ONLINE FIRST

This is a provisional PDF only. Copyedited and fully formatted version will be made available soon.

FOLIA MORPHOLOGICA

ISSN: 0015-5659

e-ISSN: 1644-3284

Fetal development and growth of extensor tendons and their sheaths in the dorsal side of the wrist and hand: a histological study

Authors: Chun-Ai Li, Shogo Hayashi, Zhe Wu Jin, Masahito Yamamoto, Yoko Ueda, Gen Murakami

DOI: 10.5603/fm.101833

Article type: Original article

Submitted: 2024-07-29

Accepted: 2024-08-22

Published online: 2024-08-26

ORIGINAL ARTICLE

Chun-Ai Li et al., Extensor tendons of the hand

Fetal development and growth of extensor tendons and their sheaths in the dorsal side of the wrist and hand: a histological study

Chun-Ai Li[1], Shogo Hayashi[2], Zhe Wu Jin[3], Masahito Yamamoto[2], Yoko Ueda[2], Gen Murakami[4]

[1]Department of Radiology, Yanbian second People's Hospital, Yanji, China

[2]Department of Anatomy, Division of Basic Medicine, Tokai University School of Medicine, Isehara, Japan

[3]Department of Anatomy, Wuxi School of Medicine, Jiangnan University, Wuxi, China

[4]Division of Internal Medicine, Iwamizawa Aska Hospital, Iwamizawa, Japan

ABSTRACT

Background: To understand considerable variations in number of adult extensor tendons at the dorsal side of the wrist and hand.

Materials and methods: We examined histological sections from 30 human fetuses of gestational age 7–39 weeks and crown-rump length 22–323 mm.

Results: At the carpal level, earlier or smaller fetuses showed a simpler configuration with fewer tendon slips, whereas later or larger fetuses had a greater number of tendon slips with considerable variations in number and topographical relationships. Tendon slips of the early extensor digitorum to the middle and ring fingers were always 1 or 2, but were seven or more at late term. A tendon of the extensor digitorum to the little finger could not be distinguished from other tendons at the carpal bone level. At the metacarpal bone level, however, it extended from the ring finger tendon toward two slips of the extensor digiti minimi tendon. At the distal carpal level at midterm and late term, in which the tendon sheath was lost, each of the extensor digitorum tendon slips further divided to provide a mediolateral linear cluster of thin bundles. This large number of tendon components joined and united together to provide a single tight tendon at the level of the metacarpophalangeal joints. The extensor pollicis longs tendon usually lost a membranous septation when it crossed the extensor carpi radialis brevis tendon.

Conclusions: Tendon slips in the fourth and fifth canals of the sheath were most likely to reduce in number after birth depending on the mechanical demand.

Keywords: extensor digitorum, extensor pollicis longus, tendon sheath, hand and wrist, human fetus

INTRODUCTION

The flexor tendon configuration at the hand shows a common rule: the superficial and deep tendons act on one finger or thumb. Likewise, at the hand dorsum, "two" extensor tendons reach the thumb (short and long extensor pollicis tendons) and the index finger (an extensor digitorum communis or ED tendon and the extensor indicis or EIN tendon; Fig. 1). However, the little finger appears to have "three" extensor tendons since the extensor digiti minimi or EDM usually carries two tendon slips [8] independent of an ED tendon to the little finger. In contrast, the middle and ring fingers are believed to receive a "single" extensor tendon, respectively. In spite of such a great difference between fingers, strangely, multiple (or even abundant) tendons from the ED and EIN muscles are bundled by a "single" extensor tendon sheath or the fourth canal (Fig. 1).

The numbers of extensor tendons at the hand dorsum have been reported to vary. For each of the fingers, multiple tendon slips have been reported in the ED [18, 19], the EIN [16, 20], and the EDM [12]. Similarly, variations in the numbers of tendons, as well as their connections and sheaths (i.e., first-third sheaths) have been reported at and around the anatomical snuffbox, consisting of the extensor pollicis longus (EPL) and the abductor pollicis longus (ABPL) at the margins and the extensor carpi radialis longus (ECRL) and the extensor carpi radialis brevis (ECRB) at the bottom of the skin hollow (Fig. 1) [3, 10, 11, 14, 21, 22]. Therefore, according to an excellent review [15], extensor tendons to one finger are counted as two or more in number in adults.

Little is known about the histology of these extensor tendons and sheaths especially in human fetuses. The variations in the numbers and connections of adult extensor tendons may result from an overproduction of extensor tendon slips during fetal development. If the number of tendon slips is excessive, adjacent slips later connect with each other and join together (termed here the “fusion hypothesis”). Alternatively, a common tendinous plate, as seen in developing flexor tendons of the hand and foot [2, 5, 6], is also likely for extensors, with the method of plate division determining the variation in number of tendon slips per finger (termed here the “dividing hypothesis”). Tendinous connections in adults may therefore result from the union of tendon slips or the division of a common tendinous plate during development.

A six-canal configuration of the extensor tendon sheath (Fig. 1) is likely to develop depending on tendon development. In early fetuses, both a thin tendon and other tight structures such as nerves are surrounded by a monolayered sheath [4, 7]. Variations in the number of tendons may also alter the morphology of the sheath. The lateralward oblique course of the EPL at the wrist is likely to disturb the sheath configuration. The present study evaluated the mechanism determining the number of tendons by assessing the histology of the extensor tendons at the wrists and hands of fetuses.

MATERIALS AND METHODS

Transverse histological sections of the bilateral hands and wrists were obtained from 30 human fetuses, including 15 early fetuses of gestational age 7–10 weeks (crown-rump length [CRL] 22–50 mm, seven mid-term fetuses of gestational age 15–16 weeks (CRL 111–154 mm) and eight late-term fetuses of gestation age 30–39 weeks (CRL 252–323 mm). All of these sections, 5–10 microns in thickness, had been stained with hematoxylin and eosin. They had been prepared and used for other studies [2, 4–7]. The research use of sections of early fetuses had been approved by the ethics committee of Complutense University, Madrid, Spain (No. B08/374, material provided and photographed by Rodríguez Vazquez, J.F.), whereas use of sections of mid- and late-term fetuses had been approved by the ethics committee of Akita University, Japan (No. 1428).

Photographs were taken with a Pentax K-1 camera with a 50–100 mm zoom lens, step by step, during the gross dissection of extensor tendons of two of the late-term fetuses, of CRL 310 mm and 322 mm. Another hand and wrist had been prepared for histology. Thus, one of the figures in this study shows both the gross appearance and histology of these specimens.

RESULTS

Early-term fetuses show a common tendinous plate and a monolayered tendon sheath

Despite being thin and flat, each extensor tendon could be identified in the dorsal aspect of the wrist at gestational age 7 weeks (Fig. 2). Much more distally, at the levels of the distal carpal bones and/or the proximal end of the metacarpal bones, a common tendinous plate was found to connect the tendons of the EPL, ED and EDM in 12 of the 15 specimens (Fig. 2). This common tendinous plate of the extensor was much thinner than the tendinous plate of the flexor tendons of the same specimen (not shown). The thickness of the plate was independent of specimen size, with some plates being thicker in smaller than in larger fetuses (insert in Fig. 2F). A fibrous connection similar to the tendinous connection in adults was not identified at the levels of the metacarpal bones. This common tendinous plate was not observed, however, in three larger specimens of CRL 35, 38 and 50 mm and gestational age 9–10 weeks (Fig. 3).

At the levels of the proximal half of the metacarpal bones, the EIN and ECRB extended medially to mesenchymal condensations near the metacarpal bones of the ring and middle fingers (Fig. 2E–G); these mesenchymal condensations appeared to correspond to developing ligaments connecting the metacarpal bones (Fig. 2H). A membrane was found to separate the EPL from the ECRB (Fig. 2E).

At gestational age 10 weeks (Fig. 3), each of the ED tendons showed a round or crescent shape. The ED tendons to the middle and ring fingers were each composed of two tendon slips (Fig. 3C). Within the level of the distal carpal bones, however, each pair of slips joined to make a single tendon to one finger (Fig. 3E). The EIN tendon was on the medial side of the ED tendon to the index finger, with the former approaching the latter at the level of the metacarpal bone (Fig. 3D). A monolayered sheath was clearly observed around and along the tendon (Fig. 3B insert), but there was no membranous septum between the EPL and ECRB (Fig. 3D). Thus, the EPL, ECRB and ECRL appeared to be contained within a single sheath.

Mid-term fetuses show a cluster of excess tendon slips of the ED

At the level of the carpal bones, the tendon slips of the ED and EIN were not flat but round, forming a round cluster with a thick bar-like appearance. The tendon of the ED to the ring finger was always composed of two or three slips (Fig. 4C–H), the tendon to the middle finger was composed of one or two slips. In the common sheath for the ED and EIN, the ED tendon to the little finger could not be distinguished from the other ED tendons whereas at the proximal carpal bone level. The little finger tendon extended medially from the ring finger tendon toward the EDM tendon after the sheath was lost at distal levels of the metacarpal bones (Fig. 4I). The EDM tendon was composed of two tendon slips.

Each tendon sheath was round or oval in shape, with the EPL, ECRB and ECRL contained within a single sheath (Fig. 4H). This tendon sheath formed a double layered configuration by gestational age 16 weeks (Fig. 4C, D). The outer layer was thick and tight, whereas the inner layer was partly connected to the tendon but largely extended into the canal space to provide a wavy flap or excess part. This tendinous connection was identified as a fascia connecting tendons on the distal side of tight tendon sheaths, corresponding to levels of the distal half of the metacarpal bones (Fig. 4I).

Late term tendons divide further outside of a thick multilayered tendon sheath

Proximally, multiple tendon slips of the ED formed a round cluster packed within a tight tendon sheath. (Figs. 5A and 6A–D). The thick multilayered sheath included an intermediate layer providing a vascular route (Fig. 5D). Each tendon to the middle and ring fingers consisted of two, three or more slips (Figs. 5, 6). Thus, at the level of the proximal carpal bones, more than four tendons of the ED were observed in the third canal of a thick sheath. The thick sheath was lost, however, at the level of the distal carpal bones (Fig. 7A, B), with each slip further divided into thinner bundles. Each tendon to the middle and ring fingers consisted of seven or more slips or bundles, with numerous components of ED tendons providing a linear cluster extending mediolaterally (Fig. 7A, B). These bundles joined together to provide a single tight tendon near the metacarpophalangeal joints (Fig. 7D). In contrast to the ED tendons, the EIN tendon appeared undivided (Figs. 6A, B, 7B).

A tendon to the little finger was consistently absent from the thick common sheath for the ED and EIN. Rather, at the level of the metacarpal bones where the thick sheath was lost, the ED tendon of the little finger extended from the ED tendon to the ring finger medially toward the EDM tendon (Fig. 7C). The EDM tendon was composed of two tendon slips in seven of the eight specimens (Figs. 5B, 6B). The EPL was contained in a common sheath with the ECRB (Figs. 5C and 6A–D), with a membranous septation between the EPL and ECRL (Figs. 5D, E and 6B–E). The ABPL and EPB were present within a proper sheath (Figs. 5D, E and 7A, B). A tendinous connection was observed at the level of the distal half of the metacarpal bones, where the tendon sheath disappeared (Fig. 7C, D).

Finger tendons usually run just to the dorsal aspect of the corresponding metacarpal bones. However, the index finger tendon of the ED, as well as the EIN tendon, ran on the medial side of the second metacarpal bone. Thus, these tendons did not attach to the second metacarpal bone, but reached the dorsal aspect of the second bone behind the metacarpophalangeal joint. Dissection of the hand extensor tendons on the contralateral side (Fig. 6G–J) did not show evidence of site-dependent changes in the numbers of tendon components per sheath.

Effects of stage and size on the number of tendon slips

Analysis of all fetal stages indicated that, after the disappearance of the common tendinous plate, the earlier or smaller fetuses tended to show a simpler configuration with fewer tendon slips at any proximo-distal level. This rule was most evident in the tendons to the middle and ring fingers. Moreover, each slip on the distal side of the tight sheath was further divided into a large number of thin bundles. Therefore, late-term fetuses showed the most complex morphology of the extensor tendons. Conversely, the likely simplest arrangement of extensor tendons, i.e., “one tendon for one finger”, was rare or absent even in fetuses.

DISCUSSION

Two hypotheses may explain the morphologic and histologic variations in the extensor tendons of the hand. The fusion hypothesis would require the development of multiple tendons per finger in early fetuses. The present study found, however, that the configuration of these tendons was simpler in earlier or smaller fetuses, with fewer tendon slips. This was especially evident in ED tendons to the middle and ring fingers. In contrast, the dividing hypothesis suggests that the process of division of the common tendinous plate would fail during an early stage of fetal development. A common tendinous plate containing the EPL, ED, EIN and EDM was observed, but the plate subsequently disappeared and only one or two tendon slips remained for each finger. A further division was observed at the metacarpal bone level in late term fetuses, providing a linear cluster of thin tendon components of the ED, especially for the middle and ring fingers. These findings suggested that division occurred during later development, whereas fusion started in late term.

Figure 8 shows a hypothetical change in extensor tendon numbers of the middle and ring fingers during life. The maximum numbers of tendon components (slips or bundles) appeared at late-term, or possibly at birth. Depending on mechanical requirements for successful movement in childhood, a reconstruction (fusion, fasciculation or even elimination) of slips may occur toward the most effective configuration, such as “one tendon to one finger”. The maturation of extensor tendons was most likely on-going at birth. Actually, the “one tendon to one finger” configuration has been reported to occur in the middle and ring fingers of an almost half the world population [18]. However, this was unexpected in the present fetuses because these fingers were each characterized by multiple tendon slips. Conversely, the suggested postnatal reconstruction should be drastic. Recent advances in 3D ultrasound techniques [1, 9, 17] may enable the visualization of the marked decreases in number of extensor tendons in children. In contrast to the ED and EDM, the EIN and EPL did not consist of multiple slips at any stage. The medial-to-lateral oblique courses of the tendons might provide a continuous tensile stress to avoid divisions.

A thick and tight sheath seemed to play a critical role in the determination of tendon morphology. The division of tendons into numerous bundles occurred at the level of the metacarpal bones, at which the tendon sheaths became thin or disappeared. Conversely, the round cluster-like appearance of multiple ED tendons at the proximal carpal bone level suggested that the tight tendon sheath limited the space and accelerated fasciculation of tendon slips. Conversely, an ED tendon slip to the little finger was observed at the distal metacarpal bone level, at which the tendon sheath was thin or unclear. Following the disappearance of the common tendinous plate of the flexor tendons, the lumbricalis muscles are most likely to fasciculate the flexor tendon slips of the hands and feet [2]. A long extensor tendon of the foot was also found to be composed of numerous slips in fetuses (unpublished data), with these slips bundled by the short extensor as well as the tight sheath and retinaculum. If short extensor muscles join the ED on the fetal hand, such as the extensor digitorum brevis manus [12], a linear cluster of numerous bundles would not appear or reduce in size, even on the distal side of the tendon sheaths.

Variations in the number of tendons may be considered products of a “tendinous connection”, always present in the dorsum of the adult hand. However, a fascia-like tendinous connection in fetuses was present at the levels of the distal half of the metacarpal bones, being distal to the linear cluster of numerous thin tendon components in late term fetuses. Similarly, a common tendinous plate in early term fetuses was present on the proximal side of tendinous connections in adults. Although muscle splitting may also cause tendon variations, muscle division occurs much earlier [13] than the drastic late-term divisions of ED tendons.

A common canal has been reported between the EPL and ECRB [3, 21, 22]. Although a membranous septation between the EPL and ECRB was lost from midterm and late term fetuses, a septation remained between the EPL and ECRL. This difference might result from the dorsally protruding position of the ECRB in fetuses. Both the index tendons of the ED and

EIN are present on the medial side of the second metacarpal bone, whereas the other tendons are present on the dorsal aspect of the corresponding metacarpal bones. This difference was apparently due to the medial position of these muscle bellies.

CONCLUSIONS

Tendon slips in the fourth and fifth canals of the sheath were most likely to reduce in number after birth depending on the mechanical demand.

STUDY LIMITATION

The major limitation of the present study was the absence from the histological sections analyzed of muscle bellies of the extensor tendons. The process of muscle division could not be observed, preventing assessment of the relationships between tendon morphology and the mediolateral and anteroposterior positions of the corresponding muscle belly at the forearm. It was therefore unclear whether a muscle belly does or does not correspond to a single tendon slip in fetuses.

ARTICLE INFORMATION AND DECLARATIONS

Data availability statement

The data that supported the findings of this study are available on request from the corresponding author.

Ethics statement

This study was performed in accordance with the provisions of the Declaration of Helsinki 1995 (as revised in 2013). This study was approved by Ethics Committees of Complutense University (B08/374) and Ethics Committees of Akita University (No. 1428).

Author contributions

CA Li: Data acquisition and writing original draft. S Hayashi: Data analysis and draft review of the manuscript. ZW Jin: Data analysis, manuscript editing and funding acquisition. M Yamamoto: Data analysis and figure lettering. Yoko Ueda: Data acquisition and critical revision of the manuscript. G Murakami: Design study, data analysis, writing and review manuscript.

Funding

This study was supported by Wuxi Municipal Bureau on Science and Technology (N20202008) and Zhangjiagang Science and Technology Innovation Project (ZKCXY2123) in China.

Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

1. Ammitzbøll-Danielsen M, Janta I, Torp-Pedersen S, et al. Three-dimensional Doppler ultrasound findings in healthy wrist and finger tendon sheaths - can feeding vessels lead to misinterpretation in Doppler-detected tenosynovitis? Arthritis Res Ther. 2016; 18: 70, doi: 10.1186/s13075-016-0968-3, indexed in Pubmed: 26993979.
2. Cho KH, Kim JH, Ha YS, et al. Development of the deep flexor tendons and the lumbricalis muscle in the hand and foot: a histological study using human mid-term fetuses. Folia Morphol. 2012; 71(3): 154–163, indexed in Pubmed: 22936550.

3. Cvitanic OA, Henzie GM, Adham M. Communicating foramen between the tendon sheaths of the extensor carpi radialis brevis and extensor pollicis longus muscles: imaging of cadavers and patients. AJR Am J Roentgenol. 2007; 189(5): 1190–1197, doi: 10.2214/AJR.07.2281, indexed in Pubmed: 17954660.

4. Hayashi S, Kim JiH, Jin ZWu, et al. Development and growth of the calcaneal tendon sheath with special reference to its topographical relationship with the tendon of the plantaris muscle: a histological study of human fetuses. Surg Radiol Anat. 2023; 45(3): 247–253, doi: 10.1007/s00276-023-03086-y, indexed in Pubmed: 36689056.

5. Jin ZW, Hayashi S, Cho KH, et al. Development and growth of the foot lumbricalis muscle: a histological study using human foetuses. Folia Morphol. 2021; 80(4): 904–915, doi: 10.5603/FM.a2020.0108, indexed in Pubmed: 32896871.

6. Kim JiH, Ishizuka S, Kitamura K, et al. Ontogenic transformation of the ankle from the initial mediolateral arrangement of the calcaneus and talus: A histological study of human embryos and early fetuses. J Anat. 2024; 245(3): 392–404, doi: 10.1111/joa.14039, indexed in Pubmed: 39032027.

7. Kitamura K, Suzuki R, Ishizuka S, et al. Growing stylohyoideus muscle insertion to the hyoid bone with special reference to its topographical relation to the intermediate tendon of digastricus muscle: a histological study using human fetuses. Ann Anat. 2024; 254: 152246, doi: 10.1016/j.aanat.2024.152246, indexed in Pubmed: 38460858.

8. Kosugi K, Shibata S, Yamashita H. Anatomical study on the variation of extensor muscles of human forearm 11. the relation between differentiation and variation. Jikeikai Med J. 1989; 36(2): 93–112.

9. Morisaki S, Tsuchida S, Oda R, et al. Quantitative analysis of ultrasonography for de quervain's disease: comparison of the affected side with the asymptomatic side. J Ul-

trasound Med. 2023; 42(7): 1437–1443, doi: 10.1002/jum.16152, indexed in Pubmed: 36514245.

10. Motoura H, Shiozaki K, Kawasaki K. Anatomical variations in the tendon sheath of the first compartment. Anat Sci Int. 2010; 85(3): 145–151, doi: 10.1007/s12565-009-0070-x, indexed in Pubmed: 20039153.

11. Rangarajan A, Bhaskara KG. Solitary extensor tendon in the third compartment has a companion: variant course of extensor pollicis brevis in third extensor compartment. Surg Radiol Anat. 2023; 45(4): 491–493, doi: 10.1007/s00276-023-03110-1, indexed in Pubmed: 36821053.

12. Rodríguez-Niedenführ M, Vázquez T, Golanó P, et al. Extensor digitorum brevis manus: anatomical, radiological and clinical relevance. A review. Clin Anat. 2002; 15(4): 286–292, doi: 10.1002/ca.10027, indexed in Pubmed: 12112357.

13. Rodríguez-Vázquez JF, Jin ZW, Zhao P, et al. Development of digastric muscles in human foetuses: a review and findings in the flexor digitorum superficialis muscle. Folia Morphol. 2018; 77(2): 362–370, doi: 10.5603/FM.a2017.0083, indexed in Pubmed: 28868605.

14. Sawaizumi T, Nanno M, Ito H. Supernumerary extensor pollicis longus tendon: a case report. J Hand Surg Am. 2003; 28(6): 1014–1017, doi: 10.1016/s0363-5023(03)00382-4, indexed in Pubmed: 14642519.

15. Tunali S. Forearm muscles: In Bergman's Comprehensive encyclopedia of human anatomic variations (Chapter 33). In: Tubbs RS, Shoja MM, Loukas M. ed. Bergman's Comprehensive encyclopedia of human anatomic variations. John Wiley & Sons, New Jersey 2016: 583–618.

16. Vaida MA, Gug C, Jianu AM, et al. Bilateral anatomical variations in the extensor compartment of forearm and hand. Surg Radiol Anat. 2021; 43(5): 697–702, doi: 10.1007/s00276-020-02584-7, indexed in Pubmed: 33001251.

17. Vigny S, Rubinstenn E, Michelin P, et al. Ultrasound identification of hand and wrist anatomical structures by hand surgeons new to ultrasonographic techniques. Surg Radiol Anat. 2024; 46(6): 795–804, doi: 10.1007/s00276-024-03355-4, indexed in Pubmed: 38597950.

18. Yammine K. The prevalence of the extensor digitorum communis tendon and its insertion variants: a systematic review and meta-analysis. Clin Anat. 2014; 27(8): 1284–1290, doi: 10.1002/ca.22429, indexed in Pubmed: 24953717.

19. Yoshida Y. Anatomical study on the extensor digitorum profundus muscle in the Japanese. Okajimas Folia Anat Jpn. 1990; 66(6): 339–353, doi: 10.2535/ofaj1936.66.6_339, indexed in Pubmed: 2336244.

20. Yoshida Y. Anatomical studies on the extensor pollicis et indicis accessorius muscle and the extensor indicis radialis muscle in Japanese. Okajimas Folia Anat Jpn. 1995; 71(6): 355–363, doi: 10.2535/ofaj1936.71.6_355, indexed in Pubmed: 7739845.

21. Zbrodowski A, Baltaziuk H, Spiechowicz J. Sheaths and mesotendons of the tendons of the extensor carpi radialis longus and brevis muscles and of the tendon of the extensor pollicis longus muscle. Folia Morphol. 1976; 35(1): 105–112, indexed in Pubmed: 1083356.

22. Zbrodowski A, Gajisin S, Grodecki J. Intersynovial communication between the tendon sheaths of the extensor pollicis longus and extensor carpi radialis brevis muscles. J Hand Surg Br. 1985; 10(2): 162–164, doi: 10.1016/0266-7681(85)90006-3, indexed in Pubmed: 4031594.

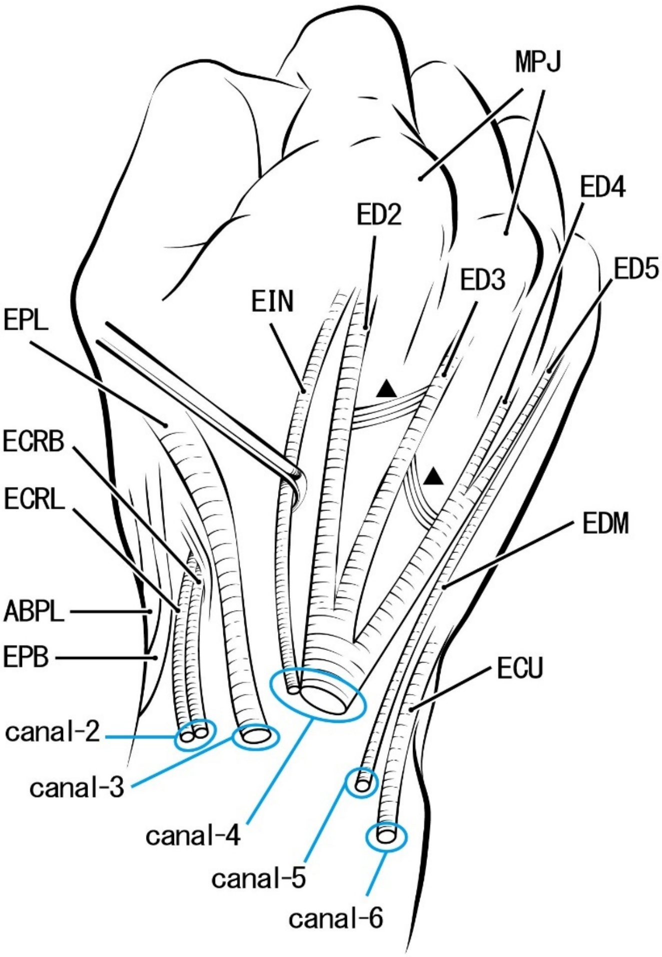

Figure 1. Usual understanding of extensor tendons in the dorsal aspect of the right hand and

wrist. The EIN is exposed by lateral traction. The tendon of the ED5 is considered to meet the EDM near the MPJ. The so-called tendinous connection (triangles) is considered to exist in the metacarpal bone level. Extensor tendon sheathes make six canals (canal-1 to canal-6), but the first canal for the EPB and ABPL is not shown. These two tendons make a skin hallow "anatomical snuff box" in association with the EPL tendon. The other captions, see the common abbreviation. ABPL — abductor pollicis longus; ECRB — extensor carpi radialis brevis; ECRL — extensor carpi radialis longus; ECU — extensor carpi ulnarus; ED5 — extensor digitorum to the little finger; EDM — extensor digiti minimi; EIN — extensor indicis tendon; EPB — extensor pollicis brevis; EPL — extensor pollicis longus; MPJ — metacarpophalangeal joint.

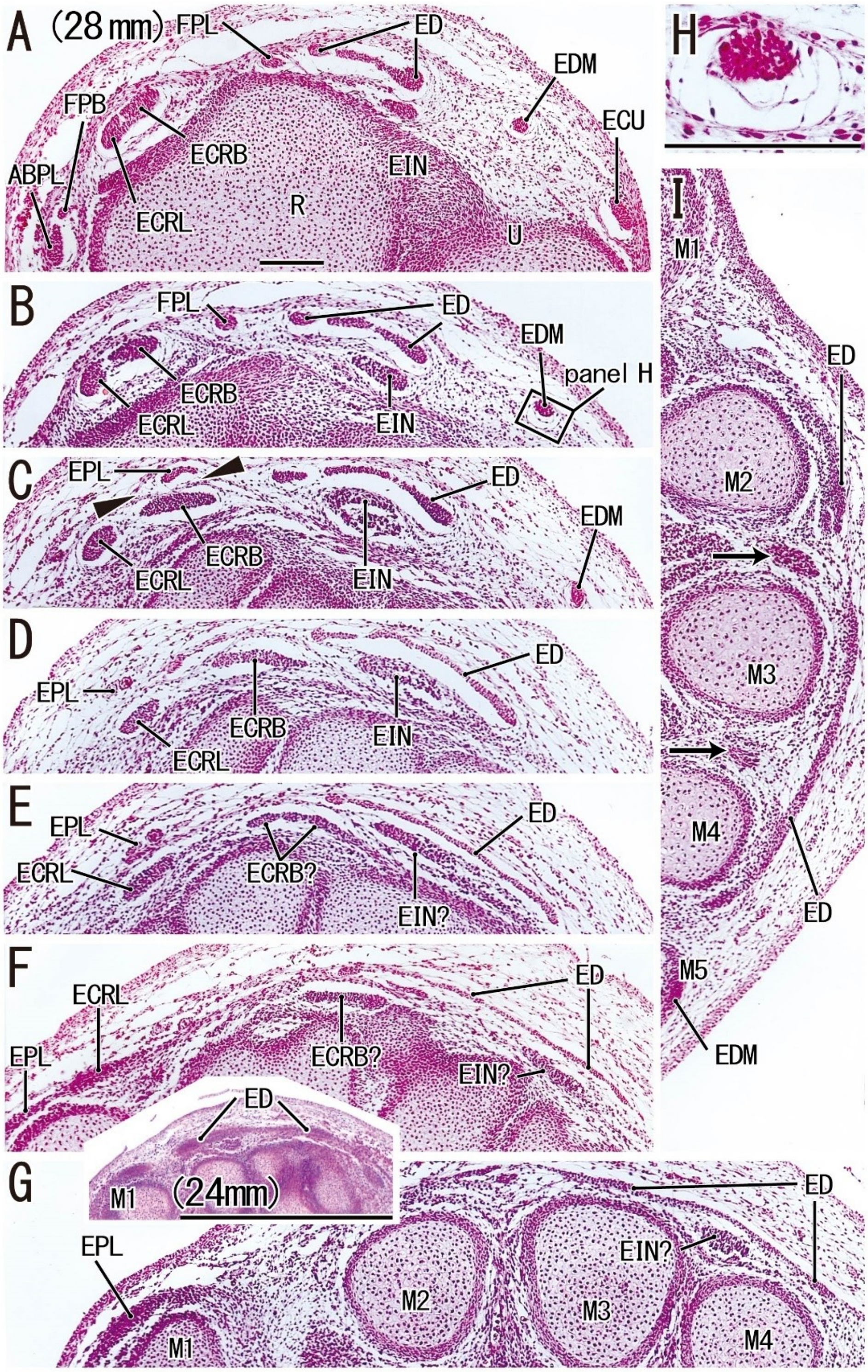

Figure 2. Transverse sections of the wrist and hand of a fetus with 28 mm CRL

(approximately 7 weeks). Panel A displays the most proximal plane, while panel I the most distal plane. The radial side (or The ulnar side) of the specimen corresponds to the left-hand side (or the right-hand side) of each panel. Panel H, corresponding to a square in panel B, exhibits an initial sheath of the extensor digiti minimi tendon (EDM) at the higher magnification. The extensor digitorum tendon (ED) appears to be divided into three slips to the index, middle and ring fingers in the carpal bone level (panels A–C), but it extends mediaolaterally in the distal sites (panels E–G and I). Strangely, a candidate extensor indicis (EIN) as well as a candidate extensor carpi radialis brevis (ECRB) extends medially to connect mesenchymal condensations (the captions with a question mark; panels E–G). the mesenchymal condensations appeared to correspond to ligaments sandwiched by metacarpal bones of the index, middle and ring fingers (arrows in Fig. 2I). A tendon of the extensor pollicis longus (EPL) is separated by a membrane from the extensor carpi radialis brevis (arrowheads; panel C). In the metacarpal bone level (panels F–I), the extensor digitorum tendons widely extended to provide a common tendinous plate-like appearance. An insert between in panel F and G exhibits a hand of the different specimen (24 mm CRL) that contains the thickest common plate. Panels A–G and I were prepared at the same magnification (scale bars, 1 mm in panel A; 0.1 mm in panel H). The other captions, see the common abbreviation.

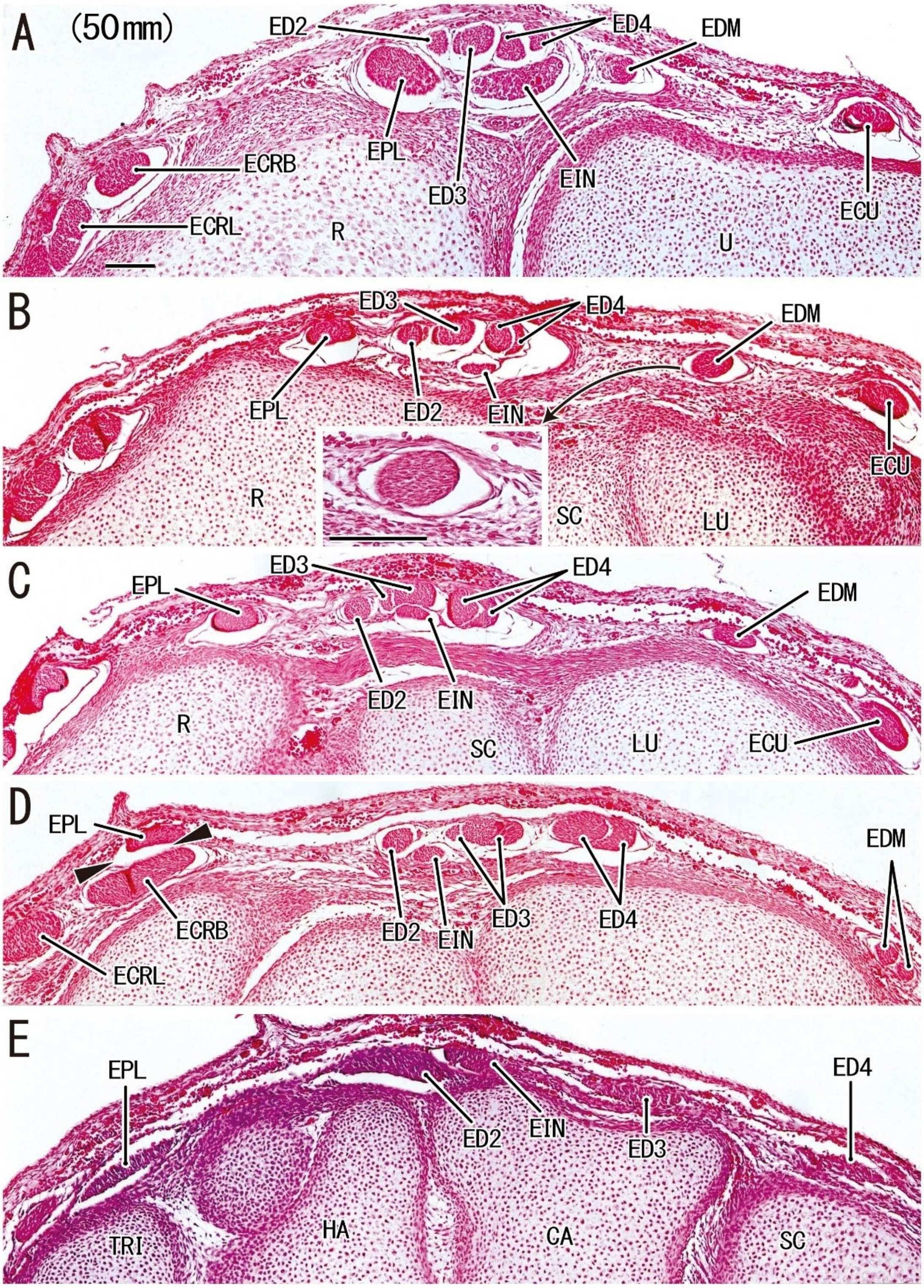

Figure 3. Transverse sections of the wrist and hand of a fetus with 50 mm CRL

(approximately 10 weeks). Panel A displays the most proximal plane, while panel E the most distal plane. The radial side (or The ulnar side) of the specimen corresponds to the left-hand side (or the right-hand side) of each panel. An insert in panel B exhibits a monolayered sheath of the EDM tendon at the higher magnification. A tendon of the EPL is surrounded by a proper sheath and migrate from a site adjacent to the ED2 (panel A) to a site in the dorsal side of a tendon of the ECRB (panel D). There is a membranous septum is losing between the EPL and ECRB (double arrowheads in panel D). The ED3, ED4 is composed of two tendon slips (panels A–E). Panels A–E were prepared at the same magnification (scale bars, 1 mm in panel A; 0.1 mm in the insert in panel B). CA — capitatum; ECRB — extensor carpi radialis brevis; ECRL — extensor carpi radialis longus; ED2 — extensor digitorum tendon to the index finger; ED3 — extensor digitorum tendon to the middle finger; ED4 — extensor digitorum tendon to the ring finger; EDM — extensor digiti minimi; EIN — extensor indicis; EPL — extensor pollicis longus; HA — hamatum; LU — lunatum; R — radius; SC — scaphoideum; TRI — triquetrum; U — ulma.

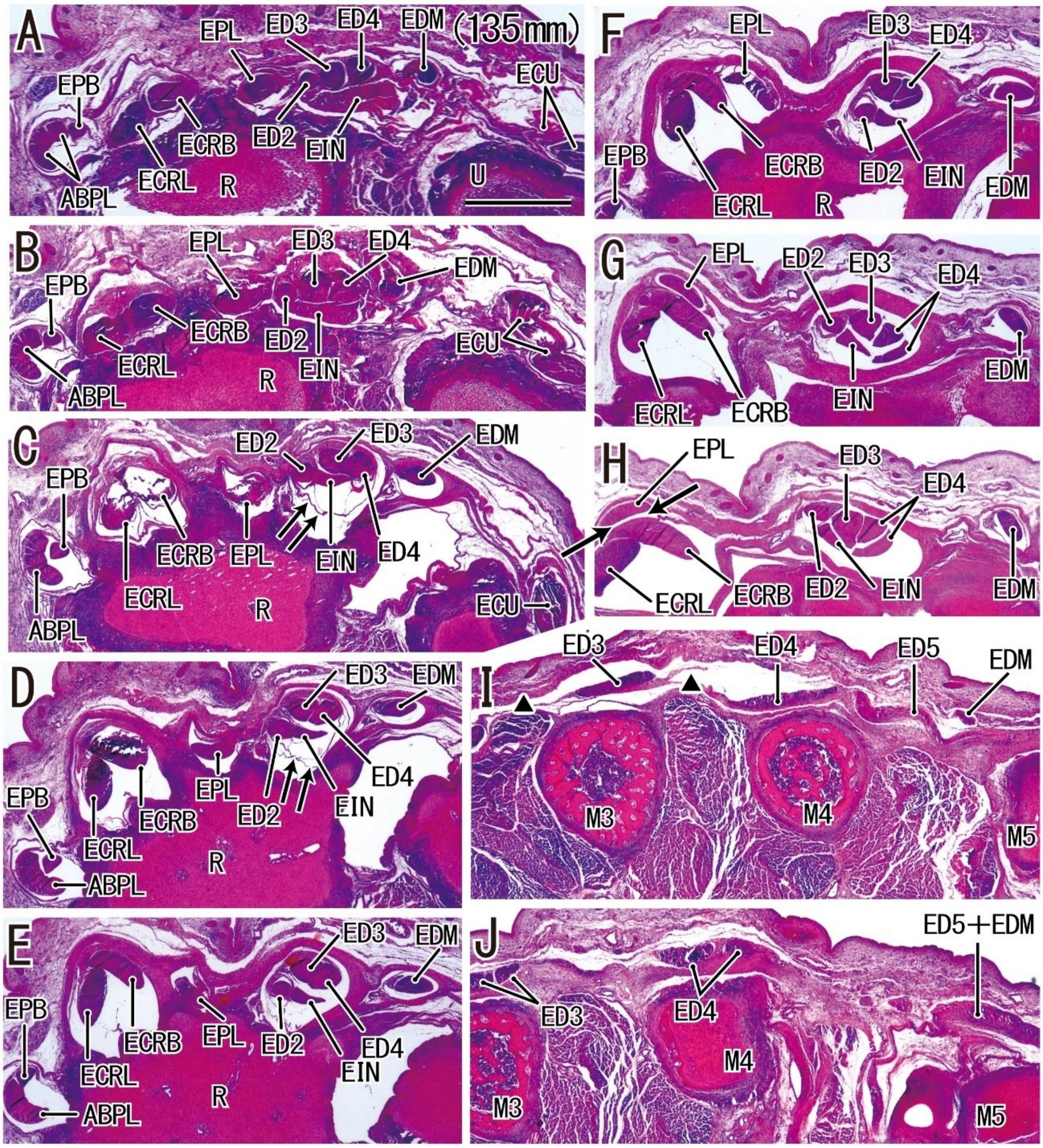

Figure 4. Transverse sections of the wrist and hand of a fetus with 135 mm CRL

(approximately 16 weeks). Panel A displays the most proximal plane, while panel J the most distal plane. The radial side (or The ulnar side) of the specimen corresponds to the left-hand side (or the right-hand side) of each panel. The EIN appeared large proximally (panels A and B). A tendon of the EPL is contained in a same canal of sheath with the ECRB and ECRL without septation (double arrows in panel H). The extensor digitorum tendon to the index or ring finger (ED2, ED4) is composed of 2 tendon slips (panels G and H). Some of the tendons were injured during histological procedure (e.g., ECRL and ECRB in panel C). A thin layer of the sheath appeared to be detached from the tendon (double arrows in panels C and D). Triangles in panel I indicate the so-called tendinous connection. All panels were prepared at the same magnification (scale bar in panel A, 1 mm). ABPL — abductor pollicis longus; ECRB — extensor carpi radialis brevis; ECRL — extensor carpi radialis longus; ECU — extensor carpi ulnarus; ED2 — extensor digitorum tendon to the index finger; ED3 — extensor digitorum tendon to the middle finger; ED4 — extensor digitorum tendon to the ring finger; EDM — extensor digiti minimi; EIN — extensor indicis; EPL — extensor pollicis longus; HA — hamatum; LU — lunatum; M3, M4 or M5 — 3^{th}, 4^{th} or 5^{th} metacarpal bone; R — radius; U — ulma.

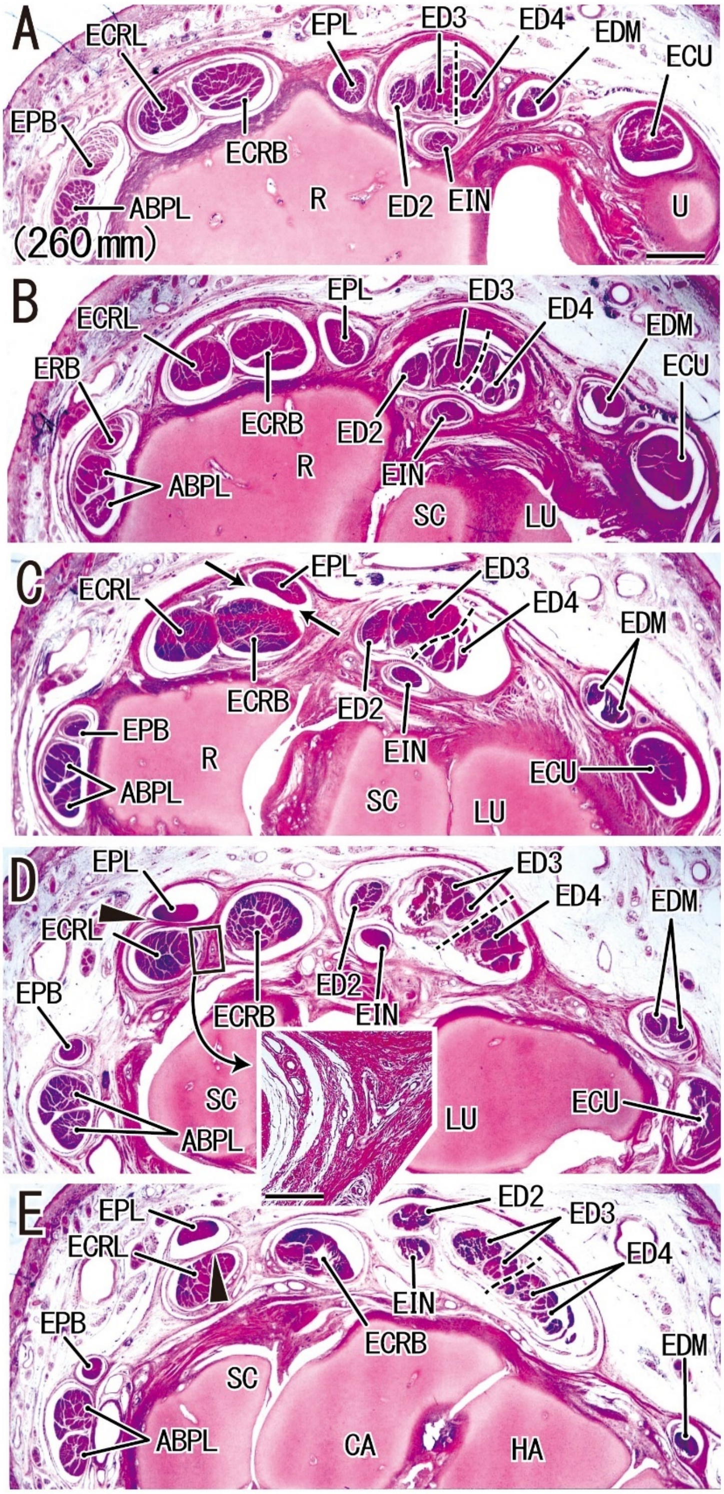

Figure 5. Transverse sections of the wrist and hand of a fetus with 260 mm CRL

(approximately 31 weeks). Panel A displays the most proximal plane, while panel E the most distal plane in the figure. More distal planes will be shown in Figure 6. The radial side (or The ulnar side) of the specimen corresponds to the left-hand side (or the right-hand side) of each panel. A tendon of the EPL loses the proper sheath (double arrows in panel C) in the dorsal side of ECRB, but there is a definite membrane (arrowhead in panel D) facing the ECRL. Tendon slips of the ED3 are close to those of the ED4 without a clear demarcation (dotted line in panels A–C). The ED2 is separate from the EIN by membranes (panels A–D). Two tendon slips make tendons of the ABPL and EDM. An insert in panel D exhibits a multilaminar tendon sheath of the extensor carpi radialis longus at the higher magnification: its intermediate layer of the sheath contains vessels. Panels A–E were prepared at the same magnification (scale bars: 1 mm in panel A, 0.1 mm in the insert). ABPL — abductor pollicis longus; ECRB — extensor carpi radialis brevis; ECRL — extensor carpi radialis longus; ECU — extensor carpi ulnarus; ED2 — extensor digitorum tendon to the index finger; ED3 — extensor digitorum tendon to the middle finger; ED4 — extensor digitorum tendon to the ring finger; EDM — extensor digiti minimi; EIN — extensor indicis; EPL — extensor pollicis longus; HA — hamatum; LU — lunatum; R — radius; SC — scaphoideum; U — ulma.

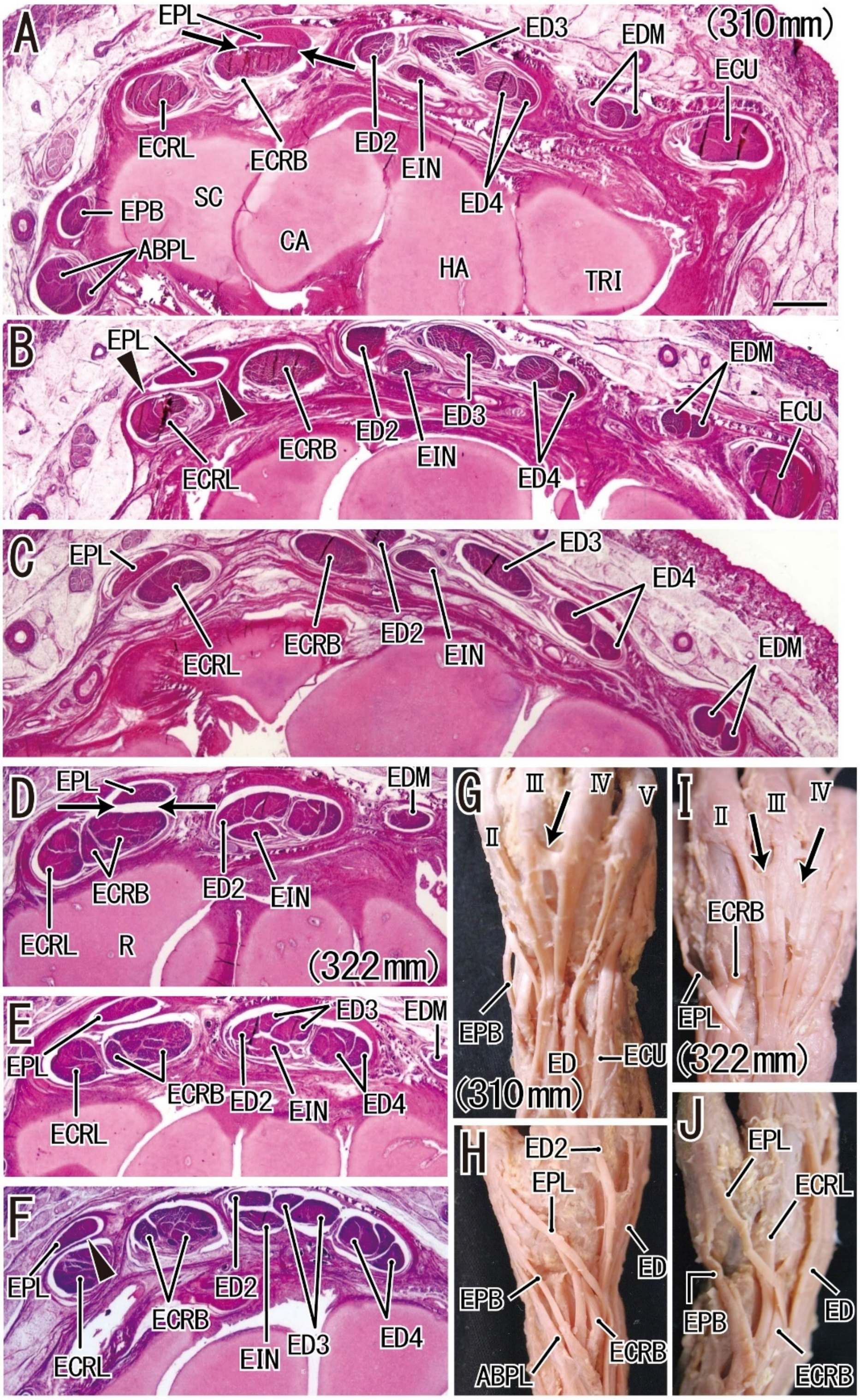

Figure 6. Transverse sections of the wrist and hand of two late-stage fetuses with a clear

separation between tendons. Panels A–C, a fetus with 310 mm CRL (approximately 37 weeks); panels D–F, a fetus with 322 mm (approximately 38 weeks). Panels A and D display the most proximal plane in each of these two specimens. The radial side (or The ulnar side) of the specimen corresponds to the left-hand side (or the right-hand side) of each panel. In the larger specimen, a tendon of the EPL loses the proper sheath (double arrows in panels A and D) near the ECRB. However, the EPL tendon re-obtains the sheath in the distal plane (double arrowheads in panels B and F). Tendon slips of the extensor digitorum (ED2, ED3, ED4) are arranged in line in contrast to those in Figs. 4D and 7A–F. Panels G and H exhibit gross anatomy of another hand of the same specimen (322 mm). The so-called tendinous connection appears to exist (arrow), but the multi-slips configuration of each finger tendon of the ED is not clear in gross observation. All panels were prepared at the same magnification (scale bar in panel A, 1 mm). ABPL — abductor pollicis longus; CA — capitatum; ECRB — extensor carpi radialis brevis; ECRL — extensor carpi radialis longus; ECU — extensor carpi ulnarus; ED2 — extensor digitorum tendon to the index finger; ED3 — extensor digitorum tendon to the middle finger; ED4 — extensor digitorum tendon to the ring finger; EDM — extensor digiti minimi; EIN — extensor indicis; EPL — extensor pollicis longus; HA — hamatum; LU — lunatum; M2, M3, M4 or M5 —2nd, 3th, 4th or 5th metacarpal bone; R — radius; SC — scaphoideum; TRI — triquetrum.

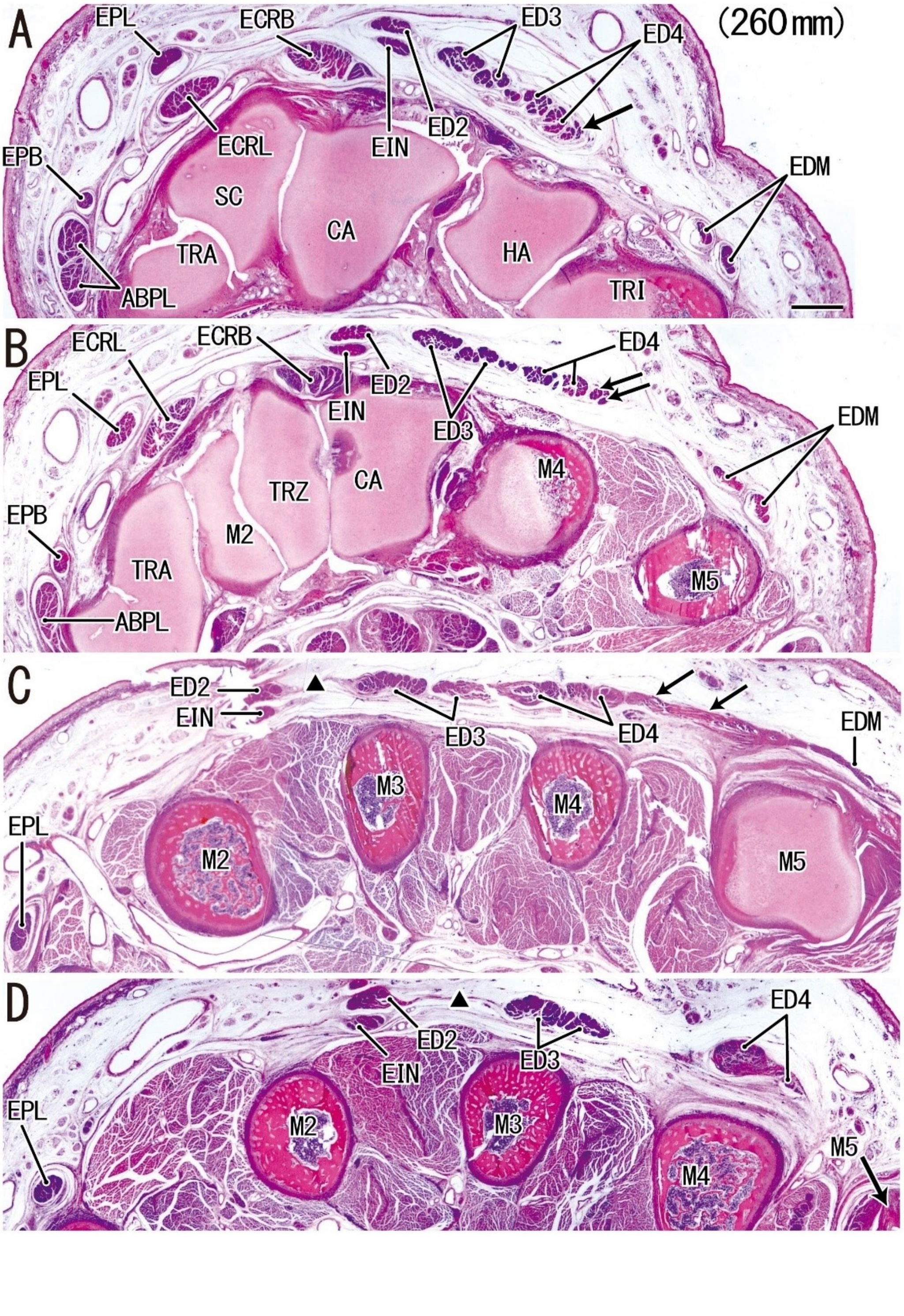

Figure 7. Distal transverse sections of a specimen with 260 mm. The same specimen shown

in Figure 5 (approximately 31 weeks). Panel A displays the most proximal plane, while panel E the most distal plane in the figure. The radial side (or The ulnar side) of the specimen corresponds to the left-hand side (or the right-hand side) of each panel. Tendons for the ED3 and ED4 are divided into abundant thin tendon slips: the most medial (ulnar) group of the slips (arrow in panels A and B) extends medially to connect with EDM tendon at the metacarpal bone level (arrows in panel C). The abundant tendon slips are fused in the distal site (panel D) and a membranous connection (triangle) is seen between tendons of the ED2 and ED3. All panels were prepared at the same extends magnification (scale bar in panel A, 1 mm). ABPL — abductor pollicis longus; CA — capitatum; ECRB — extensor carpi radialis brevis; ECRL — extensor carpi radialis longus; ECU — extensor carpi ulnarus; ED2 — extensor digitorum tendon to the index finger; ED3 — extensor digitorum tendon to the middle finger; ED4 — extensor digitorum tendon to the ring finger; EDM — extensor digiti minimi; EIN — extensor indicis; EPL — extensor pollicis longus; HA — hamatum; LU — lunatum; M2, M3, M4 or M5 —2^{nd}, 3^{th}, 4^{th} or 5^{th} metacarpal bone; R — radius; SC — scaphoideum; TRA — trapezium; TRZ — trapezoideum; U — ulma.

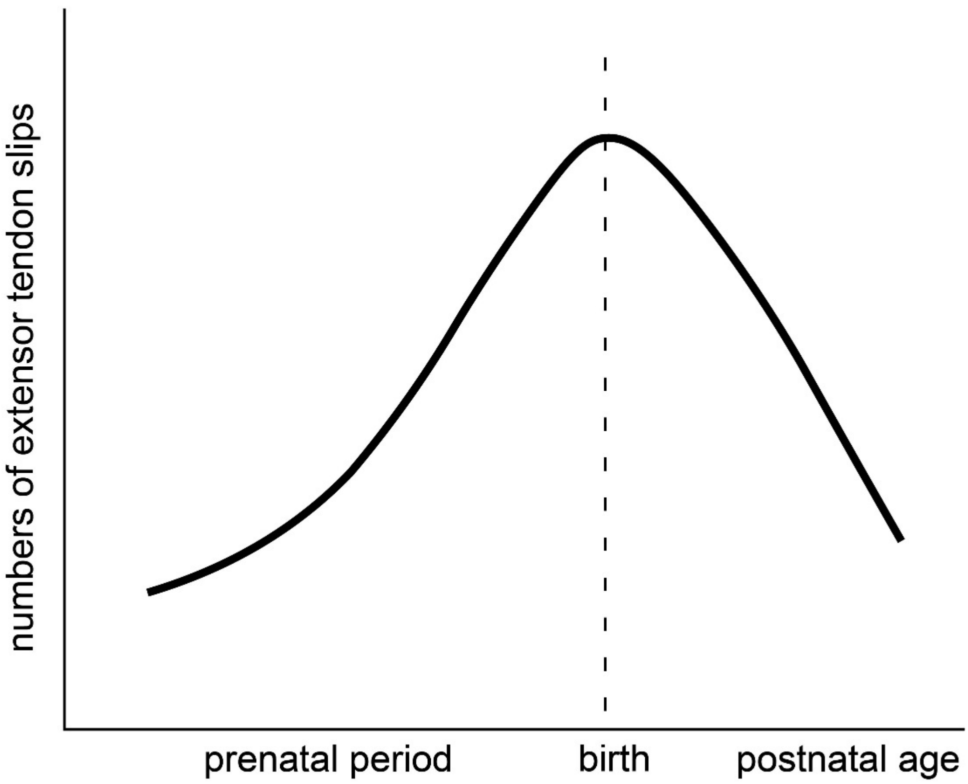

Figure 8. Possible ch8nges in extensor tendon numbers for the middle and ring fingers of the hand: a hypothesis. Earlier fetuses showed a simpler configuration with fewer extensor tendon slips, whereas later fetuses had a greater number of tendon slips. The hand extensor tendon seemed to be the greatest in number at birth and, postnatally, they seemed to be reduced in number because of reconstruction (elimination and/or fusion) depending on learning of movements and mechanical demands.