor en hombres que en mujeres, excepto en el segmento desde la unión musculotendinosa hasta la articulación interfalángica, y no se observaron diferencias entre ambos lados. El tendón del flexor largo del hálux mostró relaciones anatómicas consistentes con las estructuras neurovasculares y los puntos de referencia circundantes, con diferencias en la longitud del tendón relacionadas con el sexo y sin un efecto significativo de la lateralidad.

PALABRAS CLAVE: Flexor largo del háux; Transferencia de tendón; Pie; Flexor largo de los dedos; Cadáver.

REFERENCES

Amlang, M.; Rosenow, M. C.; Friedrich, A.; Zwipp, H. & Rammelt, S. Direct plantar approach to Henry's knot for flexor hallucis longus transfer. *Foot Ankle Int., 33(1)*:7-13, 2012.

Beger, O.; Elvan, Ö.; Keskinbora, M.; Ün, B.; Uzmansel, D. & Kurtoglu, Z. Anatomy of master knot of Henry: a morphometric study on cadavers. *Acta Orthop. Traumatol. Turc., 52(2)*:134-42, 2018.

Den Hartog, B. D. Flexor hallucis longus transfer for chronic Achilles tendonosis. *Foot Ankle Int., 24(3)*:233-7, 2003.

Edama, M.; Kubo, M.; Onishi, H.; Takabayashi, T.; Yokoyama, E.; Inai, T.; Watanabe, H.; Nashimoto, S. & Kageyama, I. Anatomical study of toe flexion by flexor hallucis longus. *Ann. Anat., 204*:80-5, 2016.

Henry, A. K. *Extensile Exposure*. 2nd ed. Edinburgh & London, E. & S. Livingstone Ltd., 1957. pp.300-4.

LaRue, B. G. & Anctil, E. P. Distal anatomical relationship of the flexor hallucis longus and flexor digitorum longus tendons. *Foot Ankle Int., 27(7)*:528-32, 2006.

Lui, T. H. Endoscopic-assisted flexor hallucis longus transfer: harvest of the tendon at zone 2 or zone 3. *Arthrosc. Tech., 4(6)*:e811-e814, 2015.

Mao, H.; Dong, W.; Shi, Z.; Yin, W.; Xu, D. & Wapner, K. L. Anatomical study of the neurovascular in flexor hallucis longus tendon transfers. *Sci. Rep., 7(1)*:14202, 2017.

Mulier, T.; Rummens, E. & Dereymaeker, G. Risk of neurovascular injuries in flexor hallucis longus tendon transfers: an anatomic cadaver study. *Foot Ankle Int., 28(8)*:910-15, 2007.

O'Sullivan, E.; Carare-Nnadi, R.; Greenslade, J. & Bowyer, G. Clinical significance of variations in the interconnections between flexor digitorum longus and flexor hallucis longus in the region of the knot of Henry. *Clin. Anat., 18(2)*:121-5, 2005.

Park, K. R.; Park, W. J.; Lee, S. W.; Kim, H.; Lee, H. & Lee, J. H. A simple method to locate the master knot of Henry using the correlation between the flexor tendon length parameter and the foot length. *Int. J. Environ. Res. Public Health, 19(4)*:2281, 2022.

Plaass, C.; Abuharbid, G.; Waizy, H.; Ochs, M.; Stukenborg-Colsman, C. & Schmiedl, A. Anatomical variations of the flexor hallucis longus and flexor digitorum longus in the chiasma plantare. *Foot Ankle Int., 34(11)*:1580-7, 2013.

Tashjian, R. Z.; Hur, J.; Sullivan, R. J.; Campbell, J. T. & DiGiovanni, C. W. Flexor hallucis longus transfer for repair of chronic Achilles tendinopathy. *Foot Ankle Int., 24(9)*:673-6, 2003.

Vasudha, T. K.; Vani, P. C.; Sankaranarayanan, G.; Rajasekhar, S. S. S. N. & Dinesh Kumar, V. Communications between the tendons of flexor hallucis longus and flexor digitorum longus: a cadaveric study. *Surg. Radiol. Anat., 41(12)*:1411-9, 2019.

Wan-Ae-Loh, P.; Danginthawat, P.; Huanmanop, T.; Agthong, S. & Chentanez, V. Surface localisation of master knot of Henry, in situ and ex vivo length of flexor hallucis longus tendon: pertinent data for tendon harvesting and transfer. *Folia Morphol. (Warsz), 80(2)*:415-24, 2021.

Wong, M. W. & Ng, V. W. Modified flexor hallucis longus transfer for Achilles insertional rupture in elderly patients. *Clin. Orthop. Relat. Res., (431)*:201-6, 2005.

Corresponding author:
Thi Cao
University of Medicine and Pharmacy at Ho Chi Minh City
Department of Orthopaedics and Rehabilitation
School of Medicine
217 Hong Bang Street
Ward Cho Lon
Ho Chi Minh City 70000
VIETNAM

E-mail: caothibacsi@ump.edu.vn

ORCID ID: 0000-0001-7961-4707