

ORIGINAL ARTICLE

What is new in flexor tendon pulleys and the gaps between them in triphalangeal fingers of the hand?

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Abstract

The flexor tendon pulleys in the fingers of the hand are fibrous structures of variable size, shape, and thickness that cover the synovial sheath of these tendons. Despite their clinical relevance, their arrangement and configuration in each of the triphalangeal fingers have been little studied and with small sample sizes. 192 triphalangeal fingers belonging to 48 fresh body donors' hands were dissected. Multivariate analysis was carried out. Twenty-five cases (52%) were left hands, and 26 of the 48 hands belonged to female donors (54.2%). The results were analyzed by fingers for each of the 5 annular pulleys, the 3 cruciform pulleys and the gaps between them. In addition, the most and least frequent configurations of the pulleys in each of the fingers were studied, observing that the classic pattern with all the pulleys appeared only in 3 fingers (1.56%), while the most frequent pattern was A1-A2-C1-A3-A4, which was seen in 35 fingers (18.22%).

Conclusions: The flexor pulleys in the triphalangeal fingers of the hand have shown enormous variability in arrangement and shape, and also rarely appear all in the same finger. This peculiar anatomical arrangement can help the different professionals who perform their clinical work in this region.

KEYWORDS

annular, cruciform, flexor tendon, pulley, trigger finger

1 | INTRODUCTION

Pulleys are fibrous tissue bands of variable width, thickness, shape, and configuration that overlay the synovial sheath of the flexor tendons (Doyle, 1988; Doyle & Blythe, 1975).

The first known description of finger flexor pulleys is credited to Leonardo Da Vinci (1452–1529). Classically, anatomists considered

the flexor fibrous sheath to be composed of 2 pulleys only (Winslow, 1732). In 1969, Barton described the flexor sheath as a continuous structure, starting 1 cm proximal to the metacarpophalangeal joint (MCF) and ending at the distal interphalangeal joint (DIP), and presenting 3 thickened portions, the pulleys (proximal, middle, and distal pulley). Verdan also describes 3 independent pulleys, the first one at the level of the palmar plate of the MFC joint, the second over the

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proximal phalanx (PF), and the third one over the middle phalanx (MF) (Verdan, 1972).

The current nomenclature of the pulleys of the flexor tendons in triphalangeal fingers is based on the descriptions made by Doyle and Blythe, who named the annular bands with "A," and the cruciform bands with "C." They identified 4 annular and 3 cruciform pulleys, and numbered them from proximal to distal: from A1 to A4 for the annular ones, and from C1 to C3 for the cruciform ones. These pulleys were arranged from proximal to distal in the following sequence: A1-A1-C1-A3-C2-A4-C3 (Doyle & Blythe, 1975) (Figure 1).

Furthermore, two new annular pulleys were described. Firstly, a distal annular pulley named as pulley A5 (Hunter et al., 1980), which appeared consistently in triphalangeal fingers. From Hunter onwards, successive works already mostly mentioned the presence of

this annular pulley A5 (De Las Heras et al., 2022; Doyle, 1988, 1989; Lin et al., 1989; Moutet, 2003).

The other annular pulley subsequently described was proximal to the others, the A0 pulley, which is actually made up by the transverse fibers of the palmar aponeurosis. This pulley A0, or proximal pulley, functionally can act as a flexor tendon pulley (Manske & Lesker, 1983).

Subsequent publications have already used Doyle's classification extended by Hunter and Manske for the study of pulleys (Lin et al., 1989; Moutet, 2003).

At the same time, other research on flexor pulleys has appeared, with mixed results; 6 annular pulleys (AP1, AP2, AP3, AD1, AD2, AD2) and 2 cruciform (C1, C2) (Strauch & De Moura, 1985).

The study of the pulleys has shown that there are substantial differences in incidence, shape, and size of the pulleys, depending on the type of pulley and the side of the hand (Barton, 1969; De la Caffinière, 1971; De Las Heras et al., 2022; Doyle, 1988, 1989; Doyle & Blythe, 1975; Lin et al., 1989; Strauch & De Moura, 1985).

The published works mentioned above have been performed on fingers from fresh frozen donors, with small sample sizes ranging from 10 to 80 fingers (Barton, 1969; De la Caffinière, 1971; Doyle, 1988, 1989; Lin et al., 1989; Strauch & De Moura, 1985). Other publications do not specify the sample size and base their results on the observation of intraoperative cases, isolated dissections, and reviews of previous works (Doyle & Blythe, 1975; Verdan, 1972). With some exceptions, it is not specified whether the fingers belong to the same hand or to different hands (De la Caffinière, 1971; Lin et al., 1989). Furthermore, the iconography of all these works does not clearly show the pulleys present and absent on the different fingers.

The methodology for measuring the length of the pulleys has not been specified in any work, moreover, the distance between the most distal and the most proximal point is called width (Doyle, 1988, 1989), and in other publications it is called length (Lin et al., 1989).

No work focuses on the gaps between consecutive pulleys, except for the gap between pulleys A1 and A2 (gap A1-A2). This gap does not exist for some authors (Barton, 1969; De la Caffinière, 1971), while for others it is present, and appears with variable incidences (35%–100%) according to the different publications consulted (De Las Heras et al., 2022; Doyle, 1988, 1989; Hunter et al., 1980; Lin et al., 1989; Strauch & De Moura, 1985). It has also been described that the A1-A2 gap may be occupied by a cruciform pulley (Kleinert & Lubahn, 1984).

There are no previous reports about the gaps between the remaining pulleys of the triphalangeal fingers.

Although some authors already state that some of the pulleys do not always appear (De Las Heras et al., 2022; Doyle, 1988, 1989; Lin et al., 1989), until today there are no data on which fingers present fewer pulleys, or what pattern we expect to find with greater probability when analyzing a flexor sheath of a particular triphalangeal finger.

With the data presented above, we believe that it is necessary to carry out a study of the flexor pulleys in the triphalangeal fingers and the gaps between them, in a large sample, which will allow us to analyze and clarify their location, morphology, incidence, and size in a precise, detailed, and methodologically reproducible way, in each finger.

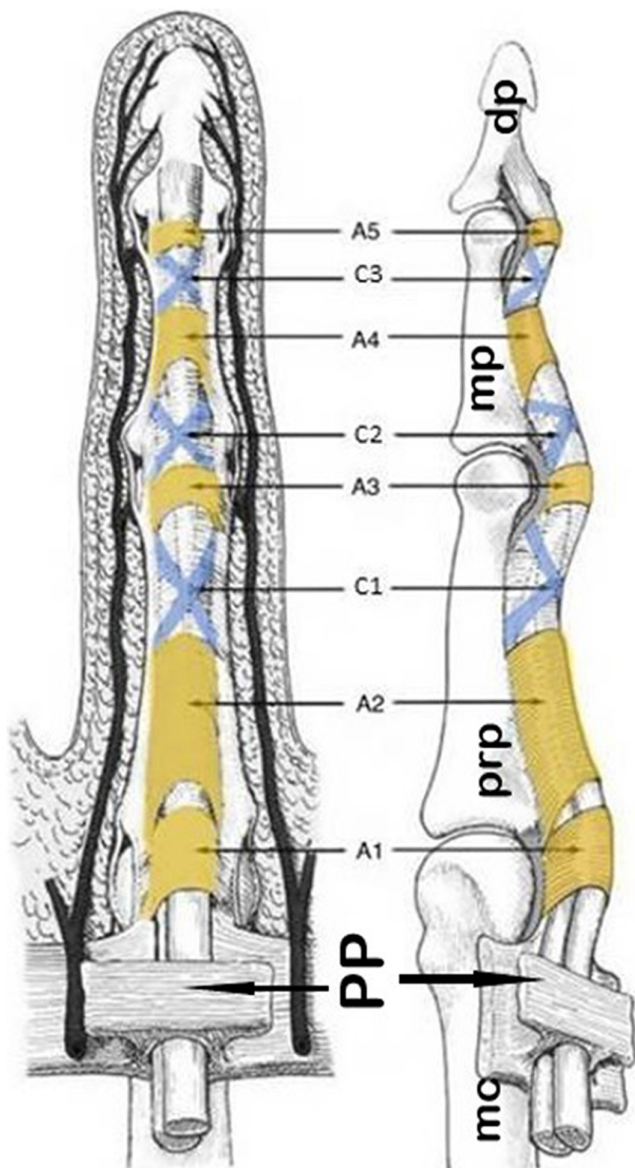


FIGURE 1 Diagram of the pulleys of a triphalangeal finger (mc: metacarpian, prp: proximal phalanx, mp: middle phalanx, dp: distal phalanx, pp: proximal pulley).

2 | MATERIALS AND METHODS

2.1 | Specimens

Forty-eight fresh cadaveric hands were studied and a total of 192 fingers dissected. All hands dissected belong to donors from "Body Donation Center and Dissection Rooms (CDC & SD)," Universidad Complutense Madrid, Spain. All the bodies were under a strict control by the ethical committee in accordance to the ethical standards as laid down in the 1964 Declaration of Helsinki.

The age at death of the donors was between 46 and 97 years. In 13 donors, both hands were dissected (26 bilateral hands), and the remaining 22 hands belonged to 22 different bodies (22 unilateral hands). Twenty-three were right-sided (48%) and 25 were left-sided (52%). Twenty-six donors were women (54.2%) and 22 men (45.8%). None of the specimens had previous hand injuries or surgeries. Thumbs were not included.

2.2 | Dissection and measurements

Dissection was performed from the midcarpal area to the distal end of each finger. The skin and soft tissues around the tendon sheath were removed and the pulleys and gaps between them of the digital flexor sheath were identified, assisted with 3.5× magnifying glasses or with a 10× dissecting microscope. The pulleys analyzed were those of the digital flexor sheath (A1 and distal pulleys).

Microsurgical instruments were used for dissection of the pulleys. In some cases, in order to identify and for subsequent measurement, the pulleys were painted with a dilute solution of methylene blue.

The location of each of the pulleys, when present, was identified and described, and the frequency of occurrence of each of the pulleys in each of the triphalangeal fingers was also noted.

Each pulley was described according to the arrangement of its proximal and distal borders and its morphology (annular, cruciform, Y-shaped, or made up of an oblique band). If present, special characteristics, such as the presence of lateral openings, thickening, thinning, the presence of several rings, or overlapping between different pulleys without space between their proximal and distal borders, were described.

To measure the length of the pulleys, originally, the width of the finger was measured proximally and distally and a mid-longitudinal line was drawn and used as a reference for the measurement of all pulleys and the gaps between them (Figure 2).

The length of pulley A2 was measured, this being the distance between its proximal and distal border measured on the medial longitudinal line of the finger (Figure 2). A 150 mm digital caliper was used for the measurements.

The measurements of the rest of the pulleys and the gaps were taken with the help of Adobe Photoshop CC 2014. For this, a photo was taken with a Nikon camera from a fixed support, all always at the same height and with the same specifications on the camera.

The measurement scale was adjusted taking as reference the measurements of the A2 pulleys measured with the caliper. Once

the scale was adjusted, the measurements were taken in each triphalangeal finger, in millimeters (mm), of each of the pulleys present and the gaps between them.

Because the configuration of the pulleys and the gaps between them are often not straight lines, the following system has been designed to define each annular or cruciform pulley limits and to make the measurements:

- The length of the annular pulleys was made in a straight line on the longitudinal line of the finger, joining the proximal and distal borders of the pulley (Figure 2). In the case of more than one ring, the overall length of the pulley with all rings was measured.
- The length of the cruciform pulleys was measured in a straight line projecting orthogonally to the median longitudinal line the most proximal point of the pulley and the most distal point (Figure 2)
- The length of the gaps between the pulleys was made in the same way (Figure 2).

2.3 | Statistics

Differences between each finger were analyzed with the Chi squared, Fisher's homogeneity tests, or two-factor experiment design depending on the measure considered. The Chi squared test has been used in the case of big samples or good equilibrated 2×2 contingency tables. Otherwise, the Fisher's test has been considered. The level of significance was set at $p < 0.05$.

3 | RESULTS

To clarify the exposition of the section, the results have been subdivided by the different pulleys; 5 annular and 3 cruciform, and the gaps between each consecutive pulleys. The results of global incidence, incidence by type of finger, and the length of each of the pulleys and gaps are presented (Tables 1 and 2).

Finally, the statistical study carried out with the hypotheses proposed and the experimental designs constructed is presented.

3.1 | Pulley A1

Pulley A1 was present in all 192 dissected fingers (100%). Proximally, it ranged from the palmar plate of the metacarpophalangeal joint (MF) and distally it attached into the proximal area of the palmar aspect of the proximal phalanx (PRP) (Figure 1).

This pulley was found to be formed by a single ring (123 fingers, 64.1%), by two consecutive rings (50 fingers, 26%), by three consecutive rings (16 fingers, 8.3%), and in 3 fingers it appeared with 4 rings (1.6%) (Figure 3).

The pulley A1 with only 1 ring was most frequently found in the third and fourth fingers (79.9%), the arrangement with 2 rings in the fifth finger (39.6%), with 3 rings in the 2nd and 5th fingers (10.4%), and

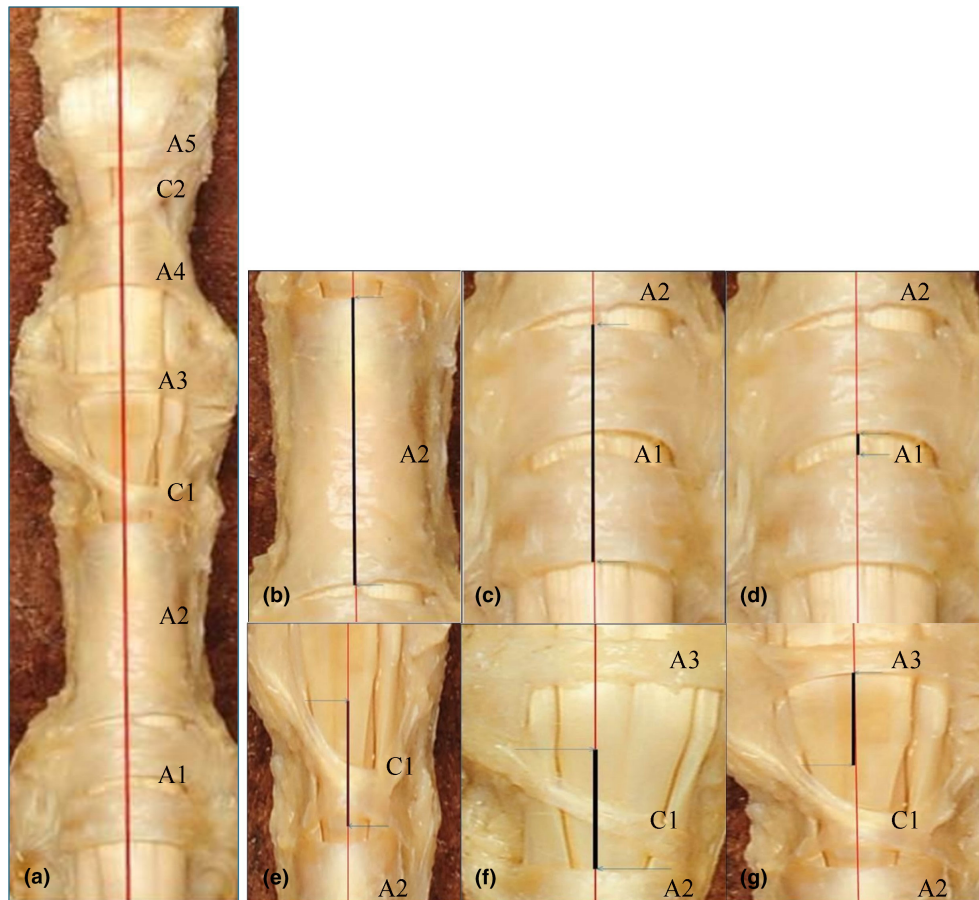


FIGURE 2 (a) Mid longitudinal line on the flexor sheath of a second finger used to measure the length of the different pulleys. (b) Measurement of pulley A2, used as a reference for the measurement of the rest of the pulleys of that finger. (c) Measurement of the length of an A1 pulley composed of several rings. (d) Measurement of the length of the gap between consecutive rings of pulley A1 (the measurement between consecutive annular pulleys would be performed in the same way). (e) Measurement of the length of a cruciform pulley. (f) Measurement of the length of an oblique pulley. (g) Measurement of the length of the gap between a cruciform pulley and the consecutive pulley. (The blue arrows mark the most proximal and most distal point of the pulley projected over the midline).

finally the arrangement with 4 rings only appeared on 3 specimens, one in a second finger, one in a third finger and one in a fifth finger (Table 3).

Considering the hand as a whole with its four triphalangeal fingers, there were 13 cases (27%) in which all four pulleys A1 had only one ring and 4 cases (8.3%) in which all of these pulleys had more than one ring (Figure 3). In one of these four cases, all the pulleys A1 had 2 rings.

3.2 | Gap A1-A2

In 157 cases (81.8%) there was a gap between pulleys A1 and A2, with an average length of 2.76 mm, while in 35 cases (18.2%) there was no gap and the pulleys were arranged consecutively (Figure 4, Table 2). The length of this gap for each different finger, when it was present, has been reported (Table 2).

The pattern with gap A1-A2 was more frequently observed in the fifth fingers (89.6%), while the pattern without this gap appeared more frequently in the second fingers (25%) (Table 2).

3.3 | Pulley A2

Pulley A2 appeared in all 192 fingers analyzed (Table 1).

Its configuration was also constant and characteristic, with an arciform beginning formed by thick cruciform fibers originating on both sides of the proximal and palmar zone of the PRP. It presents wide lateral openings in its proximal zone, subsequently a long middle zone with annular configuration and an end orthogonal to the longitudinal axis of the finger, thicker than the rest, which makes it very easily identifiable (Figures 1 and 4). In all cases it is made up by a single ring of these characteristics that covers a large area of the digital canal in the proximal and middle part of the PRP.

3.4 | Gap A2-C1

Pulley C1 appeared in 145 fingers (75.5%), and of these there were 128 cases (88.3%) in which there was no space between pulley A2 and C1, being arranged consecutively.

TABLE 1 Global incidence of each pulley and average length. Incidence and length detailed by finger (Inc: incidence, Lng: length).

	Global Inc	Av. length	2nd finger		3rd finger		4th finger		5th finger	
			Inc	Lng	Inc	Lng	Inc	Lng	Inc	Lng
A1	192 (100%)	8.7	48 (100%)	9.68	48 (100%)	9.49	48 (100%)	8.4	48 (100%)	7.26
A2	192 (100%)	15.93	48 (100%)	15.7	48 (100%)	19.07	48 (100%)	17.54	48 (100%)	11.45
C1	145 (75.5%)	7.82	37 (91.7%)	7.75	37 (91.7%)	8.28	37 (91.7%)	7.47	34 (70.8%)	7.8
A3	173 (90.1%)	3.22	44 (91.7%)	3.26	47 (97.9%)	3.34	47 (97.9%)	3.13	35 (72.9%)	3.12
C2	26 (13.5%)	7.8	7 (14.6%)	3.32	10 (2.98%)	4.7	4 (8.3%)	4.53	5 (2.6%)	4.32
A4	192 (100%)	7.91	48 (100%)	7.34	48 (100%)	8.46	48 (100%)	8.52	48 (100%)	7.33
C3	76 (39.6%)	5.27	21 (43.8%)	4.63	26 (51.2%)	6.14	21 (43.8%)	5.19	8 (16.7%)	4.39
A5	99 (51.5%)	2.75	23 (47.9%)	2.59	26 (54.2%)	2.65	27 (56.3%)	31.19	23 (47.9%)	2.52

TABLE 2 Global incidence of each gap between consecutive pulleys and average length. Incidence and length detailed by finger (Inc: incidence, Lng: length).

	Global Inc	Av. Lng	2nd finger		3rd finger		4th finger		5th finger	
			Inc	Lng	Inc	Lng	Inc	Lng	Inc	Lng
A1-A2	157 (81.8%)	2.76	36 (75%)	2.93	37 (77.1%)	2.65	41 (85.4%)	2.42	43 (89.6%)	3.07
A2-C1	17 (8.9%)	1.41	6 (12.5%)	0.96	6 (12.5%)	2.21	4 (8.3%)	1.08	1 (2.1%)	0.67
C1-A3	110 (55.6%)	4.05	29 (60.4%)	4.21	30 (62.5%)	4.52	35 (72.9%)	4.00	16 (33.3%)	3.01
A3-C2	15 (7.8%)	2.72	5 (10.4%)	2.53	7 (14.6%)	3	2 (4.2%)	3.02	1 (2.1%)	1.19
C2-A4	12 (6.25%)	3.28	4 (8.3%)	2.27	3 (6.3%)	4.87	3 (6.3%)	3.18	2 (4.2%)	3.06
A4-C3	4 (2.1%)	2.04	0	-	0	-	3 (6.3%)	2.49	1 (2.1%)	0.68
C3-A5	13 (6.77%)	2.27	4 (8.3%)	3.2	5 (10.4%)	2.05	3 (6.3%)	1.83	1 (2.1%)	0.98
A5-Tip	99 (51.5%)	23.9	23 (47.9%)	24.05	26 (54.2%)	25.73	27 (56.3%)	24.92	23 (47.9%)	20.33

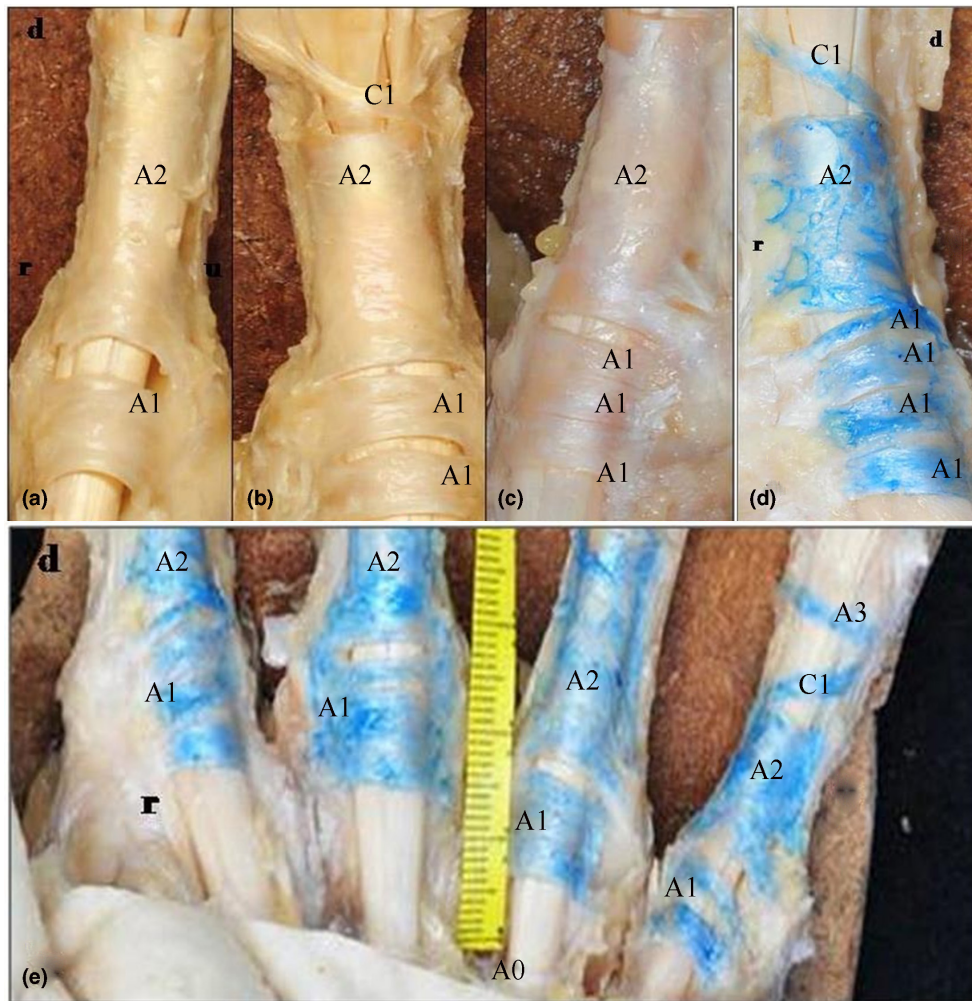


FIGURE 3 Pulley A1 on left hands. (a) one ring only. (b) two rings. (c) three rings. (d) four rings. (e) hand with the A1 pulleys with more than one ring on the four triphalangeal fingers (d: distal, r: radial) (methylene blue has been used to facilitate identification of the pulleys).

TABLE 3 Number of rings of pulley A1 in each triphalangeal finger.

		Finger				Total
		2nd	3rd	4th	5th	
Number of rings Pulley A1	1	30 (62.5%)	35 (79.92%)	35 (79.9%)	23 (47.92%)	123 (64.1%)
	2	12 (25%)	8 (16.7%)	11 (22.92%)	19 (39.58%)	50 (26%)
	3	5 (10.4%)	4 (8.3%)	2 (4.2%)	5 (10.4%)	16 (8.3%)
	4	1 (2.1%)	1 (2.1%)	0 (0%)	1 (2.1%)	3 (1.6%)

This space appeared in 6s fingers (35.29%), the incidence and lengths of this gap for each finger has been reported (Table 2).

3.5 | Pulley C1

Pulley C1 appeared in 145 fingers of the sample (75.52%) (Table 1). This is a cruciform pulley with a variable configuration located in the distal third of the PRP (Figure 1). The frequency of this pulley for each finger is shown in Table 1.

In 59 cases (40.7%) it was made up by two oblique bands criss-crossed in the form of a cross, in 77 cases (53.1%) by a single oblique band (19.3% radial orientation and 33.8% ulnar orientation), and in 4 cases (2.75%) with an ipsiliform shape (Figure 5).

In 5 cases, the C1 pulley presented an unusual configuration: 2 cases with 2 consecutive cruciform pulleys, 1 case with a cruciform pulley followed by an ulnar oblique band (2nd finger) (Figure 6), 1 case of two consecutive ulnar oblique bands (5th finger), and 1 case of an annular configuration with one single ring (4th finger) (Figure 6).

Within the cases in which the C1 was present, the cruciform configuration appeared with a probability of 51.4% in the second finger, 45.9% in the third finger, 40.5% in the fourth finger, and 17.6% in the fifth finger. The simple oblique configuration occurred in 40.5%

in the second finger, 48.6% in the third finger, 48.6% in the fourth finger, and 76.5% in the fifth finger.

Considering the hand, there were 3 hands (6.25%) with all four triphalangeal fingers without C1.

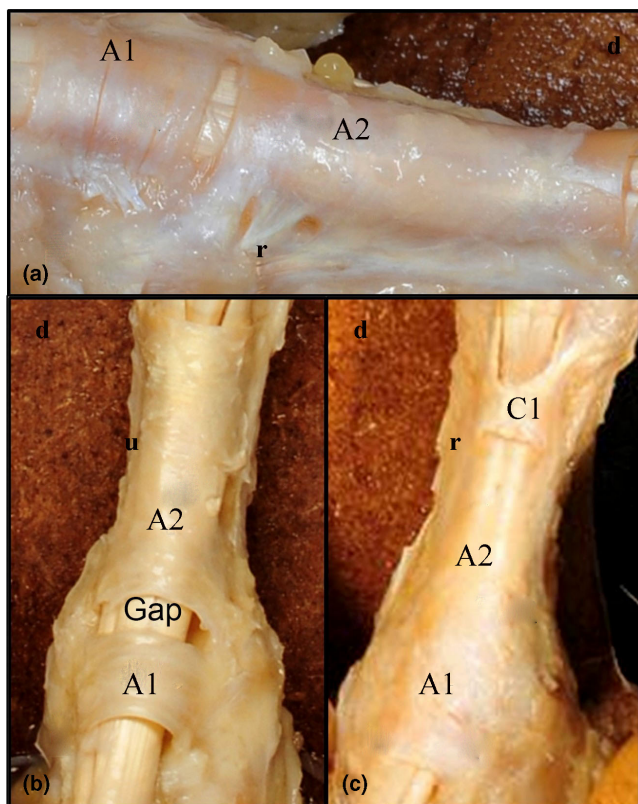


FIGURE 4 (a) Pulley A2 with annular configuration on a right finger, lateral openings and thickening in its distal part. (Arrows: lateral openings). (b) Gap between pulleys A1 and A2 on a right finger. (c) Pulleys A1 and A2 arranged consecutively without GAP between them on a left finger (d: distal, r: radial, u: ulnar).

3.6 | Gap C1-A3

In 131 fingers (68.23%), there were both pulley C1 and pulley A3. Of these fingers, there were 21 cases (12.14%) in which there was no gap between the pulleys C1 and A3, and 110 cases (83.96%) in which there was a gap between both pulleys, with a mean length of 4.05 mm (Table 2). The incidence and length of this gap for each triphalangeal finger is shown (Table 2).

3.7 | Pulley A3

Pulley A3 has been found in 173 fingers (90.1%) (Table 1). It is a pulley with annular configuration, thinner and shorter than the previous annular pulleys, in the palmar surface of the proximal interphalangeal (PIP) joint (Figure 1). The proximal and distal borders are orthogonal to the axis, equal in shape, easily identifiable, without thickening, and without mixing their fibers with neighboring pulleys.

Its variability was low: in 170 cases (88.5%) it consisted of a single ring and in 3 cases (1.6%) of 2 consecutive annular bands (Figure 7).

The 3 cases in which pulley A3 had 2 rings corresponded to second fingers. Being a second finger, the probability that A3 had 2 rings was 6.25%, while this variability was not observed in the other fingers.

Of the 19 cases in which there was no A3 pulley, the absence was much more frequent in the 5th finger (37.1%) (Table 1).

In 12 hands, A3 was absent only in 1 finger, in 2 hands of the sample A3 was absent in 2 fingers (second and fifth fingers), and

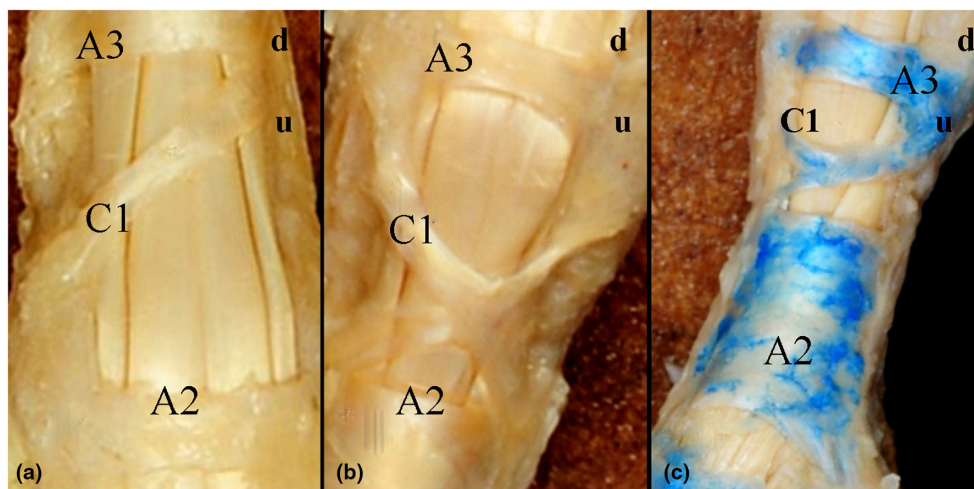


FIGURE 5 Pulley C1 on left fingers. (a) oblique shape. (b) cruciform shape. (c) Y-shaped (d: distal, r: radial, u: ulnar) (methylene blue has been used to facilitate identification of the pulleys).

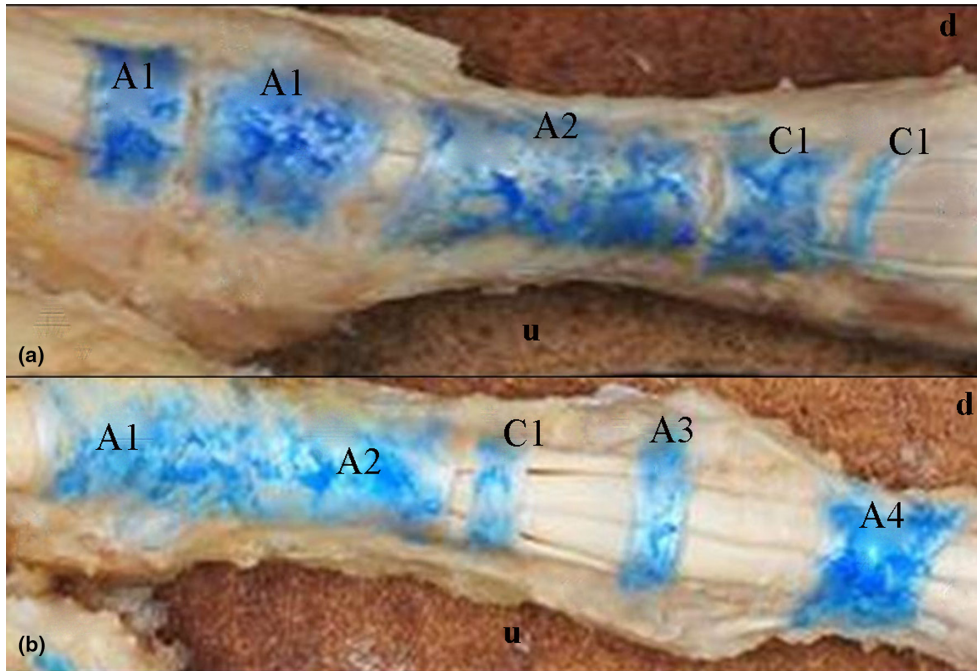


FIGURE 6 Less frequent configurations of pulley C1 on left fingers. (a) Pulley C1 composed of a cruciform pulley followed by a simple oblique pulley. In addition, pulley A1 with 2 rings and pulley A2 are observed, with a gap between them. (b) Pulley C1 with annular configuration. In addition, pulleys A1 and A2 arranged consecutively, pulley A3 and pulley A4 are shown (methylene blue has been used to facilitate identification of the pulleys) (d: distal, u: ulnar).

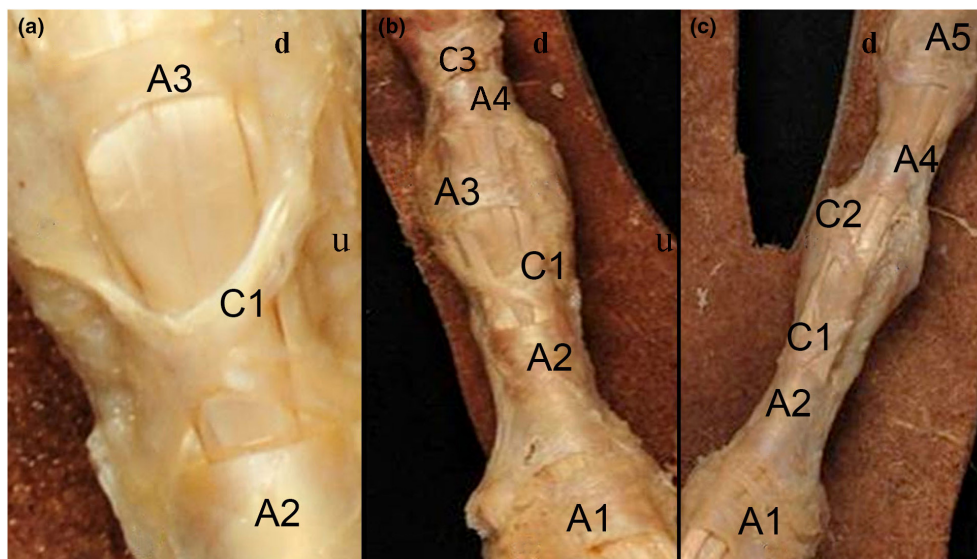


FIGURE 7 Pulley A3. (a) A3 in a left finger. (b) pulley A2 in a left finger made up by two consecutive rings. (c) Absence of A3 and C3 in a left fifth finger (d: distal, u: ulnar).

in only 1 hand the pulley did not appear in three fingers (second, fourth, and fifth fingers).

3.8 | Gap A3-C2

The space between the pulleys A3 and C2 is located in the proximal third of the middle phalanx, starting just distal to the PIP joint (Figure 1). The end of the A3 pulley, as mentioned above, constant in

shape, straight and orthogonal to the axis, and the beginning of the C2 pulley formed by oblique fibers, make it easily identifiable when it exists (Figure 8).

Pulley C2 only appeared in 26 cases (13.5%) (Table 1). Within these, in 15 cases (68.2%) there was a gap between the A3 and C2 pulleys. Incidence and lengths of this space for each finger has been noted (Table 2).

There was no gap between A3 and C2 in 7 cases (31.8%): this was more frequent in the third fingers (4) (Table 2).



FIGURE 8 Pulley C2. (a) Left finger. Clear gap between pulleys A3-C2. Pulleys A1, A2, A4, A5 and cruciform C1 are shown. Pulley C2 with an oblique shape. C3 is absent. (b) Right fifth finger. Minimum gap between an oblique C2 and A4. Pulleys A1 with 3 rings, A2, A5 and oblique C1 can be observed. Pulleys A3 and C3 are absent (methylene blue has been used to facilitate identification of the pulleys) (d: distal, u: ulnar, r: radial).

3.9 | Pulley C2

The pulley C2 was present in 26 fingers of the sample (13.5%) (Table 1), and was located in the proximal third of the middle phalanx (MP), a few millimeters from the PIP joint (Figures 1 and 8). The distribution and length of this pulley in each of the fingers is shown in Table 2, appearing most frequently in the third fingers (20.8%).

In the 166 cases in which the presence of the C2 was not detected, 41 cases were in the second finger, 38 cases in the third finger, 44 cases in the fourth finger, and 43 cases in the fifth finger. Therefore, the probability that the C2 pulley did not exist in the second finger was 85.42%, in the third finger 79.17%, in the fourth finger 91.67%, and in the fifth finger 89.58%.

3.10 | Gap C2-A4

The gap between pulleys C2 and A4 was located in the proximal third of the MP (Figure 1). The end of the pulley C2 has been variable depending on its configuration, as mentioned above, and the

beginning of the A4 pulley was easily identifiable as it was a constant, thick, annular pulley.

In the 26 cases where C2 has appeared, there were 14 cases with no gap between C2 and A4 because they were contiguous (53.8%) (3s fingers, 7 third fingers, 1 fourth finger, and 3 fifth fingers) (Figure 8).

In the 12 remaining cases (6.25%), a gap between pulleys C2 and A4 was present. Lengths and incidence of this pulley for each finger are shown in Table 2.

3.11 | Pulley A4

Pulley A4 was found to be present in 100% of the fingers in the sample (Table 1). It consisted of an easily identifiable single thick ring covering a large area of the digital canal in the middle part of MP (Figure 1).

The proximal edge has been straight orthogonal to the axis or slightly arciform with oblique fibers originating on both sides and crisscrossing in the middle part. The shape of the distal edge was more variable, being able to be straight orthogonal of easy identification, or ending in the form of a cross or oblique toward radial or ulnar, being difficult to identify the beginning of the pulley C3. Sometimes the distal third of 4 was made up by cross-shaped fibers as if they overlapped or a cruciform pulley was impressed (Figure 9).

3.12 | Gap A4-C3

Pulley C3 was identified in 76 cases. Within these there were 72 cases (94.74%) in which there was no gap between pulley A4 and C3 (Figure 9). In 4 cases there was a gap between pulley A4 and pulley C3, values of length and incidence of this gap has been collected (Table 2).

3.13 | Pulley C3

Pulley C3 was found to be present in 76 cases (39.6%) (Table 1), located in an area where identifying it as an isolated pulley or as part of the end of pulley A4 has been difficult (Figures 1 and 9).

The distribution of this pulley in each of the fingers, as well as their average lengths are shown in Table 1.

In the 116 cases in which the pulley C3 was not found (Figure 8), this occurred most frequently in the 5th finger (45.8%) (Table 1).

3.14 | Gap C3-A5

The gap between the pulleys C3 and A5 was located between the distal third of the MP and the DIP (distal interphalangeal) joint. The end of the C3 pulley was highly variable depending on its configuration, as mentioned above, and the beginning of the A5 pulley was easily identifiable as it coincided with the DIP joint and was orthogonal to the longitudinal axis of the finger (Figure 9).

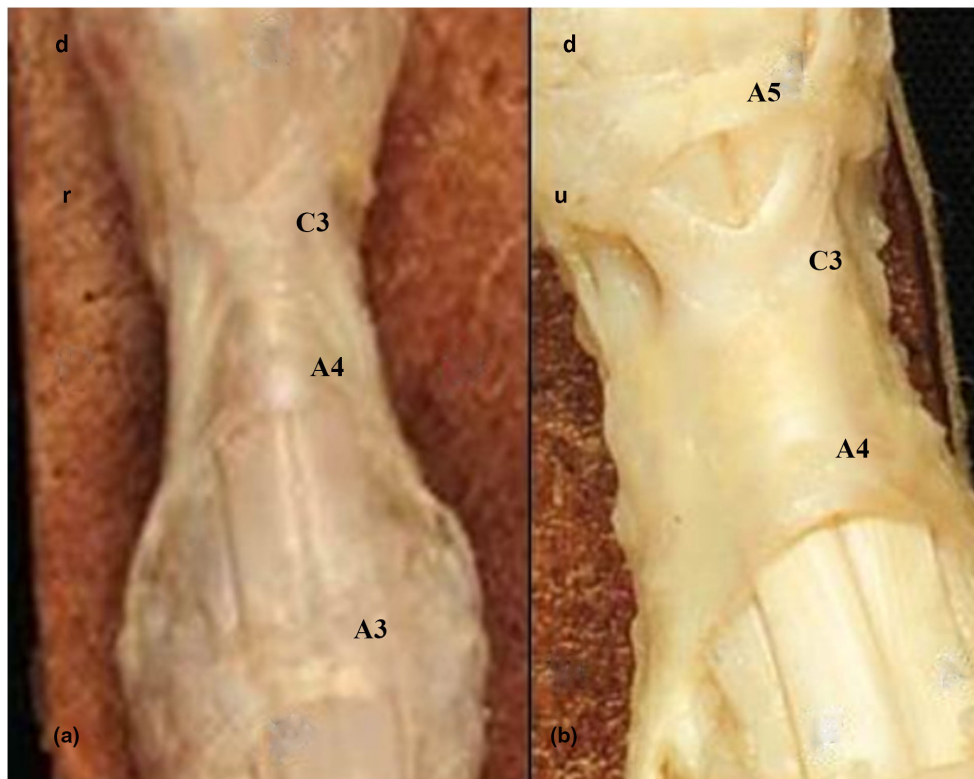


FIGURE 9 Pulley C3. (a) Left finger. Pulleys A3, A4 and C3. Pulley C3 made up by cruciform fibers coming from A4. (b) Right finger. Pulley A4 with pulley C3 seated on its distal part (d: distal, u: ulnar, r: radial).

Forty-five cases were observed in which pulley C3 and pulley A5 appeared in the same finger. Among these, in 32 cases there was no gap between pulley C3 and A5. In the remaining 13 cases (6.77%) there was a gap between this consecutive pulleys, incidence and length values for each finger has been studied (Table 2).

3.15 | Pulley A5

The pulley A5 appeared in 99 fingers of the sample (51.5) (Table 1). It consisted of a pulley with an annular configuration, thin and short, similar to pulley A3, in the palmar area of the DIP joint (Figure 1).

In 97 cases it was configured by a single ring (Figure 9) and in 2 cases (2%) it was made up by 2 annular bands.

The incidence of occurrence of the A5 pulley and its average length are shown in Table 5 for each of the fingers.

The 2 fingers in which A5 was made up by 2 rings were two fourth fingers. Therefore, the probability that this pulley had 2 rings in a fourth finger was 4.17%, while this variability was not observed in the other fingers.

Of the 93 cases in which there was no pulley A5, this absence was more frequent in the 2nd and 5th fingers (52.1%, respectively) (Table 1). In 60 cases, the absence of pulley A5 coexisted with the absence of C3.

3.16 | Gap A5-tip of the finger

In the 99 cases in which the presence of the pulley A5 was identified, the mean distance to the tip of the finger from its distal border was 23.86mm. The mean distance of this gap per finger is shown in Table 2.

3.17 | Pulley distribution pattern per finger

Twenty-four different digital patterns were found (Table 4). The most frequent pulley pattern was A1-A2-C1-A3-A4 in 35 fingers (18.22%) (Figure 10). In second place, the pattern A1-A2-C1-A3-A4-C3-A5 in 31 fingers (16.14%), and in third place the pattern A1-A2-C1-A3-A4-A5 in 28 fingers (14.58%).

Considering the finger, in the second and fifth fingers the most frequent pattern was A1-A2-C1-A3-A4, in the third finger A1-A2-C1-A3-A4-C3-A5, and in the fourth finger A1-A2-C1-A3-A4-A5 (Figure 10).

Three fingers (1.56%) were found with all possible pulleys present (A1-A2-C1-A3-C2-A4-C3-A5) (all three cases were in the third finger) (Figure 11), while the minimum possible pulley pattern was A1-A2-A4, and was found in 2 fifth fingers (1.04%) (Table 4).

In 27 fingers (14.06%) there were no cruciform pulleys at all, so that the digital canal was made up only by annular pulleys (Figure 11). Considering the finger, this occurred in 6s fingers, 3 third fingers, 5 fourth fingers, and 13 fifth fingers. Within the 27 fingers without cruciform pulleys, in 18 there was also no pulley A5 (Figure 11).

TABLE 4 Pattern of pulleys and number of fingers with each pattern.

Pulleys	N° of fingers	Pulleys	N° of fingers
A1-A2-C1-A3-C2-A4-C3-A5	3	A1-A2-A3-C2-A4-C3-A5	1
A1-A2-C1-A3-C2-A4-C3	2	A1-A2-A3-C2-A4-C3	0
A1-A2-C1-A3-C2-A4-A5	9	A1-A2-A3-C2-A4-A5	1
A1-A2-C1-A3-C2-A4	6	A1-A2-A3-C2-A4	1
A1-A2-C1-A3-A4-C3-A5	31	A1-A2-A3-A4-C3-A5	8
A1-A2-C1-A3-A4-C3	18	A1-A2-A3-A4-C3	8
A1-A2-C1-A3-C2-A4-A5	28	A1-A2-A3-C2-A4-A5	7
A1-A2-C1-A3-A4	35	A1-A2-A3-C2-A4	15
A1-A2-C1-C2-A4-C3-A5	1	A1-A2-C2-A4-C3-A5	0
A1-A2-C1-C2-A4-C3	0	A1-A2-C2-A4-C3	0
A1-A2-C1-C2-A4-A5	3	A1-A2-C2-A4-A5	0
A1-A2-C1-C2-A4	0	A1-A2-C2-A4	0
A1-A2-C1-A4-C3-A5	1	A1-A2-A4-C3-A5	0
A1-A2-C1-A4-C3	2	A1-A2-A4-C3	1
A1-A2-C1-A4-A5	4	A1-A2-A4-A5	2
A1-A2-C1-A4	3	A1-A2-A4	2

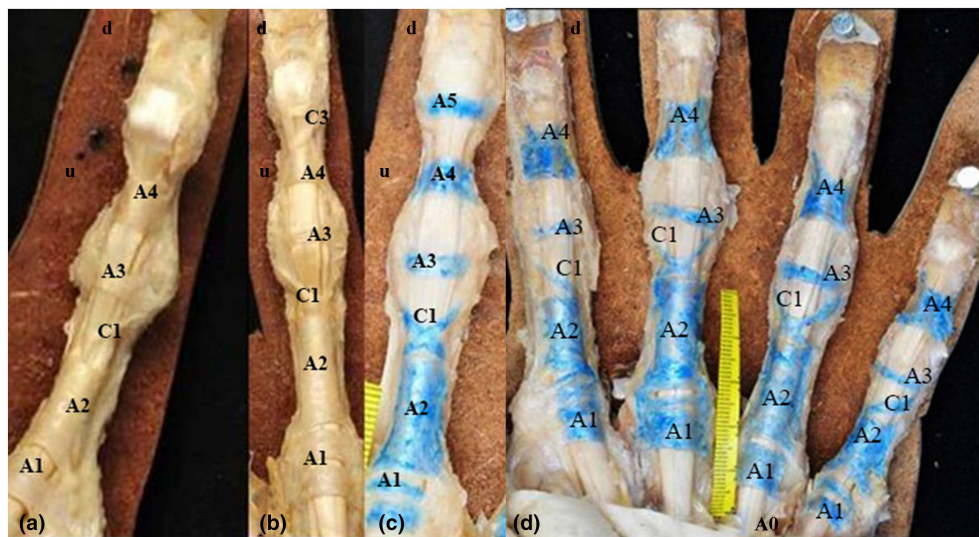


FIGURE 10 Pattern of pulleys. (a) Fifth left finger. Pattern of pulleys most frequent observed globally and in 2nd and 5th fingers (A1-A2-C1-A3-A4). (b) Left third finger. Most frequent pattern in 3rd fingers (A1-A2-C1-A3-A4-C3-A5). (c) Right fourth finger. Most frequent pattern in 4th fingers (A1-A2-C1-A3-A4-A5). (d) A left hand showing the most frequent pattern of pulleys (A1-A2-C1-A3-A4) in the four triphalangeal fingers (methylene blue has been used to facilitate identification of the pulleys) (d: distal, u: ulnar, r: radial).

4 | DISCUSSION

4.1 | Incidence of pulleys and gaps between consecutive pulleys

We analyzed the incidence, shapes, and sizes of the pulleys in the fingers according to the configurations described by Doyle and Blythe (1975), Kleinert et al. (1981), and Strickland (1986). The description of the location, shape, and incidence of these pulleys has been previously studied by several authors, although with small

sample sizes and without interpreting the results for each of the different triphalangeal fingers (Barton, 1969; De la Caffinière, 1971; De Las Heras et al., 2022; Doyle, 1988, 1989; Doyle & Blythe, 1975; Hunter et al., 1980; Lin et al., 1989; Strauch & De Moura, 1985).

In our sample we found that pulleys A1, A2, and A4 appeared in all fingers, as described in previous works (Doyle, 1988, 1989; Hunter et al., 1980; Lin et al., 1989; Strauch & De Moura, 1985). For the rest of the annular pulleys, the incidences were variable, so that pulley A3 in our sample appeared in 90.1% of the fingers (Table 1), while other authors describe its incidence in a range of 87%–100%

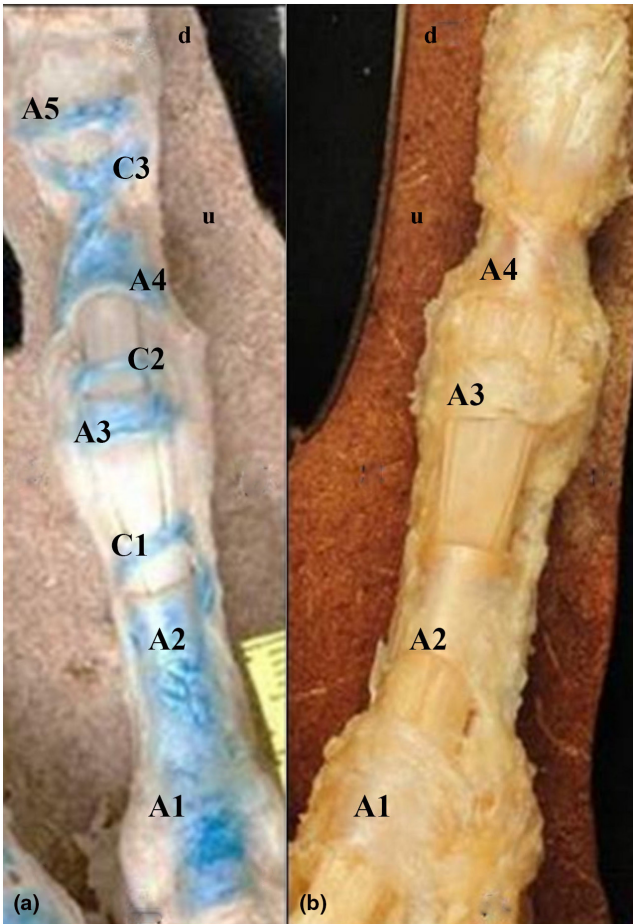


FIGURE 11 (a) Third left finger showing all pulleys. (b) Fifth right finger showing a pattern conformed only by annular pulleys (A1-A2-A3-A4) (methylene blue has been used to facilitate identification of the pulleys) (d: distal, u: ulnar, r: radial).

(Doyle, 1988, 1989; Doyle & Blythe, 1975; Hunter et al., 1980; Lin et al., 1989). A5 was observed in only half of the fingers in our sample (51.5%) (Table 1), being its frequency of occurrence much higher in previous reports (80%–100%) (Doyle, 1988, 1989; Doyle & Blythe, 1975; Hunter et al., 1980; Lin et al., 1989).

The incidence of the different flexor pulleys has been analyzed according to each of the triphalangeal fingers (Table 1), thus we have found that the pulley A3 is absent more frequently in the 5th finger: in 13 cases of the 48 fifth fingers studied this pulley was absent (27.01%). This data had been described by Doyle JR in a sample of 15 fifth fingers, where the A3 pulley was absent in only 2 of them (13.3%). For this author, the A3 pulley was absent more frequently in the fourth fingers (in 3 of the 16 analyzed he did not find it) (Doyle, 1988) (Table 5). The other authors who analyzed the incidence of these pulleys did so globally, not specifically for each of the fingers (De la Caffinière, 1971; De Las Heras et al., 2022; Doyle, 1989; Doyle & Blythe, 1975; Hunter et al., 1980; Lin et al., 1989; Strauch & De Moura, 1985).

We found that pulley A4 was present in 100% of the sample (Table 1), but this was not the case for other authors, as it was absent in one case in a second finger in a sample of 61 fingers (Doyle, 1988) (Table 5).

TABLE 5 Overall and individual finger incidences comparing the results of this work with those of Doyle (1988) (Inc: incidence).

	Global Inc		Inc 2nd finger		Inc 3rd finger		Inc 4th finger		Inc 5th finger	
	De Las Heras et al., 2022, n 192	Doyle, 1988, n 61	De Las Heras et al., 2022, n 48	Doyle, 1988, n 14	De Las Heras et al., 2022, n 48	Doyle, 1988, n 16	De Las Heras et al., 2022, n 48	Doyle, 1988, n 16	De Las Heras et al., 2022, n 48	Doyle, 1988, n 15
A1	192 (100%)	57 (93.4%)	48 (100%)	12 (85.7%)	48 (100%)	16 (100%)	48 (100%)	15 (93.8%)	48 (100%)	15 (100%)
A2	192 (100%)	57 (93.4%)	48 (100%)	12 (85.7%)	48 (100%)	16 (100%)	48 (100%)	15 (93.8%)	48 (100%)	15 (100%)
C1	145 (75.5%)	61 (100%)	37 (91.7%)	14 (100%)	37 (91.7%)	16 (100%)	37 (91.7%)	16 (100%)	34 (70.8%)	15 (100%)
A3	173 (90.1%)	53 (86.9%)	44 (91.7%)	13 (92.9%)	47 (97.9%)	14 (87.5%)	47 (97.9%)	13 (81.3%)	35 (72.9%)	13 (86.7%)
C2	26 (13.5%)	44 (72.1%)	7 (14.6%)	12 (85.7%)	10 (2.98%)	12 (75%)	4 (8.3%)	11 (68.8%)	5 (2.6%)	9 (60%)
A4	192 (100%)	60 (98.4%)	48 (100%)	13 (92.9%)	48 (100%)	16 (100%)	48 (100%)	16 (100%)	48 (100%)	15 (100%)
C3	76 (39.6%)	48 (78.7%)	21 (43.8%)	11 (78.6%)	26 (51.2%)	14 (87.5%)	21 (43.8%)	12 (75%)	8 (16.7%)	11 (73.3%)
A5	99 (51.5%)	57 (93.4%)	23 (47.9%)	13 (92.9%)	26 (54.2%)	15 (93.8%)	27 (56.3%)	15 (93.8%)	23 (47.9%)	14 (93.3%)

Pulley A5 was absent in 93 fingers (48.4%) (Table 1), being more frequent not found in second fingers (25 cases, 52.1% of the second fingers) and fifth fingers (25 cases, 52.1% of the fifth fingers). In Doyle's work, this pulley was absent in only 7% of the 61 fingers, with very similar results in the incidence for the different fingers (Doyle, 1988) (Table 5).

In the case of cruciform pulleys, C1 was absent in 47 fingers, its absence in the fifth finger being more frequent (14 of 48 fifth fingers studied, 29.1% of fifth fingers did not have C1 pulley). In previous work, C1 was a constant pulley in all fingers (Doyle, 1988) (Table 5).

C2 did not appear in 166 fingers in our sample, being more frequent not to be found in the fourth finger: 44 times absent (91.7% of the fourth fingers did not have pulley C2). In Doyle's work, this pulley was not found in 17 of 61 fingers (27.9%), with its absence also being most notable in the 4th finger (31.25%) and in the 5th finger (40%) (Doyle, 1988) (Table 5).

Pulley C3 was absent 116 times, being more frequent in the 5th finger (40 fingers, 83.3%). Comparing with previous reports, we observe that this pulley did not appear in 13 of 61 fingers, being more frequent not to find it also in the 5th finger (absent in 26.7%) (Doyle, 1988) (Table 5).

We have observed a large discrepancy between the incidence of cruciform pulleys in previous studies (Doyle, 1988) and our study, particularly for C2 and C3 pulleys (Table 4). These differences are probably due to the fact that the borders and characteristics of these pulleys have been interpreted differently by different authors (e.g., it is difficult to identify the C3 pulley since it sometimes appears overlapped with the distal edge of the A4 pulley) (Figure 9).

What is really novel is the analysis of the gaps between consecutive pulleys, their lengths, and their distribution in each of the triphalangeal fingers (Table 2). Until now, these spaces had not been analyzed by other authors, except for the gap A1-A2, present in 81.8% of our sample. This gap had greater length in the fifth fingers, and it was more frequent not to find it in the second finger (absent in 25%). In previous reports, this gap had been described with a frequency in a range of 35%–100% (De Las Heras et al., 2022; Doyle, 1988, 1989; Hunter et al., 1980; Lin et al., 1989; Strauch & De Moura, 1985), and being more frequent not to find it also in the second finger (14.3%) (Doyle, 1988).

The absence of a gap between the pulleys A4 and C3 in 94.7% of the cases in which both pulleys coexisted in the same finger is noteworthy. In fact, pulley C3 in most cases is described as the end part of A4 or as a cruciform pulley attached to the distal edge of the A4 annular pulley (Figure 9). This space never appeared in second or third fingers.

The gaps C2-A4 and C3-A5 (present in only 6.25% and 6.77% of the fingers, respectively) are next in rate of absence (Table 2). The gap between the A2 and C1 pulleys did not appear in 175 fingers (91.1%), being more unlikely to find this gap in the fifth finger (present only in 1 of the 48 fifth fingers analyzed, 2.1%) (Table 2).

The most constant gap of all those described was A1-A2 (absent in 18.2%), followed by C1-A3, which was only not observed in 44.4% of the sample (Table 2).

The length of the gap between the end of pulley A5 and the tip of the pulp has been described for the first time in this work, presenting a mean length of 24.64 mm.

4.2 | Pulley distribution pattern per finger

Until recently, finger pulleys have been studied and described descriptively on a pulley-by-pulley basis. The first report that refers to the patterns of appearance of the pulleys is recent, and it describes up to 24 different patterns of sequence of the finger pulleys, the most frequent pattern being A1-A2-C1-A3-A4, found in 35 fingers (18.22%) (De Las Heras et al., 2022).

In our sample, we also analyzed the most frequent pulley pattern in each finger, finding that in the second and fifth fingers the most frequent pattern was A1-A2-C1-A3-A4, in the third finger A1-A2-C1-A3-A3-A4-C3-A5, and in the fourth finger A1-A2-C1-A3-A4-A5 (Figure 10).

The pattern with all pulleys described from A1 to A5 (A1-A2-C1-A3-C2-A4-C3-A5) was only found in 3 fingers of the sample (1.56%) (all three cases were in the third finger) (Figure 11), while the minimum possible pulley pattern was A1-A2-A4, and it was found in 2 fifth fingers (1.04%) (Table 4). The latter corroborates that the most important pulleys from a biomechanical point of view are A1, A2, and A4 (Barton, 1969; Chow et al., 2014; Doyle & Blythe, 1975; Kwaiben & Elliot, 1998; Manske & Lesker, 1983).

In 4 fingers, no cruciform pulley was observed (2.08%), the patterns found in these cases were A1-A2-A3-A4 (2 fingers) and A1-A2-A4 (2 fingers) (Figure 11).

The variability of the pattern within the same hand was very high since there were only 3 hands (6.25%) in which the pulley pattern in the four triphalangeal fingers was the same.

Interestingly, until now these observations on the pulleys and the gaps between them in the different fingers had not been described. Given the high frequency of pathology affecting the flexor tendon pulleys that require surgical management, such as trigger fingers, pulley cysts, tendon injuries (Moutet, 2003), and pulley ruptures in certain activities such as climbing (Bollen, 1988), a thorough knowledge of these structures and their possible variations is of great importance.

The hand surgeon should be aware that the classic arrangement known with all the pulleys present (A1-A2-C1-A3-C2-A4-C3-A5) is only present in 1.6% of the fingers, making this finding of great value when reconstructing the fibrous tunnel of the flexor tendons.

5 | CONCLUSIONS

The flexor tendon pulleys in 192 triphalangeal fingers belonging to 48 hands have been studied. The incidence of the 8 pulleys and the gaps between consecutive pulleys have been described globally and for each finger.

The gaps between consecutive pulleys were not always present: overall, the gap that appeared least often was A4-C3 (only present in 4 fingers, 2.1%). One by one, gaps A1-A2, A2-C1, C1-A3, A3-C2, C2-A4, C3-A5 appeared less frequently always in the 5th finger (absent in 25%, 97.9%, 72.7%, 97.9%, 95.8%, and 97.9% of the 5th fingers, respectively). The only gap that was less frequent in a finger other than the 5th finger was A4-C3, which was not observed in any 2nd or 3rd finger. These data are important during surgical reconstructions of the flexor sheath, as 2 consecutive pulleys can often be confused with a single one, especially in the 5th fingers.

Furthermore, it is important to note that the classically described pattern with all flexor tendon pulleys present is very uncommon (1.6%) and can also lead to confusion during surgery.

AUTHOR CONTRIBUTIONS

JH was involved in the development of the project, dissection, photography, and data collection. CSB was responsible for conducting the statistical study. SQ and LO created the diagrams, helped with photo edition and tables configuration. GJS and IK collaborated with the dissections and data collection. JRS and MGE performed the protocol development and collaborated with manuscript editing. PA was responsible for the writing of the manuscript, and processed the figures for publication. Approval of the final version of the manuscript: All authors.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interests.

DATA AVAILABILITY STATEMENT

The data from this research work have not been shared to date.

ETHICS STATEMENT

The cadaver belonged to the Donors and Dissecting Rooms Center, Universidad Complutense de Madrid, Spain. The body was under a strict control by the ethical committee in accordance to the ethical standards as laid down in the 1964 Declaration of Helsinki.

INFORMED CONSENT

Written informed consent was obtained from all subjects before the study.

CONSENT FOR PUBLICATION

The authors affirm that human research participants provided informed consent for publication of the images in [Figures 1–11](#).

TRIAL REGISTRATION

Not applicable.

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