Ultrasonographic test for detecting the chiasma plantare formation between the flexor hallucis longus and flexor digitorum longus

Daisuke Bai[1,2] • Hiroaki Kurokawa[2,3] • Shigeki Morita[2,3] • Takuma Miyamoto[2,3] • Pasuk Mahakknaukrauh[4] • Yasuhito Tanaka[2,3]

[1] Department of Rehabilitation, Heisei Memorial Hospital, 827, Shijyocho, Kashihara, Nara, 634-0813, Japan

[2] Graduate School of Medicine, Musculoskeletal Reconstructive Surgery, Nara Medical University, Nara, Japan

[3] Department of Orthopedic Surgery, Nara Medical University, Nara, Japan

[4] Department of Anatomy, Faculty of Medicine, Chiang Mai University, Chiang Mai, Thailand

Corresponding author: Daisuke Bai

E-mail: h1371019@kio.ac.jp

Abstract

Purpose Flexor hallucis longus (FHL) and flexor digitorum longus (FDL) tendons are frequently used in surgery. Therefore, it is necessary to evaluate the chiasma plantare formation preoperatively. The development of ultrasonography (US) may help the chiasma plantare formation evaluation. The purpose of this study is to prove usefulness of the US method using cadavers.

Methods Eleven cases (twenty-two ankles) were obtained from Asian adult cadavers. At first, we evaluated and compared the chiasma plantare formation using US. Later, we evaluated that using the findings after dissection as type A (connection from FHL to FDL of the second toe), type B (connection from FHL to the second and third toes), type C (connection from FHL to the second through fourth toes), or type D (connection from FHL to all lesser toes).

Results Chiasma plantare formation was classified as types A and B in fifteen and seven ankles, respectively. After dissection, chiasma plantare formation was classified as types A, B, and C in fourteen, six, and two ankles respectively. Therefore, there was an 86% similarity between the two methods.

Conclusion Chiasma plantare formation can be reliably and noninvasively evaluated using US. This may be useful for preoperative rehabilitation or surgical procedure planning.

Keywords Chiasma plantare・Flexor hallucis longus・Flexor digitorum longus・Ultrasonography

Introduction

The flexor hallucis longus (FHL) and flexor digitorum longus (FDL) muscles are two of the four muscles that mainly compose the deep posterior compartment of the lower limb. These muscles are involved in the great toe and plantar flexion [2]. The longitudinal arch of the foot, which is important for walking and maintenance of balance is supported by toe flexors [4,5,8]. Additionally, it is necessary for the windlass mechanism, which supports the rigid supination of the foot during push-off, enabling smooth progression of the body during walking [4].

The chiasma plantare (or knot of Henry) was first identified as referring to the intersection territory, where the tendon of FDL crosses over the tendon of FHL [1,12]. The chiasma plantare (or knot of Henry) has been widely used as a surgical landmark during the tendon graft harvesting [1,3,7]. And The tendons of FHL and FDL muscles are used for tendon transfers in foot and ankle surgeries [3,7,10,12]. The chiasma plantare is the narrow space between the anatomical crossing of the FHL and FDL tendons [3,6,7,10-12]. Previous reports have described the formation of the chiasma plantare at the knot of Henry. Several anatomical variations have been reported in the chiasma plantare. Mulier [9] reported that no connection is observed between the FHL and FDL tendons in 13% of feet. In contrast, Edama [2] reported that chiasma plantare types A (connection from the FHL to the FDL of the second toe), B (connection from the FHL to the second and third toes), C (connection from the FHL to the second, third, and fourth toes), and D (connection from the FHL to all lesser toes) were observed in 37%, 54%, 9%, and 0%, respectively of all Asian cadavers evaluated in their study. Therefore, it is necessary to develop a simple and convenient method for preoperative evaluation of chiasma plantare formation. Accurate preoperative evaluation of chiasma plantare formation and tendon graft length (long or short) is important for safe harvesting of tendon grafts [7,12]. Moreover, knowledge of tendon interconnections is essential for surgeons to make the decision for harvesting the tendon or not and to minimize postoperative functional loss (for example, the causes of loss of toe functions) [12]. The most reports about chiasma plantare were cadaveric study. Therefore, a less invasive or non-invasive method is necessary for preoperative evaluation of chiasma plantare formation to perform optimal surgeries and provide appropriate physiotherapy.

In recent years, we could evaluate each muscle quantitatively by using ultrasonography (US). Interestingly, the FHL and FDL muscles can be measured at the lower calf center [13]. Therefore, we devised a US method for detecting the chiasma. Our aim was to prove usefulness of the US method using cadavers. At first, the chiasma plantare was evaluated with US and, subsequently, in dissected cadavers. Finally, we compared the results of US and those after dissection.

Material and methods

Eleven cases (twenty-two ankles) were obtained from adult Asian cadavers (nine men and two woman) and fixed in 10% formalin solution before examination as described by previous studies [2]. The mean age at death was 70±9.4 years (51–87). The cadavers were donated to our department's anatomy program. The inclusion criteria were 1) sufficient specimen quality and 2) lack of evidence of surgical intervention in the examined area, which was needed to allow complete identification of the tendon insertion. The formation of the chiasma plantare in the FHL and FDL was evaluated by using US; subsequently, the findings in each cadaver after dissection were evaluated and compared.

The right and left lower limbs of the cadavers were examined using the LOGIQ F8 expert system (GE Healthcare, Boston, MA, USA) with a 10-MHz linear probe. Based on the previous study [13], measurement was conducted with subjects in the prone position with hips and knees extended and the FHL and FDL were evaluated at locations approximately 40% proximal from the lateral malleolus to the fibular head (Figure 1), respectively. This location was identified by confirming movement of muscle fibers in a B-mode ultrasound image during passive movement of the ankle or toes. During examination, the same standardized positioning of the cadavers and the transducer exact location were carefully maintained. To improve acoustic coupling, a water-soluble transmission gel was applied to the scanning device head. The transducer was held perpendicular to the skin’s surface using the minimum pressure required to achieve a clear image (Figure 2). To evaluate the chiasma plantare for the FHL and FDL, all five toes were passive flexed and extended with monitoring the FHL movement. Finally, we classified the formation of the chiasma plantare, according to a previous report [12], as follows: type A (connection from the FHL to the FDL of the second toe), type B (connection from the FHL to the second and third toes), type C (connection from the FHL to the second, third, and fourth toes), or type D (connection from the FHL to all lesser toes).

After the evaluation of chiasma plantare formation using US, the appropriate leg area was dissected. The lower limbs were dissected by a medial and plantar incision, removing the plantar skin. The tarsal tunnel was dissected and the anatomical structures identified. The plantar aponeurosis was meticulously dissected from flexor digitorum brevis and removed; then flexor digitorum brevis, flexor hallucis brevis, and abductor hallucis were dissected and lifted to the distal side. FHL, FDL and the lumbrical muscles were then harvested. The chiasma plantare was carefully dissected and the morphological features of the FHL and FDL connection sites were evaluated (Figure 3). Two observers whose experience in with US at least 100 h together evaluated chiasma plantare formation using US, and two other observers (senior orthopedic surgeon) evaluated these findings after collectively performing anatomical dissection. We compared the US-based findings with those obtained after dissection.

Results

Chiasma plantare formation was observed in the FHL and FDL in all ankles. Using US, the formation of the chiasma plantare was classified as type A and B in fifteen and seven ankles, respectively. No types C and D were observed. Regarding the findings after dissection, the chiasma plantare formation was classified as type A, B, and C in fourteen, six, and two ankles respectively (Table 1). Therefore, the results of the chiasma plantare formation using US were matched in nineteen out of twenty-two ankles (86%) correctly to those using the findings after dissection. However, the results of only three examined ankles were different, as it was diagnosed as type B and C after US and dissection, respectively. Nevertheless, such exceptions were expected in clinical experiments.

Discussion

The formation of the chiasma plantare has been observed in more than 80% of the reported cases [2,3,6,12]. Similarly, chiasma plantare formation was observed in 100% of our findings. Edama [2] reported that 37%, 54%, 9%, and 0% of analyzed cadavers were classified as type A, B, C, and D, respectively. Chiasma plantare formation can be performed in patients undergoing surgery for posterior tibial tendon dysfunction, Achilles tendinopathy, or other reconstructive purposes [3,7,10,12]. Chiasma plantare formation evaluation with US may simplify the development of surgery plan. Moreover, it may improve the results of the surgery. This study confirmed the accuracy of the concordance rate between the chiasma plantare formation observed using US and the findings after dissection. Thus, the formation of the chiasma plantare can be sufficiently evaluated using US and non-invasive surgical procedures could be planned.

The concordance rate between the formation of the chiasma plantare based on US versus the findings after dissection was 86%. Therefore, the formation of the chiasma plantare was not accurately detected in three out of twenty-two ankles examined. When we evaluated the passive motion of the FHL and FDL tendons, we might had not kept the tension constant and the tension of passive motion was not transmitted and, thus, the formation of the chiasma plantare not observed on the ultrasound screen.

Uritani [14,15] measured the toe grip strength using a dynamometer and found that it was an important predictor of clinical outcomes. To our knowledge, there are currently few studies regarding the relationship between chiasma plantare formation and clinical outcomes, such as toe strength and range of motion. Therefore, the relationship between the chiasma plantare formation and toe grip strength by using US and a toe grip dynamometer needs to be evaluated in future studies.

Saeki [13] reported that there was a correlation between the shear elastic moduli of the FHL and FDL and the range of motion (ROM) of dorsiflexion. Furthermore, better dorsiflexion ROM was influenced by the flexibility of the FHL and FDL. We suggest that the evaluation of the chiasma plantare formation by using US was more effective when performing ROM exercise (stretching both the FHL and tendon connection of the FDL). Indeed, the formation of the chiasma plantare should be evaluated in healthy individuals in future studies. It will also be necessary to examine the relationship between the chiasma plantare formation and foot and ankle functional outcomes (e.g., toe strength and range of motion).

Our study has some limitations. First, only eleven cadaver limbs were examined. Larger sample sizes are required to verify the concordance rate between FHL variation classifications based on US and the findings after dissection. Secondly, we did not evaluate the formation of the chiasma plantare blindly using US and evaluating the findings after dissection. Furthermore, we should compare the results of magnetic resonance imaging and ultrasound to assess which is the most reliable non-invasive method for classification of anatomical variations.

Conclusions

It is possible to evaluate the formation of the chiasma plantare by using US. The concordance rate between US and after dissection findings was at 86%. Therefore, we suggest a novel, non-invasive method for the evaluation of the chiasma plantare formation.

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Author contribution

DB and HK contributed to study design and data collection, and drafted the manuscript; SM and TM contributed to data analysis and made critical revisions to the manuscript; PM made critical revisions to the manuscript; YT supervised the study, contributed to analysis and interpretation of data, and made critical revisions to the manuscript. All authors read and approved the final manuscript prior to submission.

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Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

Availability of data and material

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethical approval

The methods were carried out in accordance with the 1964 Declaration of Helsinki. And this anatomical study was approved by the ethics committee of our department (ANA-2562-06064).

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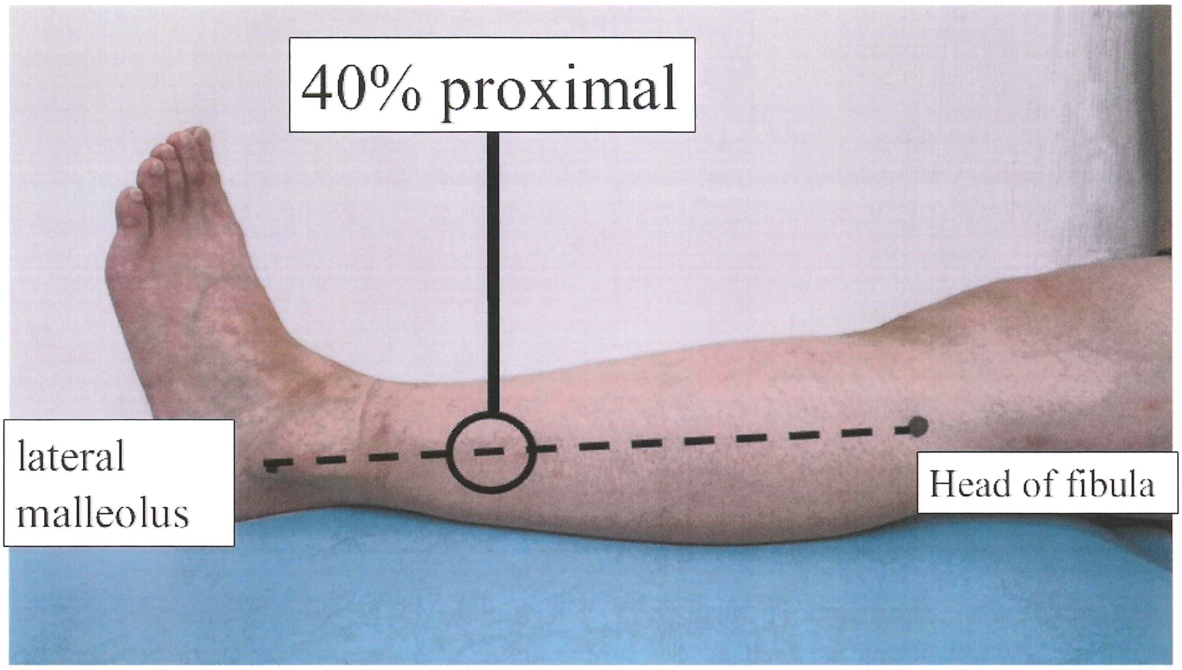

Figure 1. Location of the ultrasonography

The location of the flexor hallucis longus was measured at 40% proximal from the lateral malleolus.

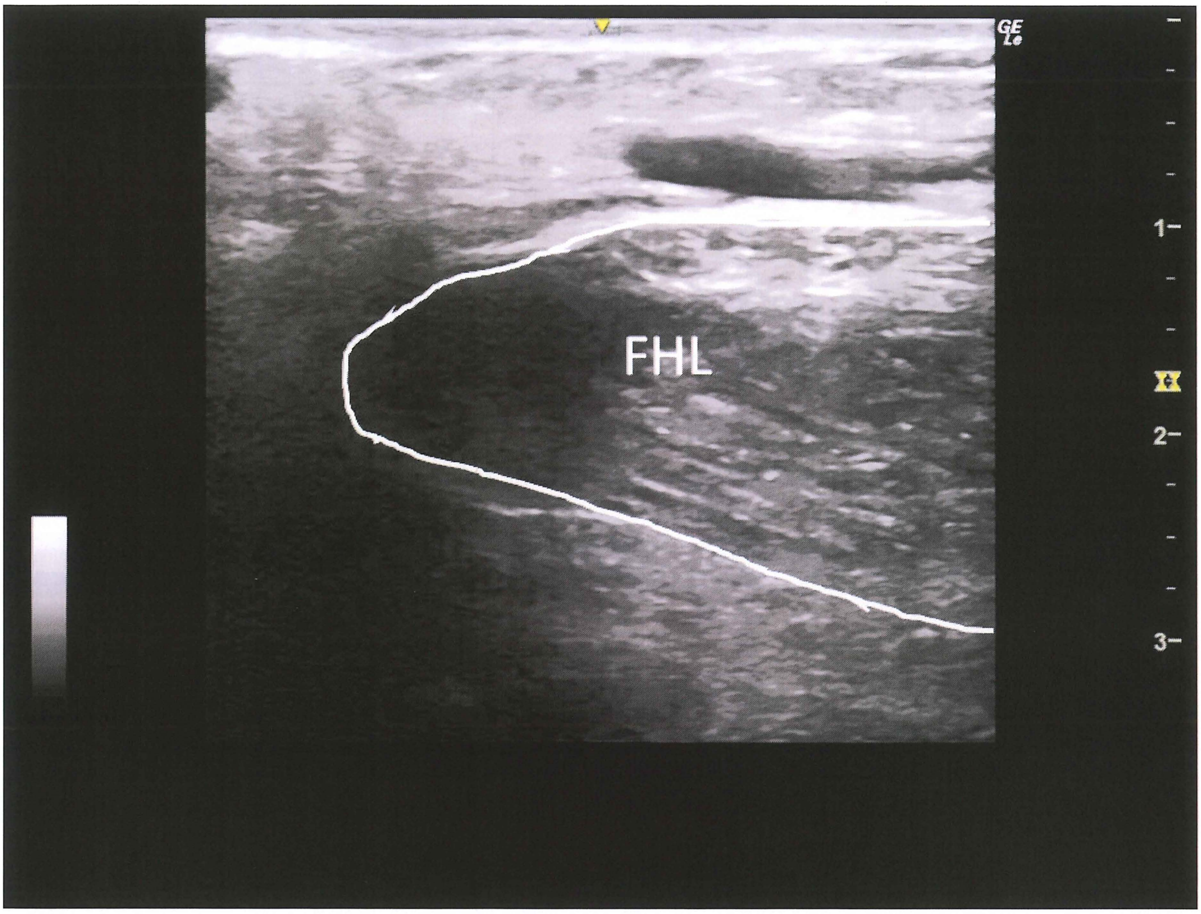

Figure 2. The image of flexor hallucis longus

Transverse ultrasound images of the flexor hallucis longus were obtained with a B-mode ultrasonography device. To evaluate the chiasma plantare, all five toes were passive flexed and extended with monitoring the flexor hallucis longus movement.

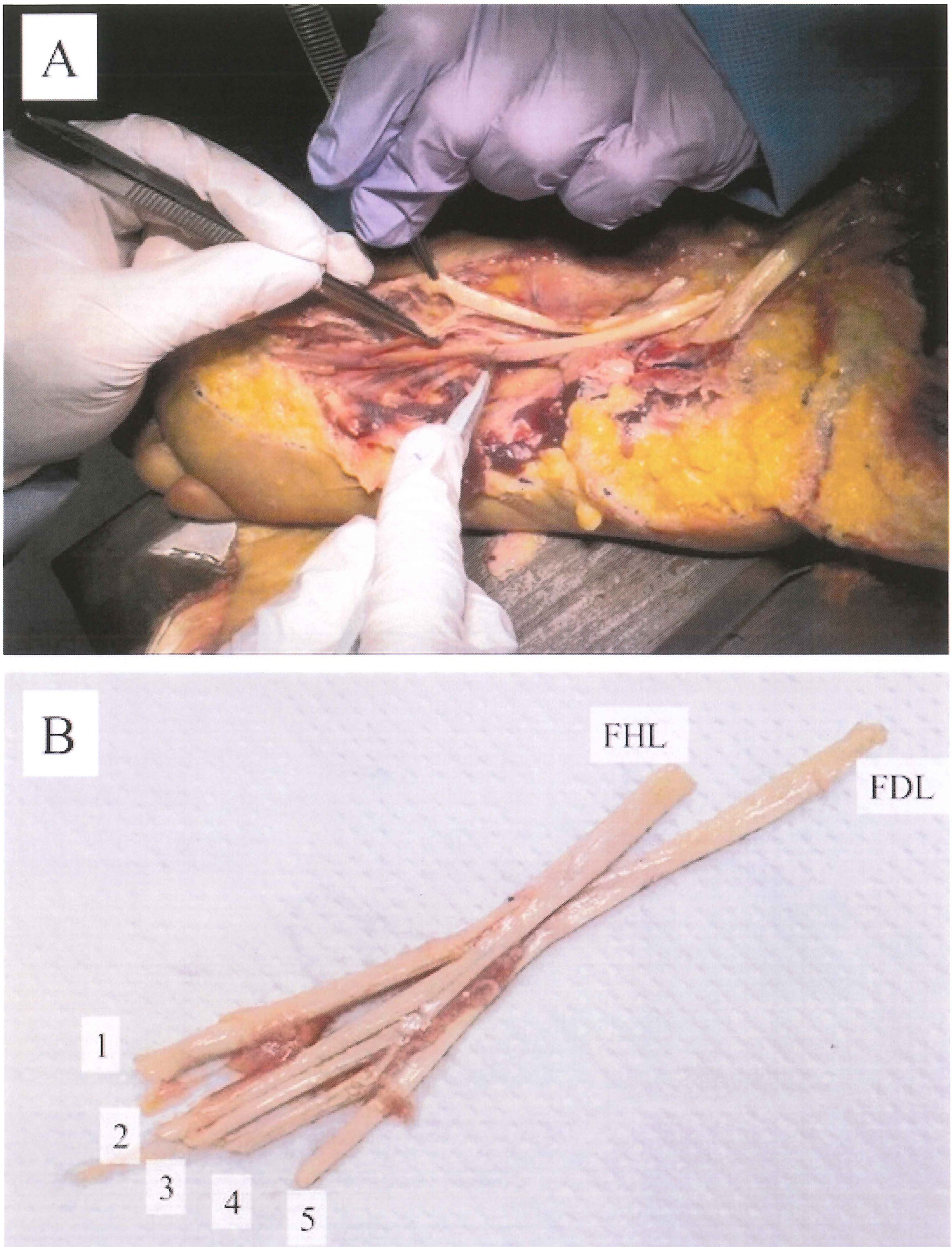

Figure 3. The image of the findings after dissection

Plantar skin was removed, and the plantar aponeurosis mobilized. The tarsal tunnel was dissected and the anatomical structures identified (A). After dissection, the chiasma plantare formation was classified as type C (B).

Table 1: Subjects' demographic and clinical characteristics

	Cadaver 1	Cadaver 2	Cadaver 3	Cadaver 4	Cadaver 5	Cadaver 6	Cadaver 7	Cadaver 8	Cadaver 9	Cadaver 10	Cadaver 11
Gender (male/female)	male	male	female	female	male	male	male	male	male	male	male
Age (years)	83	64	72	67	87	71	69	51	67	74	61
Height (cm)	165	166	148	154	164	169	160	167	173	160	170
classification of ultrasound imaging											
right leg	type A	type B	type B*	type A	type A*	type A	type A	type A	type A	type B	type B
left leg	type A	type B	type B	type A	type A	type A	type A	type A	type A	type B*	type A
classification of macroscopic observation											
right leg	type A	type B	type C*	type A	type B*	type A	type A	type A	type A	type B	type B
left leg	type A	type B	type B	type A	type A	type A	type A	type A	type A	type C*	type A

Asterisk mark means the different results between using US and the findings after dissection.