

Anatomical Constraints to Flexor Hallucis Longus Passage Through the Digital Flexor Sheath: A Cadaveric Study

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Abstract

Purpose

Secondary flexor tendon reconstruction may require tendon grafting when primary repair is no longer feasible. The flexor hallucis longus (FHL) could provide an alternative graft source when conventional donor tendons are unavailable or unsuitable. However, passage of an intact FHL through the digital flexor sheath has not been characterized.

Methods

Nine fresh-frozen cadavers provided 18 paired upper and lower limbs. Each harvested FHL was passed through the five digital flexor sheaths of the ipsilateral hand. In the index, middle, ring, and little fingers, passage was assessed separately at the A2 and A4 pulleys using a five-point semi-quantitative ordinal scale ranging from impossible passage (score 1) to passage without perceptible resistance (score 5). In the thumb, passage was assessed through the digital flexor sheath as a whole.

Results

At A2, passage was graded 4 or 5 in 17 of 18 index fingers and all 18 middle and ring fingers. At A4, passage was impossible in 7 of 18 index, 5 of 18 middle, and 6 of 18 ring fingers. In the little finger, scores of 1 or 2 occurred in 11 of 18 specimens at A2 and 17 of 18 at A4; A4 passage was impossible in 15 of 18. In the thumb, passage was impossible in 7 of 18 specimens.

Conclusion

Passage of an intact FHL was strongly dependent on the digit and pulley level. Passage was minimally restricted at A2 in the index, middle, and ring fingers, whereas A4 and the little finger represented frequent sites of restriction. These findings identify anatomical constraints to intact FHL passage but do not establish its biomechanical or clinical suitability as a flexor tendon graft.

INTRODUCTION

Secondary flexor tendon reconstruction is indicated when primary repair is no longer feasible or has failed, particularly in cases of tendon substance loss, delayed treatment, recurrent rupture, or infection-related tendon destruction [1, 4, 10]. When tendon injury is associated with substantial damage to the digital flexor sheath and surrounding tissues, staged reconstruction may be required [12].

Tendon graft selection depends on graft availability, length, caliber, mechanical properties, and donor-site morbidity. The palmaris longus and plantaris are commonly used because their harvest results in

limited functional loss. However, their presence and dimensions are variable, and alternative donor tendons have therefore been investigated [2, 5, 7].

The flexor hallucis longus (FHL) is a substantial tendon that is predominantly used as a tendon transfer in foot and ankle surgery, particularly for reconstruction of chronic Achilles tendon disorders [3, 8, 9]. Its harvest entails greater potential functional consequences than conventional expendable grafts, and the FHL should therefore not be considered a first-line donor for flexor tendon reconstruction. However, it may represent an alternative source when conventional donor tendons are unavailable or unsuitable.

The ability of an intact FHL to pass through the digital flexor sheath and its principal sites of anatomical restriction have not been characterized. The primary objective of this cadaveric study was therefore to characterize passage of an intact FHL through the digital flexor sheaths of the hand. In the index, middle, ring, and little fingers, a secondary objective was to determine whether passage differed between the A2 and A4 pulley levels. A schematic overview of the flexor tendon zones of the hand is provided in Fig. 1.

MATERIALS AND METHODS

Nine fresh-frozen human cadavers, five men and four women, were included, corresponding to 18 paired upper limbs and 18 lower limbs. One FHL tendon was harvested from each lower limb and tested in the corresponding ipsilateral hand.

Cadavers were positioned supine, with the upper limbs on arm tables and the lower limbs in hip flexion, abduction, and external rotation to expose the medial aspect of both legs. The FHL tendon was identified in the medial retromalleolar tunnel through an approximately 5-cm skin incision and looped. It was then divided distally at its insertion at the base of the distal phalanx of the hallux and extracted through the ankle incision by traction on the loop. A short plantar incision was made to release connections between the FHL and flexor digitorum longus tendons.

The five digital flexor sheaths of each hand were exposed through Bruner incisions. The flexor digitorum superficialis and flexor digitorum profundus tendons were divided distally and removed from the digital sheath, while the pulley system was preserved for assessment of FHL passage.

Each harvested FHL was tested in the digital flexor sheaths of the five digits of the ipsilateral hand. The distal end of the FHL was introduced antegrade through the digital flexor sheath. In the index, middle, ring, and little fingers, graft passage was assessed separately at the A2 and A4 pulley levels. In the thumb, passage was assessed from the entrance to the exit of the digital flexor sheath as a whole; individual pulley levels were not assessed separately.

Graft passage was assessed visually and manually using a five-point semi-quantitative ordinal grading scale developed for this study: 5, smooth passage without perceptible resistance or visible pulley displacement; 4, minimal resistance with slight pulley displacement during passage; 3, moderate resistance with visible tendon deformation or bulging during passage; 2, marked resistance with

pronounced tendon buckling during passage; and 1, inability to pass the tendon through the assessed anatomical level. Representative macroscopic examples of scores 5 to 2 are shown in Fig. 2.

During the initial dissections, the grading scale was calibrated by two assessors, one senior surgeon and one resident. Each assessor initially assigned a score independently. In cases of disagreement, graft passage was reassessed jointly and a consensus score was assigned. Individual assessor ratings were not retained for formal inter-observer reliability analysis.

Data analysis

Data were analysed descriptively. For each digit and anatomical level, the complete distribution of scores from 1 to 5 was reported as absolute counts. No inferential statistical analysis was performed because of the exploratory design, the small number of cadavers, and the non-independence of observations obtained from paired limbs and repeated assessments within the same cadaver.

RESULTS

The distribution of passage scores differed according to digit and anatomical level (Table 1). At A2, passage was graded 4 or 5 in 17 of 18 index fingers and in all 18 middle and ring fingers. Fourteen of 18 index, 17 of 18 middle, and 13 of 18 ring fingers received a score of 5 at A2.

Passage was more frequently restricted at A4. Passage was impossible (score 1) in 7 of 18 index, 5 of 18 middle, and 6 of 18 ring fingers. Scores of 1 or 2 were recorded in 9 of 18 index, 8 of 18 middle, and 13 of 18 ring fingers at A4.

Passage was particularly restricted in the little finger. Scores of 1 or 2 occurred in 11 of 18 specimens at A2 and 17 of 18 at A4. Passage at A4 was impossible in 15 of 18 specimens.

In the thumb, assessed through the digital flexor sheath as a whole, passage was impossible in 7 of 18 specimens. The remaining specimens were graded 3 in six, 4 in three, and 5 in two.

Table 1
Distribution of FHL passage scores according to digit and anatomical level.

Digit	Level assessed	Score 1	Score 2	Score 3	Score 4	Score 5
Thumb	Whole digital sheath	7	0	6	3	2
Index	A2	1	0	0	3	14
Index	A4	7	2	4	2	3
Middle	A2	0	0	0	1	17
Middle	A4	5	3	6	3	1
Ring	A2	0	0	0	5	13
Ring	A4	6	7	1	4	0
Little	A2	7	4	1	4	2
Little	A4	15	2	1	0	0
Note. Values are absolute numbers of specimens (n = 18 for each assessment). Score 1 indicates inability to pass the tendon through the assessed anatomical level; score 5 indicates passage without perceptible resistance. In the thumb, passage was assessed through the digital flexor sheath as a whole.						

DISCUSSION

The principal finding of this study was that passage of an intact FHL through the digital flexor sheath was strongly dependent on the digit and anatomical level assessed. Passage at A2 was minimally restricted in the index, middle, and ring fingers, whereas substantially greater restriction was observed at A4. The little finger represented the most restrictive pathway, particularly at A4, where passage was impossible in 15 of 18 specimens. These findings identify anatomical constraints to intact FHL passage rather than establishing the FHL as a suitable flexor tendon graft.

The choice of graft is an important component of secondary flexor tendon reconstruction. The palmaris longus and plantaris remain conventional donor options, although their presence, length, and caliber are variable. Carlson et al. demonstrated morphological and biomechanical differences between commonly used free tendon grafts and native flexor tendons [2]. Jakubietz et al. further showed variability in the adequacy of palmaris longus and plantaris tendons when both length and diameter were considered [5]. Alternative graft sources have consequently been investigated; Lynch et al., for example, evaluated hamstring autografts as potential alternatives for staged flexor tendon reconstruction [7].

The FHL should not be considered a first-line donor tendon for flexor reconstruction. Unlike expendable donor tendons such as the palmaris longus or plantaris, FHL harvest sacrifices a tendon with an established functional role. Its potential relevance would therefore concern selected situations in which

conventional graft sources are absent, inadequate, or otherwise unavailable. The present study addresses only one prerequisite in such a setting: whether an intact FHL can physically pass through a preserved digital flexor sheath.

The marked difference between A2 and A4 indicates that successful proximal passage cannot be extrapolated to the entire digital sheath. Although A2 passage was minimally restricted in the index, middle, and ring fingers, scores of 1 or 2 were recorded in 9 of 18, 8 of 18, and 13 of 18 specimens, respectively, at A4. Partial or complete venting of the A2 or A4 pulleys has been described in flexor tendon surgery to facilitate tendon passage and gliding [6, 11]. However, the present study did not quantify passage force or tendon gliding, and therefore cannot establish the functional significance of the observed macroscopic restrictions or determine whether pulley venting or pulley plasty would permit satisfactory FHL gliding.

The little finger represented the most restrictive anatomical pathway. Passage was impossible in 7 of 18 specimens at A2 and 15 of 18 at A4. These findings indicate that intact FHL passage through a preserved little-finger pulley system is frequently limited. Because neither tendon nor pulley dimensions were measured, the mechanism underlying this restriction cannot be attributed directly to tendon-pulley size mismatch.

Thumb findings should be interpreted separately from those of the four fingers. Passage was assessed through the digital flexor sheath as a whole rather than at individual pulley levels, and passage was impossible in 7 of 18 specimens. Consequently, the present data cannot identify the specific anatomical structure responsible for restriction in the thumb.

Donor-site morbidity must also be considered before the FHL is contemplated as a free graft. Available evidence predominantly concerns FHL transfer for Achilles tendon reconstruction. Coull et al. reported limited clinical impairment of hallux function despite altered plantar pressure distribution after FHL transfer [3], and other foot and ankle series have also evaluated hallux morbidity after FHL transfer [8, 9]. These data cannot be directly extrapolated to free FHL harvest for hand flexor reconstruction, and donor-site morbidity specific to this indication was not evaluated in the present study.

This study has several limitations. First, graft passage was assessed using a semi-quantitative ordinal scale developed specifically for this study. Although initial calibration involved independent assessment by two observers followed by consensus in cases of disagreement, inter- and intra-observer reliability was not formally evaluated. The reproducibility of the scale therefore remains unknown. Second, the force required for passage was not measured. The scores describe macroscopic passage characteristics and should not be interpreted as quantitative measurements of frictional resistance or work of flexion. Third, no morphometric measurements of the FHL, native flexor tendons, or pulley system were obtained; consequently, differences between digits and pulley levels cannot be attributed directly to tendon-pulley size mismatch. Fourth, both limbs from each cadaver were included and each FHL underwent repeated testing, resulting in clustered and non-independent observations. Fifth, individual pulley levels were not assessed separately in the thumb, preventing identification of the

anatomical level responsible for restriction. Finally, the fresh-frozen cadaveric model does not reproduce in vivo synovial lubrication, tissue compliance, biological healing, inflammatory response, graft-host integration, or adhesion formation.

CONCLUSION

Passage of an intact FHL through the digital flexor sheath was strongly dependent on the digit and pulley level. Passage was minimally restricted at A2 in the index, middle, and ring fingers, whereas A4 represented a frequent site of restriction. Passage was particularly limited in the little finger. These findings identify anatomical constraints to intact FHL passage but do not establish its biomechanical or clinical suitability as a flexor tendon graft. Quantitative biomechanical assessment of passage force and tendon gliding would be required before considering clinical application.

Statements and Declarations

Funding

No funding was received for conducting this study.

Competing interests

The authors have no competing interests to declare that are relevant to the content of this article.

Ethics approval

This study was approved by the CESP, Centre de Dons du Corps/Laboratoire d'Anatomie, Faculté de Médecine Montpellier-Nîmes (Approval ID: 34-2026-011).

Consent to participate

The available institutional approval documentation confirms approval of the cadaveric research project (Approval ID: 34-2026-011) but does not separately specify the consent procedure for body donation.

Data availability

The data supporting the findings of this study are available from the corresponding author on reasonable request.

Author contributions

Daoulas: Protocol/project development; Manuscript writing/editing. Le Ru: Data collection or management; Data analysis; Manuscript writing/editing. Caudmont: Data collection or management. Chammas: Protocol/project development; Manuscript writing/editing. Maroteau: Protocol/project

development; Manuscript writing/editing. Bodéré: Protocol/project development; Manuscript writing/editing.

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Figures

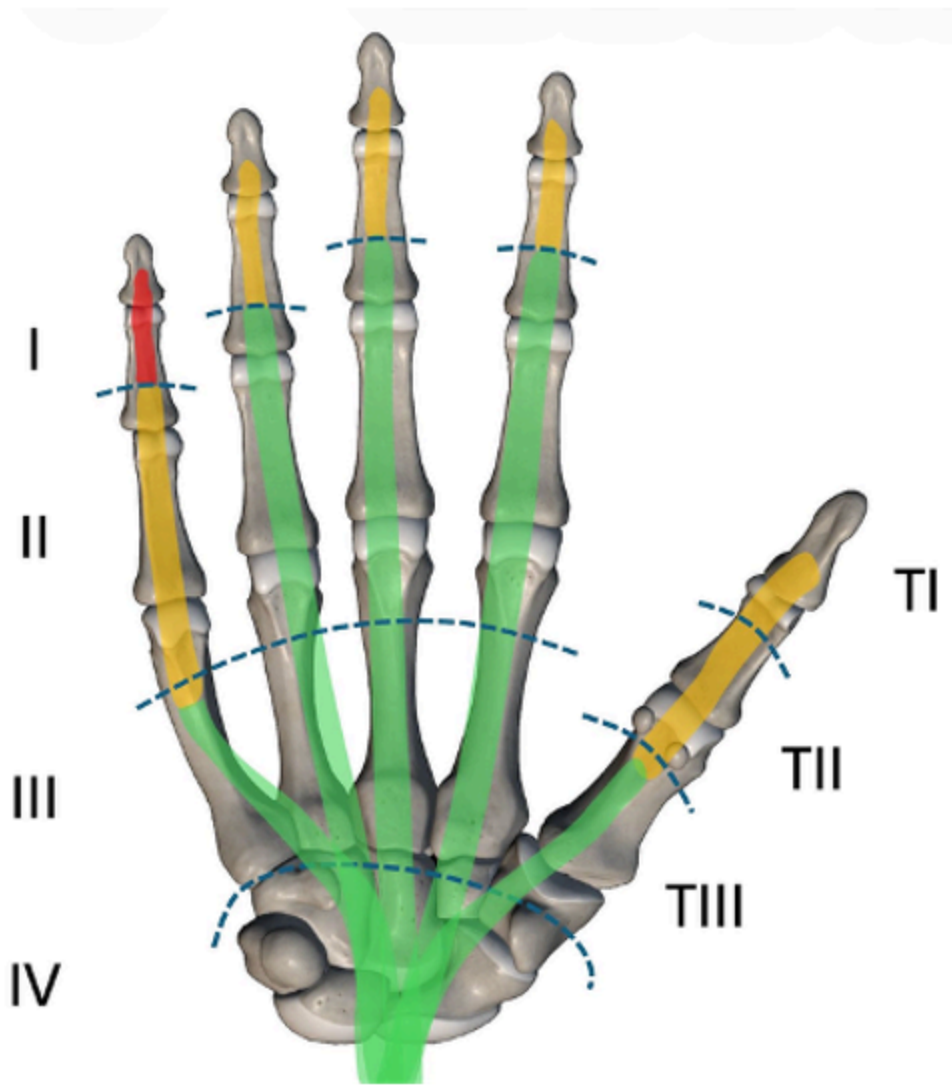


Figure 1

Schematic representation of the flexor tendon zones of the hand according to Verdan. Original illustration by the authors.

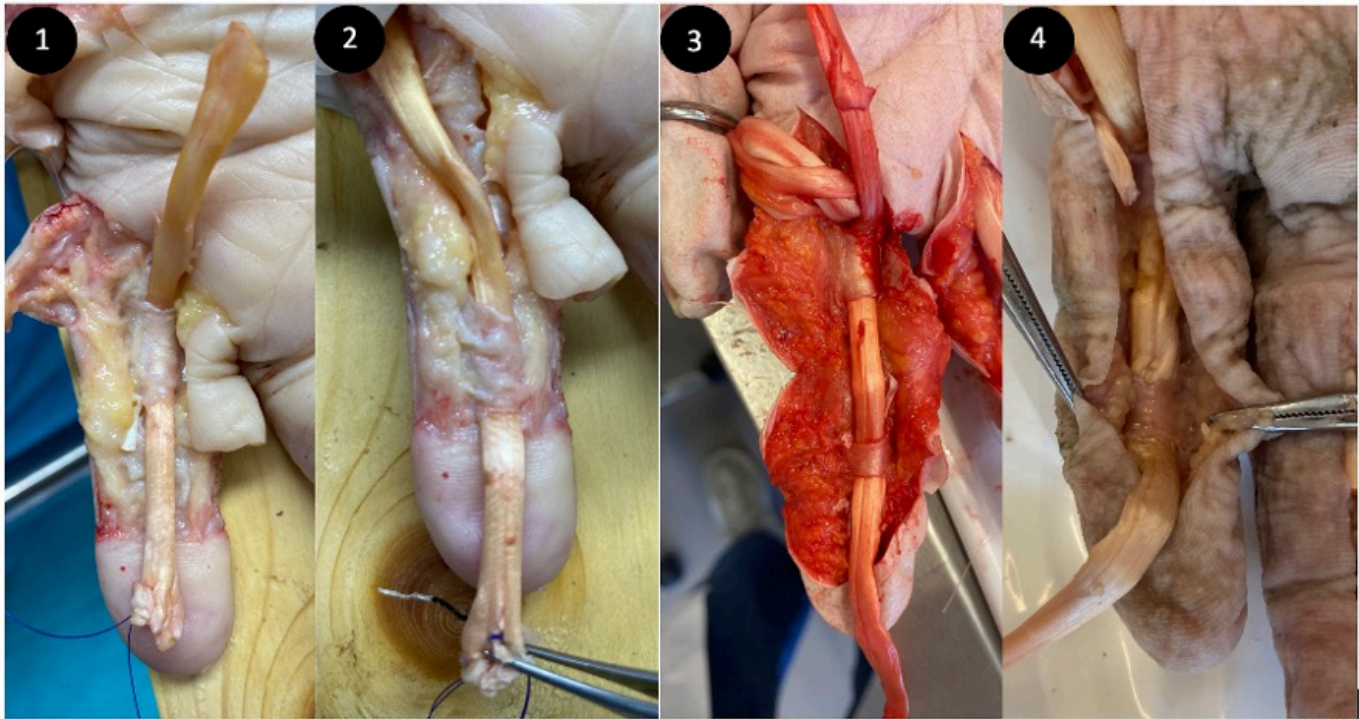


Figure 2

Representative macroscopic examples of FHL passage according to the semi-quantitative grading scale. (1) Score 5: smooth passage without perceptible resistance or visible pulley displacement at A2. (2) Score 4: minimal resistance with slight pulley displacement during passage at A4. (3) Score 3: moderate resistance with visible tendon deformation or bulging during passage at A4. (4) Score 2: marked resistance with pronounced tendon buckling during passage at A4.