Observational study

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Anatomical variations and developmental insights of tendons in the first extensor compartment of the hand: Cadaveric study with surgical implications

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Abstract

Background. Anatomical variations in first extensor compartment play a role in the development of de Quervain's disease. This study delves into the detailed examination of these anatomical variations.

Methods. 50 upper limbs (28 male and 22 female) from 25 formalin-embalmed adult human cadavers were dissected to investigate variations in tendons of first extensor compartment.

Results. Accessory tendons to main tendon of abductor pollicis longus (APL) were reported in 49 (98%) cases, with 34% having two accessory tendons, 52% having three, and 12% having four. Terminal ends of these accessory tendons were generally consistent, except in one case where it split into two tendinous bands at insertion site, which was most commonly at base of first metacarpal. Extensor pollicis brevis (EPB) was found as a single tendon in 48 cases, with one case each of duplication and absence. In 19 cases (38%), muscle belly of EPB was fused with that of APL to some extent and it typically inserted at base of the proximal phalanx of the thumb. Average length of muscle belly, tendon, and muscle tendon ratio (MTR) of APL was 15.99±0.62 cm, 5.91±0.76 cm and 2.71 and of EPB was 6.39±0.29 cm, 9.15±0.74 cm and 0.70 respectively.

Conclusion. APL variations range from accessory tendons, splitting of tendons to various insertion points. Additionally, length and insertions points of these accessory tendons are key factors in deciding their usability as graft sources for tendon reconstruction and in surgical treatments of conditions like de Quervain's tenosynovitis. ***Clin Ter 2024; 175 (1):26-33 doi: 10.7417/CT.2024.5030***

Keywords: *Extensor compartment, Hand tendons, Tendon grafting, Thumb anatomy, De Quervain's tenosynovitis*

Introduction

After humans transitioned from a quadrupedal stance to a more upright posture, the use of their hands became increasingly important. Among all the fingers, the thumb underwent significant evolution and became a vital tool for grasping and manipulating objects (1, 2). The presence of a functional extrinsic thumb tendon has been nearly constant in humans, indicating its crucial role in our ability to manipulate objects during our evolutionary history (3). Variations in tendons passing beneath the extensor retinaculum are not uncommon, but particular attention has been given to the anatomy of the muscles within the first extensor compartment, namely the abductor pollicis longus (APL) and extensor pollicis brevis (EPB), due to their involvement in conditions like de Quervain's tenosynovitis (4). Traditional anatomical literature describes APL as a flattened, spindle-shaped muscle that originates just below the supinator muscle. It crosses the wrist under the extensor retinaculum within the first extensor compartment and ultimately attaches to the lateral side of the base of the first metacarpal bone (5-7).

EPB, a muscle that is more distinct in humans compared to other species, can sometimes be absent. It may fuse with APL or continue as an independent tendon to the base of the distal thumb phalanx (5). However, many modern anatomical textbooks fail to adequately illustrate or describe these common variations in hand muscles and tendons (6), leading students to believe they have discovered new structures during laboratory dissections. Additionally, historical estimates of the frequency of thumb muscle variations have been imprecise (5).

Recent research has shown that the APL tendon exhibits much greater variability than previously believed (8, 9). These anatomical variations range from additional tendons to variations in insertion points or the splitting of tendons into multiple bands (10, 11). Familiarity with these variations is crucial, as they have been found to be clinically relevant in the development of conditions like De Quervain's tenosynovitis, particularly concerning the number, thickness, length (12), and insertion sites of these tendons (13). Failing to recognize these variations can lead to persistent pain due to

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incomplete surgical procedures or confusion during tendon transplantation surgeries (14, 15).

Given this context, our current study aims to comprehensively examine the morphological and morphometric variations in the tendons within the first extensor compartment of the hand. This research not only has significant clinical applications in hand surgery but also serves as a valuable supplement to traditional anatomy textbooks.

Materials and methods

50 upper limbs (28 male & 22 female) of 25 formalin embalmed adult human cadavers obtained from the Department of Anatomy, were dissected in the following manner:

The skin was reflected from the back of forearm, the dorsum of hand and the digits by giving skin incisions as shown in Fig. 1.

To start with skin and the superficial fascia was removed. Then the deep fascia was reflected carefully after isolating the extensor retinaculum and securing its attachments. This exposed the muscles and tendons of the dorsum of the hand. The pattern of arrangement of the tendons of these muscles as they pass beneath the extensor retinaculum was studied. Then the extensor retinaculum was divided longitudinally over the first compartment for the full exposure of the tendons, keeping the upper limb in a neutral position for optimal visualization of the tendons. Tendons of APL and EPB were isolated from their insertion to their origin using a surgical magnifying glass, the same was also used to distinguish independent tendons from tendinous slips. Independent tendons were defined as those originating directly from the muscle belly without connection to other tendons, while tendinous slips denoted the division of one tendon (usually at the insertion point) into diverse interconnected bands (16).

Fig. 1. Skin incisions for exposing posterior group forearm muscles and extensor compartments of the hand

The tendons of APL and EPL were identified on the lateral aspect of the dorsum of the hand passing within the first osteofascial compartment. They were separated from one another by splitting the fascial septa longitudinally, through which they were united in their proximal parts. The tendons were followed as they passed beneath the extensor retinaculum and on the dorsum of the hand as far as their insertions.

Variations regarding the mode of origin, insertion, and nerve supply of the APL and EPB was noted along with the presence of any accessory slips. In cases with accessory slips, mode of insertion was recorded for each slip.

The length of the fleshy part of the muscle was measured as the distance from the origin of the most proximal muscle fibers to the insertion site of the most distal muscle fibres. The most proximal and most distal points were marked with Indian ink. Digital vernier caliper (Mitutoyo, Japan) with minimum read value is 0.01 mm was used to measure the distance between the two marked points and recorded as the length of the muscle belly.

The length of the tendons was also taken in a similar manner. Tendons were defined as independent or easily divisible bands originating from a muscle. Tendon slips were defined as tendinous division distal to the origin of the tendon i.e. splitting of a single tendon into two or more separable smaller tendon slips. A tendon was considered double, triple or quadruple based on the number of separable tendons originating from the muscle at the myotendinous junction. In the case of multiple tendons of a muscle, the length of the longest and shortest tendons was recorded and the average tendon length was calculated. All the measurements were taken thrice at different point of times by the same observer and the mean value was recorded as the final for further analysis.

Muscle tendon ratio was calculated according to the following equation:

$$\text{Muscle tendon ratio} = \frac{\text{Length of the fleshy part of the muscle}}{\text{Tendon length}}$$

The observations were recorded on the proforma and master chart was made of the muscle and tendon lengths. The data was compiled and analyzed statistically to determine any significant difference between sides of the limb and sex. (p value <0.05 was taken.

Results

APL: No variation was observed regarding the site of origin and nerve supply. However, the muscular belly of APL was fused with that of EPB in 19 cases confirming the fact that these muscles are differentiations of a common muscle. Of all the extensor tendons the tendons of APL were found to vary the most. In 49 specimens (98%), accessory tendons to the APL main tendon were observed

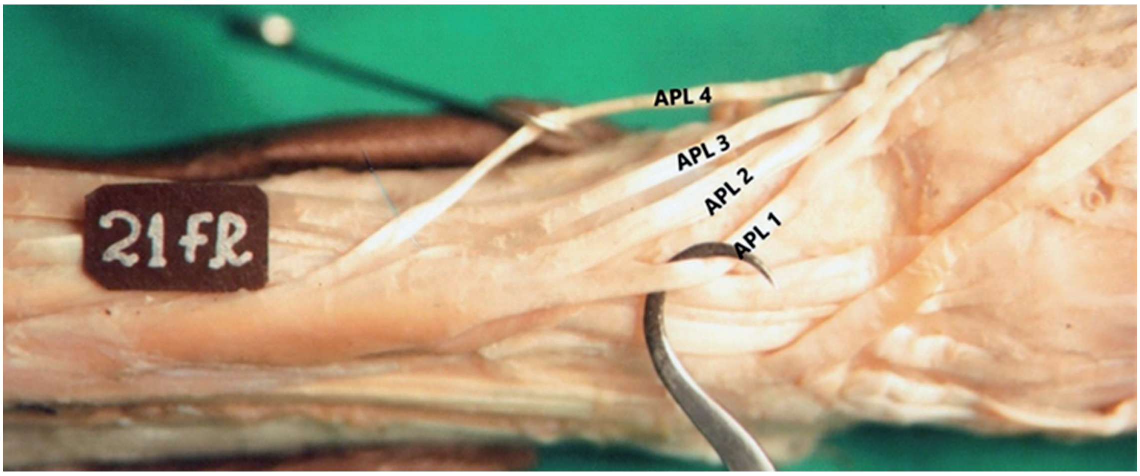

Fig. 2. Right hand specimen (21FR) shows four independent tendons originating directly from the muscle belly without connection to other tendons. APL 1, APL 2, APL 3 inserted into the base of the 1rstMTC bone, APL 4 to the trapezium.

and were characteristically arranged palmarly and medially to the main APL tendon. The number of accessory tendons was two in 17 (34%), three in 26 (52%) and four in 6 cases (12%) (Fig. 2).

Almost in all the cases, the terminal end of each accessory tendon was consistent, except in one case where it split into two tendinous bands at the site of insertion) (Fig. 3).

These accessory tendons inserted at various sites which in order of frequency were the base of the first metacarpal, the trapezium, the abductor pollicis brevis (APB), capsule of first carpometacarpal joint and the volar carpal ligament.

Mode of insertion of APL when only one accessory tendon was present:

Out of 17 specimens with one accessory tendon; in 8 cases accessory tendon inserted into trapezium (Tz), in 4 into APB, in 3 into CMJ (capsule of first carpometacarpal joint) and in 2 into VCL (volar carpal ligament).

Mode of insertion of APL when two accessory tendons were present:

Out of 26 specimens with two accessory tendons; in 20 cases, one slip inserted into the Tz and another on to the tendon of APB; in four cases, one slip inserted on to the Tz and another on to the CMJ; in two cases, one slip inserted on to the APB and the another on to the deep fascia (DF).

Mode of insertion of APL when three accessory tendons were present:

Out of six specimens with three accessory slips; in four cases, one slip each inserted into Tz, CMJ and APB; in two cases, one slip each inserted into TZ, DF and APB.

The main tendon always inserted on to the base of first metacarpal except in one case where the APL had a single tendon which inserted onto the trapezium. It has been observed that the absence of slip to the base of first metacarpal results in the subluxation of the trapezio-metacarpal joint of thumb due to stretching of its capsular ligament

EPB: EPB muscle belly was found in all the cases, except one, where it was entirely tendinous arising from the deep fascia covering the dorsum of the wrist. The sporadic absence of the muscle belly of the EPB reflects that it is a phylogenetically young structure, found as a separate entity only in humans.

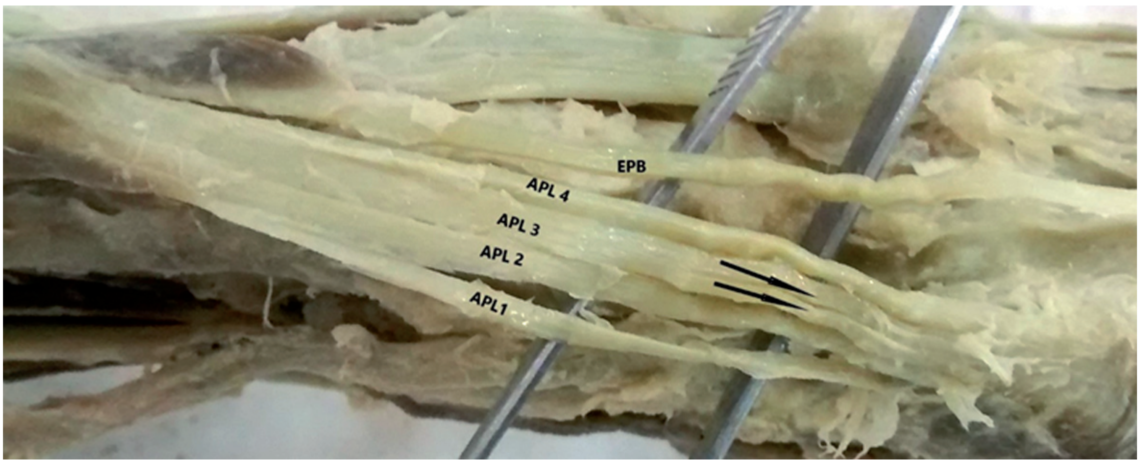

Fig. 3. Left hand specimen characterized by a main APL tendon (APL) split into two tendinous bands and both of them inserts on to the 1rstMTC (arrows).

In rest of the cases, the muscle belly of EPB was either entirely distinct (30 cases), or was fused to a variable extent (19 cases) with the muscle belly of APL.

Pattern of the insertion of EPB:

In 49 (98%) limbs, the belly of the EPB ended into a single tendon. Out of them, in 46 (92%) limbs, it inserted onto the base of the proximal phalanx of the thumb, in 2 (4%) limbs, the tendon inserted onto the base of distal phalanx of thumb and in 1 (2%) limb, the tendon was connected with the tendon of EPL by an intertendinous connection (Fig. 4) and then it inserted onto the base of the proximal phalanx of the thumb.

The sole case where the tendon of EPB split into two slips, one inserted on to the proximal and other to the base of the distal phalanx of thumb.

Table 1 shows the average muscle and tendon lengths of the first extensor compartment of the hand muscles (cm)

Discussion

The existing body of literature suggests that the typical anatomical description of the abductor pollicis longus (APL) tendon is more of an exception than the rule. In 1892, Quain (17) noted that among all the extensor tendons, the APL tendons were the most likely to exhibit variations.

Our current study has reinforced the idea that APL tendon anatomy is incredibly diverse, with significant differences observed among individuals. Remarkably, out of all the dissected upper limbs, only one (2%) displayed a single APL tendon insertion at the base of the first metacarpal bone (7, 18). In contrast to what classical literature has described, the majority (98%) exhibited variations in the number of tendons and their points of insertion. These findings align with contemporary evidence, which suggests that the percentage of APL muscle variants can vary widely, ranging from 33% to 100% (8, 9, 13, 19-26).

Numerous studies have consistently shown that the presence of accessory or supernumerary APL tendons is not unusual in human anatomy; in fact, it's quite common. This phenomenon may be linked to the evolutionary development of the thumb, which underwent significant changes to become one of the primary tools for grasping, securing, and manipulating objects (1, 27). The nearly constant presence of a functional extrinsic thumb tendon in humans indicates a strong selective pressure for retaining this structure to enhance our manipulative abilities during the course of human evolution. Regrettably, many modern anatomical textbooks do not adequately cover these common muscle and tendon variations in the hand. Therefore, it is advisable to incorporate these findings into textbooks and emphasize the importance of teaching students about the variability in thumb anatomy and its clinical implications to minimize adverse outcomes during surgery.

Previous studies have reported substantial variations in the number of APL tendons. However, these studies did not

Table 1

Muscle	ML (mean±SD)	Range	TL (mean±SD)	Range	ML: TL
APL	15.99±0.62	14.80-18.10	5.91±0.76	4.20-7.30	2.71
EPB	6.39±0.29	6.00-6.90	9.15±0.74	7.40-10.50	0.70

ML, Muscle length; TL, Tendon length; ML: TL, Muscle tendon ratio
*No significant difference was reported between male and female hands

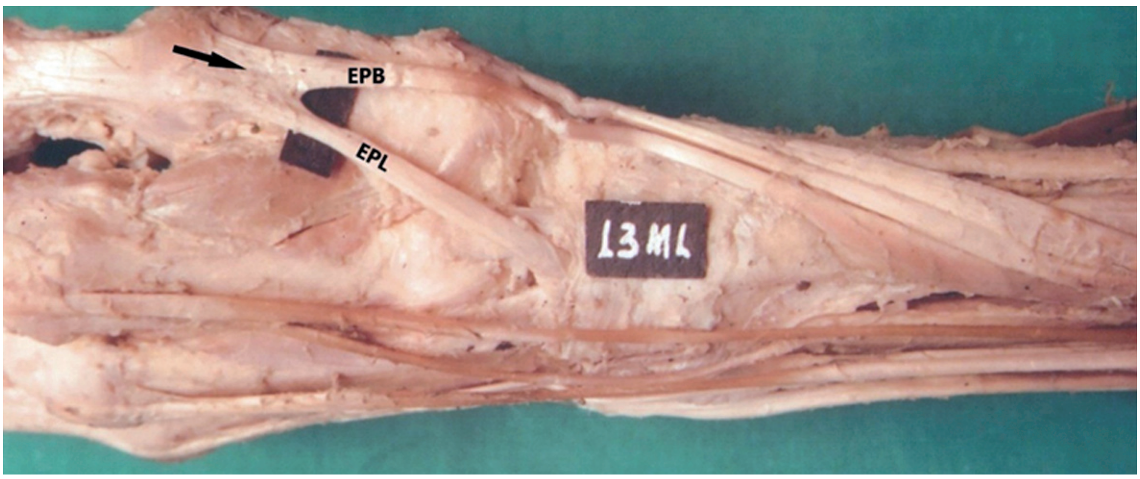

Fig. 4. Left hand specimen (13 ML) shows tendinous interconnections (arrow) between the tendon of EPB and EPL, finally the tendon of EPB inserts onto the base of the proximal phalanx of the thumb.

consistently differentiate between tendons and tendinous bands, making comparisons challenging. Therefore, it is essential to establish standardized definitions before reporting such variations (8, 15, 25, 28). Additionally, findings should be confirmed using dissection microscopes for intratendinous dissection (15, 28-30), as accessory tendons may be mistaken for ruptured tendons. In cases of suspicion, ultrasonography should be employed for a more accurate diagnosis (11).

The presence of accessory APL tendons has been associated with the development of chronic tenosynovitis known as de Quervain's syndrome (12, 29). However, it's important to note that the presence of accessory tendons alone doesn't always lead to symptoms. Instead, it is the presence of fibrous septa between these tendons or between them and the extensor pollicis brevis (EPB) tendon that can compromise the normal anatomical space of the first radial groove, increasing the risk of de Quervain's syndrome (31). Although surgical release of the APL tendons has proven to be an effective treatment for de Quervain's tenosynovitis (32), recent systematic reviews have not found a significant relationship between a patient having more than one APL tendon and a predisposition to develop de Quervain's tenosynovitis (13).

Considering the variability in the number of tendons, it is advisable to utilize accessory abductor pollicis longus (APL) tendons for grafting purposes rather than other tendon fragments. However, it's crucial to take into account variations in their points of insertion and mechanical orientation during the procedure. The wide array of insertion patterns found in our study provides a comprehensive overview of the most common sites where APL tendons attach. Generally, the primary APL tendon inserts at the base of the first metacarpal, while accessory tendons can insert at various locations, including the trapezium, first metacarpal, abductor pollicis brevis (APB), opponens pollicis (OP), flexor pollicis brevis, thenar fascia, volar carpal ligament, and trapeziometacarpal (TMC) joint. Different authors have investigated APL insertion points and reported variations (8, 15, 25, 28).

The embryological development of the upper limb may help explain the diversity in APL insertion modes. Hand morphogenesis begins between six and 14 weeks of gestation (33), with the digits forming as single chondrogenic condensations around 36 days after conception (34). Thumb development starts at six weeks and undergoes rotation between weeks eight and ten (33). During this period, the APL tendon begins as an undifferentiated mass, indistinguishable from the surrounding mesenchyme. Over time, it evolves into a three-slip tendon with attachments to the trapezium, the first metacarpal, and typically a distal site on the OP muscle. As the thenar muscles develop, the connection between the OP and APL tendon weakens, while the APB gains its connection, considering that the APB muscle originates independently from the APL (35). Some researchers have attributed specific functions to tendons based on their insertion points. For instance, it has been suggested that tendons inserting on the trapezium primarily abduct the carpus rather than the first metacarpal and stabilize the TMC joint (36, 37).

In our study, the primary APL tendon consistently inserted at the base of the first metacarpal, except in one case where a single APL tendon inserted onto the trapezium. Notably, the absence of a slip attaching to the base of the first metacarpal can lead to subluxation of the trapeziometacarpal joint of the thumb due to the stretching of its capsular ligament. As for accessory tendons, their insertion sites varied depending on their number, but the trapezium was the most common site of insertion in all cases. This contrasts with findings from other researchers who reported a lower percentage of tendons inserting on the trapezium (16, 24, 29).

From a clinical perspective, the exact site of APL tendon insertion has been linked to the development of de Quervain's tenosynovitis (13), possibly due to increased friction experienced by accessory tendons during activity and their heightened susceptibility to trauma (30). Additionally, the absence of trapezial insertions has been associated with the development of TMC arthritis in some studies (38), while others have found no direct relationship (39). Furthermore, thenar insertions alone do not guarantee a stable TMC joint (40), as active thumb movement can result in subluxation (41). This type of insertion has also been related to retention of the capacity for opposition in patients with median nerve injuries (25). The presence of supernumerary APL tendons inserted into the thenar muscles has been closely associated with the development of TMC osteoarthritis (41), and a surgical procedure involving the tenotomy of these accessory or supernumerary APL tendons has been proposed for treating TMC osteoarthritis (42).

In nutshell, when harvesting accessory APL tendons for grafting in procedures like resection-suspension-interposition-arthroplasty, careful consideration must be given to the specific tendon's insertion point. Tendons inserting on the trapezium may not be suitable for this type of procedure.

Bunnel (43), the first individual to recognize the presence of accessory tendons pointed out that anomalies in these tendons can disrupt the biomechanics of the involved tendon, leading to longitudinal strain and the generation of pain. This occurs because the aberrant tendon has a limited range of motion compared to the primary tendon, with which it shares a common origin. The abnormal tendon experiences greater stress during activities due to its course around the radial styloid process, making it more susceptible to injury. Since it attaches to the trapezium (Tz) or its vicinity, its contraction results in the outward rotation of the trapezium, allowing for greater abduction of the first metacarpal bone. However, if the attachment to the base of the first metacarpal is absent, it can lead to subluxation of the trapeziometacarpal joint of the thumb due to the stretching of its capsular ligament, a result of an imbalance in the intrinsic and extrinsic tendon forces. This unique attachment pattern is considered a remnant of the primitive musculature pattern seen in primates (41).

Regarding the extensor pollicis brevis (EPB), a muscle that is more developed in humans, it can sometimes be absent and fused with the abductor pollicis longus (APL), especially in simians (5). Alternatively, its tendon may merge with that of the long extensor or continue as an independent slip attaching to the base of the distal phalanx (1). Wood (27), Parsons and Robinson (44) and Stein (45) observed the muscle belly of EPB to be absent in 6.35%, 7% and 6% of arms respectively. In our study, we found that in 38% of cases, the EPB was fused to varying degrees with the APL muscle belly. This fusion suggests that evolutionarily, EPB and APL originated from a common muscle mass. The absence of the EPB muscle belly in a small percentage of cases reflects its relatively recent appearance in human evolution as a distinct structure.

Understanding the variations in EPB is particularly relevant in the context of de Quervain's disease, where failure to recognize these variants can result in persistent pain due to incomplete surgical release of the tendon sheaths. Additionally, knowledge of accessory EPB tendons is crucial for reconstructive hand surgery. Dawson & Barton (46) laid emphasis on the importance of knowing the anatomical variations of the EPB for a full understanding of extensor apparatus of thumb. In the case where EPB was interconnected to EPL, if the tendon of EPL ruptures, the interphalangeal extension of the thumb may still be intact and be surprisingly good. This is because interphalangeal extension is carried out by the EPB in such cases.

Tendon length is an important consideration when selecting grafts for tendon transfer procedures (47). Longer tendons are often preferred for these procedures. Evidence suggests that muscle-tendon ratio (MTR) plays a role in muscle development and strength. A higher MTR, which can result from a longer tendon, is associated with greater strength. In our study, we calculated the MTR for APL and found that it had the maximum isokinetic strength among the forearm extensors.

Various studies have examined the length and thickness of accessory APL tendons. Most have not found significant differences between sexes but have noted that tendons become longer as they move laterally (47). This finding suggests that more medial tendons are thicker, implying a negative linear relationship between tendon length and thickness. These characteristics may explain why supernumerary APL tendons are not directly linked to the development of de Quervain's tenosynovitis and may be useful in planning correcting surgeries of the congenital thumb anomalies (48). Tendon length is a crucial factor in selecting suitable grafts, and the findings in our study support the potential use of APL tendons for certain surgical procedures (50).

Our study has some limitations, including the use of formalin-preserved cadaveric limbs, which can cause tissue shrinkage and potential differences compared to fresh cadavers. The sample size, although sufficient for basic statistical analysis, may limit the generalizability of our findings. Additionally, the lack of standardized nomenclature in reporting extensor tendon variations makes it challenging to compare studies. Future research could benefit from analyzing these variations in fresh cadavers combined with ultrasound investigations.

Conclusion

Variations in the abductor pollicis longus (APL) tendon are frequently encountered and encompass a broad spectrum of anomalies, including the presence of additional tendons or tendon-like structures and variations in their points of attachment. These deviations can be elucidated by considering the embryological development and evolutionary origins of thumb muscles. When the APL tendon fails to extend to the base of the first metacarpal bone, it can result in the dislocation of the trapezio-metacarpal joint of the thumb due to the stretching of its ligaments. The fusion of the muscular portion of APL with that of the extensor pollicis brevis (EPB) provides further evidence that these muscles share a common ancestral origin. The sporadic absence of the EPB muscle suggests that it is a relatively recent evolutionary development unique to humans. A comprehensive understanding of the anatomy of this tendon compartment is essential for surgical interventions, such as tendon release procedures for conditions like de Quervain's tenosynovitis. Additionally, these supplementary tendons can serve as valuable sources for grafts required in tendon reconstruction surgeries.

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