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Full length article

The anatomy and function of Cleland's ligaments

R. L. Zwanenburg[1], P. M. N. Werker[1] and D. A. McGrouther[2]

Abstract

The cutaneous ligaments of the digits have been recognized by anatomists for several centuries, but the best known description is that of John Cleland. Subsequent varying descriptions of their morphology have resulted in the surgical community having an imprecise view of their structure and dynamic function. We micro-dissected 24 fresh frozen fingers to analyze the individual components of Cleland's ligamentous system. Arising from the proximal interphalangeal (PIP) joint, proximal, and sometimes middle phalanx, we found strong ligaments that ran proximally (PIP-P) and distally (PIP-D). On each side of each finger there was a PIP-P ligament present, which passed obliquely from the lateral side of the proximal and sometimes middle phalanx towards its insertion into the skin at the level of the proximal phalanx. The distal (PIP-D) ligaments were found to pass obliquely distally on the radial and ulnar aspects of the digit towards cutaneous insertions around the middle phalanx. A similar arrangement exists more distally with fibres originating from the DIP joint and middle phalanx (the DIP-P pass obliquely proximally, and the DIP-D, distally). Each individual PIP ligament consisted of three different layers originating from fibres overlying the flexor tendon sheath, periosteum or joint capsule, and extensor expansion. Ligaments arising at the DIP joint had two layers equivalent to the anterior two layers of the proximal ligaments. Cleland's ligaments act as skin anchors maintaining the skin in a fixed relationship to the underlying skeleton during motion and functional tasks. They also prevent the skin from 'bagging', protect the neurovascular bundle, and create a gliding path for the lateral slips of the extensor tendon.

Introduction

Knowledge of the anatomy and anatomical pathology of the digital fascial structures is important, not least in surgery for Dupuytren's disease. Although the anatomy of the palmar fascias is clearly defined (McFarlane, 1974; 1990; McGrouther, 1982; Zancolli and Cozzi, 1992), the microanatomy of the fascial structures of the human finger is more controversial, possibly due to their more delicate nature and difficulty of pictorial description. This paper will focus on comparing historical descriptions of Cleland's ligaments with new dissections to arrive at a common structural definition.

Review of historical descriptions

The first description of Cleland's ligaments as we recognize them was reported in 1556 by Juan Valverde, who described fascial fibres in the human digit (Zancolli, 1992). Weitbrecht in 1742 introduced the name 'ligamentum cutaneum' for ligaments that were found to connect the extensor expansion with the skin (Chrysopoulo et al., 2002). In 1867 Professor John Cleland, anatomist at the University of Glasgow, presented a study to the British Association for the Advancement of Science on "strong ligaments, hitherto undescribed on the lateral aspects of the digits" (Cleland, 1878). In the same year, Sevestre also reported a description of these ligaments (Sevestre,
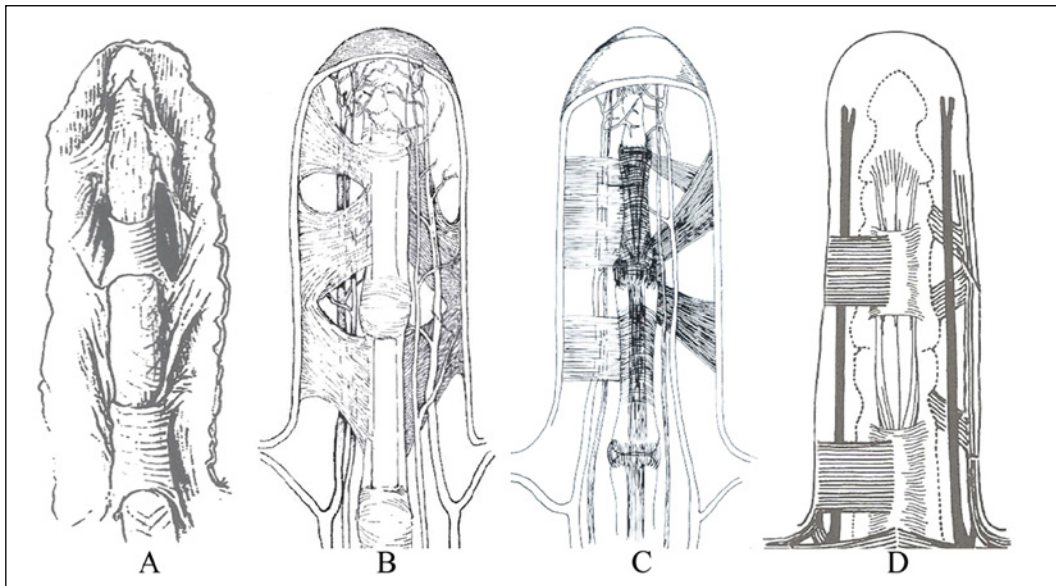
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Figure 1. Four representations of the digital fascia. In (B–D), Cleland's ligaments are depicted on the right and Grayson's ligaments on the left side of the finger. (A) Cleland's original drawing. The fingers joints are not distinguishable. (B) Grayson's illustration. (C) Milford's findings. (D) McFarlane's drawing, merely based on (C) and the most widely used figure about the orientation of the cutaneous ligament (Cleland, 1878; Grayson 1941; McFarlane, 1990; Milford, 1968).

1867), but it was Cleland whose name has become associated with these structures.

Professor Cleland's text reported "exceedingly well-developed ligaments, obvious and strong, extending from the sides of the phalanges, near the phalangeal articulations" (Cleland, 1878). The illustration (Figure 1) of his findings is confusing; the ligamentous system is shown without any landmarks of the finger, such as the joints or tendon sheath annular pulleys. Nor did he show the insertions into the skin or level of insertion relative to the nerves and vessels. He stated that the primary function of the ligament was "to prevent the skin from bagging" (Cleland, 1878). Grayson referred to Cleland's ligament in 1941 as the dorsal protective layer of the neurovascular tunnel and postulated that it prevents the nerve and artery from being crushed. Grayson added drawings reputedly made by his Professor Frederick Wood-Jones as a schematic overview (Figure 1), which however, show a completely opposite fibre orientation of Cleland's ligaments in comparison to Cleland's original description (Grayson, 1941).

Milford reviewed Cleland's work and noted quite marked differences in the arrangement of these ligaments, providing a three-dimensional description (Milford, 1968). He viewed Cleland's ligaments as cone-shaped structures having an apex at the interphalangeal joints and fanning out towards the lateral skin. He published his findings in his book *The*

Retaining Ligaments of the Digit of the Hand in 1968 (Milford, 1968). Milford's drawing of the orientation of Cleland's ligaments in the human finger (Figure 1), copied as a two-dimensional diagram by McFarlane, is the most widely used blueprint for pictures in textbooks (Figure 1) (McGrouther, 2005; Milford, 1968).

In Zancolli's text, *The Atlas of Surgical Anatomy of the Hand*, Cleland's ligament is named the dorsal digital septum, being part of what he termed the retinaculum cutis. He described in detail the proximal two ligaments. For the distal ligaments he referred to Cleland's original paper. His most important contribution was the multilayer configuration of Cleland's ligament, whereby in cross-section (Figure 2) fibres were depicted as arising from the skeleton and from the flexor tendon sheath (Zancolli and Cozzi, 1992).

Chrysopoulo et al. (2002) published a cross-sectional diagram (Figure 2) that seems to provide a mirror image of Zancolli's findings with layers separating laterally, but this arrangement has not been supported by other studies.

De Ary-Pires et al. (2007) published an extensive dissection study on 300 digits. This study was performed using both formalin-fixed and fresh specimens. Their most important finding was that the morphometry of Cleland's ligaments relative to the dimensions of the digit was quite constant for all fingers. In this paper a wealth of morphometric data are provided as well as a detailed description
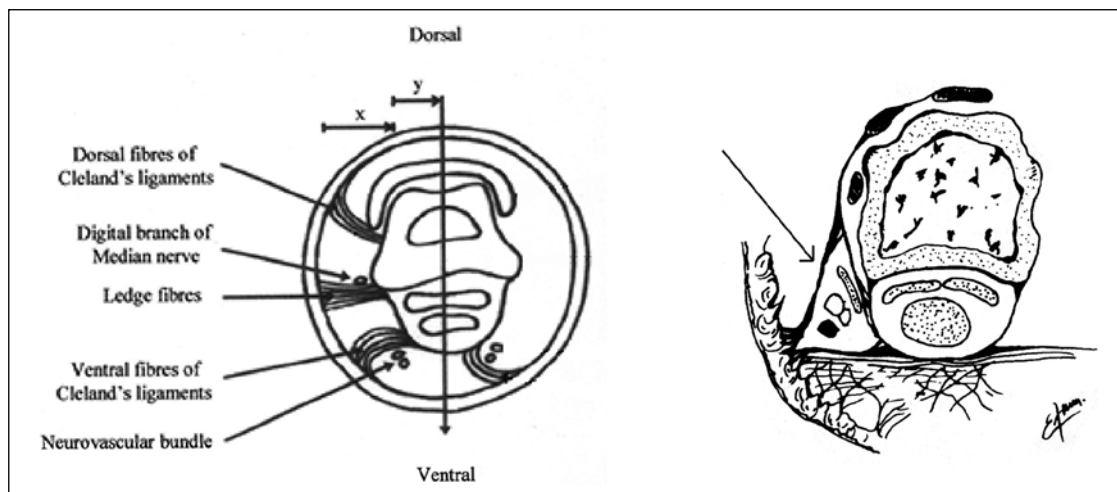
Figure 2. Cross-sections of the finger, immediately proximal to the PIP joint, made by Chrysopoulo (*left*) and Zancolli (*right*). Chrysopoulo mentions three different fibrous structures of Cleland that diverge after their origin. This diagram is open to misinterpretation as the neurovascular structures are depicted in a very anterior position. It does, however, illustrate three origins for Cleland's ligament fibres. The arrow in Zancolli's illustration points at Cleland's ligaments and shows fibres originating from the bone and extensor expansion. The insertion into the skin is drawn volar to the mid-axial line of the finger (Chrysopoulo et al., 2002; Zancolli and Cozzi, 1992).

of the origin and insertion of Cleland's ligament. Unfortunately, the data are not illustrated by figures, apart from a drawing that originates from the publication of McFarlane in 1974. It is difficult to relate this drawing to the description in the text, and so the confusion in the literature prevails (de Ary-Pires et al., 2007).

We believe that reasons for the varying descriptions may include the specimen preservation techniques used in various previous studies (formalin, soft-fixation, or fresh tissue), position in which specimens were preserved (often in flexion), and lack of fine instrumentation and magnification for the dissection. In addition, a more complex problem that until now has not been overcome is the pictorial depiction of the complex three-dimensional network of fascial fibres and. in particular, the dynamic movements of the ligaments during traction in such dissection manoeuvres as retracting skin edges. Therefore, a three-dimensional network of fibres that seem to have no preferred orientation in the resting posture can appear to line up when tensioned to produce a specific ligament; it can be difficult to know if some descriptions of ligamentous structures are true or artefactual. Nevertheless, there are certain well-defined skin-retaining ligaments that can be clearly defined with the tissues relaxed.

In our anatomy lab at the University of Groningen the problems of fixation were analyzed and we were able to perform dissections under, what we considered, circumstances least likely to produce artefacts.

The aim of this study was to produce a clear description of the anatomy and function of the cutaneous ligaments of the finger.

Methods

Cadaveric study

The study was performed using fresh frozen human cadaver hands (frozen –24°C and thawed for 16 h at 3°C). Cadavers were obtained from the Department of Neuroscience, University of Groningen, The Netherlands, and from the Department of Functional Anatomy, University of Utrecht, The Netherlands. Twenty adult cadaveric digits, six little, eight ring, and six middle fingers were dissected from 12 male and eight female cadavers. None of the specimens showed signs of previous injury or disease. The age of the cadavers was between 56 and 95, with a mean age of 76 years. We also dissected four fingers from three human cadavers preserved by Thiel's method in order to understand the dynamics of Cleland's ligaments (Thiel, 1992). This preservation method keeps the tissues soft and preserves them in a near normal state, making functional studies possible. The dissections were performed at 12.5-times magnification using a Zeiss universal S2 surgical microscope (Zeiss, Oberkochen, Germany) and micro- and regular-sized surgical instruments. A Canon EOS 500D camera with macro lens was used for making detailed pictures (Canon, Oita, Japan). Measurements on

dissected fingers were taken with a calibrated digital slide gauge. Drawings were made of all dissections.

Before dissection started, detailed measurements of the surface anatomy of each finger were obtained to allow for correction in size of the finger under study. We measured the lengths of the proximal, middle, and distal phalanges, the transverse diameter of the proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints, and the transverse diameters of the width of the finger at the middle of the proximal, middle, and distal phalanges by using a slide gauge between pin markings positioned into the joints.

Dissection technique

Cleland's ligaments, volar approach: A longitudinal midline incision was made on the palmar surface of the digit from the metacarpophalangeal (MP) joint crease up to the distal pulp. This incision extended in depth just through the dermis but not into the subcutaneous fat. In addition, palmar transverse incisions were made through the most prominent flexor creases at each joint from one mid-lateral line to the other. The skin was carefully lifted from the fatty tissue using sharp dissection. Blunt dissection was continued deep through the fatty tissue down to the flexor tendon sheath, taking care to keep the flexor tendon sheath intact. By elevating the fat and all overlying ligamentous structures (Grayson's ligaments), the neurovascular bundles were exposed and left intact. After careful and delicate blunt removal of the fat located between the different layers of the cutaneous ligaments, a clear exposure of Cleland's ligaments was achieved and measurements could be taken.

Cleland's ligaments, dorsal approach: A midline dorsal dermal incision was made, with transverse extensions at the MCP-joint level and border of the fingernail as far as the middle-lateral lines at the side of the finger. The skin was sharply dissected from the extensor tendon complex and the dorsal wrinkle ligaments (Law and McGrouther, 1984). After blunt dissection and reflection of the subcutaneous tissues laterally, the dorsal aspect of Cleland's ligaments was exposed.

Dynamics of Cleland's ligaments: These were studied in the fingers of cadavers preserved using Thiel's method (Thiel, 1992). After having exposed Cleland's ligaments as described above, controlled passive flexion and extension movements of the finger were made between 0° and 90° at the PIP joint and displacement of the borders of the ligament relative to the MCPJ was monitored in a plane parallel to the

frontal plane. The change in fibre orientation was noted.

Following dissection we measured the various components of Cleland's ligament: the location and width of the origin of the ligament at the area where it leaves the flexor tendon sheath; width of the ligament at its insertion into the skin; and length of the fibrous condensation between these two points.

Statistical analysis.   We used the Student's *t*-test and Wilcoxon-square test, having confirmed the normal distribution of the data. Statistical significance was set at $p < 0.05$. All data are presented as mean (SD).

Formal approval for the anatomical experiments (cadaveric dissection) was granted by the Department of Anatomy, University Medical Center Groningen.

Results

Cleland's ligaments were present in all 24 digits dissected on ulnar and radial aspects of the digits, and were found dorsal to the neurovascular bundle and volar to the transverse retinacular ligament of Landsmeer. Cleland's ligaments clearly separate the volar fat-containing compartment from the dorsal compartment where almost no fat cells were seen.

Cleland's ligaments at the PIP joint

On each side of the digit at the PIP joint there were two components of the ligament: a smaller component passing proximally, which we termed PIP-P (proximal), and a larger ligament passing from the joint distally, which we termed PIP-D (distal) (Figure 3). Measurements of the lengths and widths of the ligaments are shown in Table 1.

The proximally orientated component of Cleland's ligament (PIP-P) was significantly shorter ($p < 0.001$) than PIP-D with a mean fibre length of 8.8 ± 1.6 mm and coursing less obliquely then PIP-D in a proximal direction towards the skin. In six digits (30%) we found that part of the origin of PIP-P was on the middle phalanx up to a maximum of 44% of its width. The most proximal edge of the insertion of the PIP-P ligament was in continuation with fibres of the lateral digital sheet.

The Cleland PIP-D ligaments were the largest ligaments in every finger with a mean fibre length of 13.4 ± 3.2 mm. From its origin at the neck and head of the proximal phalanx and joint capsule of the PIP joint, it ran distally in an oblique fashion towards the skin. In eight dissected fingers (40%) we found that part of the ligament also originated from the middle phalanx,
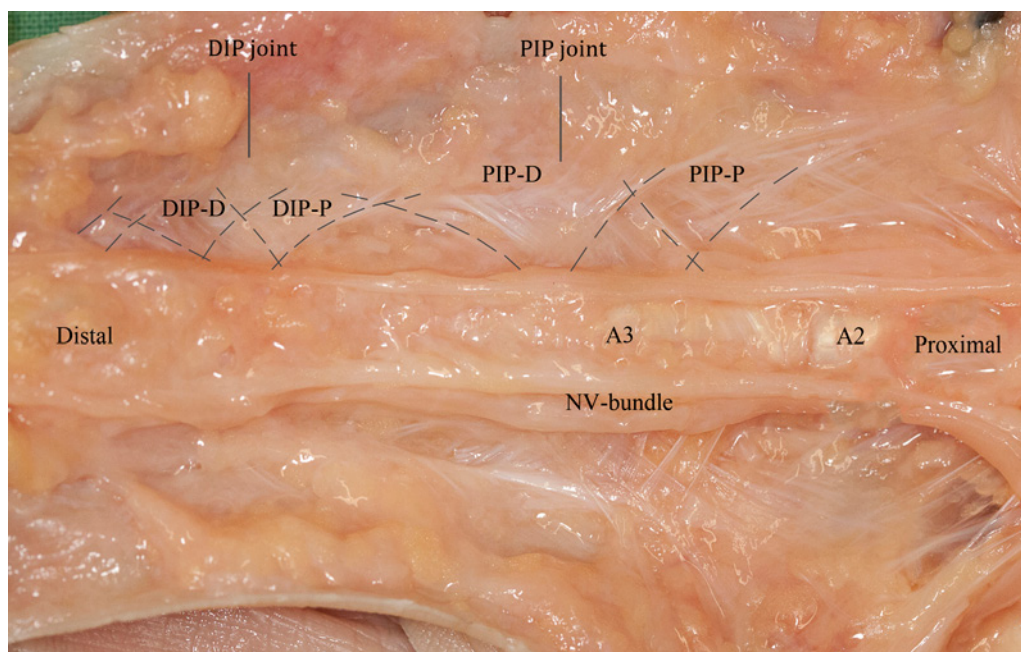
Figure 3. This picture shows the orientation of Cleland's ligaments; PIP-D and PIP-P originating mainly from the proximal phalanx and the DIP-D and DIP-P ligament arising from the distal part of the middle phalanx. The possible fifth ligament of Cleland is shown just distal to the DIP-D in a proximal direction.

Table 1. Measurements of Cleland's PIP-D and PIP-P ligaments.

	PIP-D		PIP-P	
	Mean (SD)	Range	Mean (SD)	Range
Width origin (mm)	9.9 (2.3)	5.8–15.6	6.8 (2.4)	3.5–10.6
Width insertion (mm)	11.8 (1.8)	6.0–13.5	7.4 (1.9)	4.0–11.6
Length proximal margin (mm)	11.3 (2.8)	6.0–16.8	8.7 (1.9)	4.9–13.1
Length distal margin (mm)	13.4 (3.5)	6.0–9.2	8.3 (2.2)	4.5–15.1

representing a maximum of 46% of the total width of origin of Cleland's PIP-D.

In a cross-sectional view of the finger, both Cleland's PIP-D and PIP-P ligaments consisted of three different layers. From the flexor to the extensor surfaces the layers originated separately from (i) fascial fibres immediately overlying the tendon sheath; (ii) periosteum or joint capsule; or (iii) fibres on the palmar or dorsal surfaces of the extensor apparatus.

This arrangement is shown in a cross-section of the finger just proximal to the PIP joint (Figure 4). The most anterior fibres arise from areolar tissue over the flexor tendon sheath. The middle and thickest layer originates from the periosteum on the palmar surface of the phalanx, which is in continuation with the floor of the flexor tendon sheath. The vinculum brevium of the flexor digitorum superficialis tendon was found to be a cone shaped structure continuous with this middle layer of the ligament. The most dorsal part of Cleland's ligament consists of two layers originating from the superficial and deep planes of the extensor tendon apparatus. This is the thinnest part of the ligament. Further distally at the PIP joint the volar part was again found to originate from the flexor tendon sheath, mainly over the A-3 pulley for both PIP-D and PIP-P. The proximal border of the PIP-D ligament was a continuation of the C-1 pulley.

As the three layers joined and the PIP-D and PIP-P ligaments were formed, they were initially found to lie in the same antero-posterior plane with intermingling fibres. They then separated to reach their individual insertions, respectively distally or proximally, into the skin or lateral digital sheet.

It was difficult to identify precise dermal insertions, as the insertions blended with a three-dimensional network of subcutaneous fascial fibres that has been
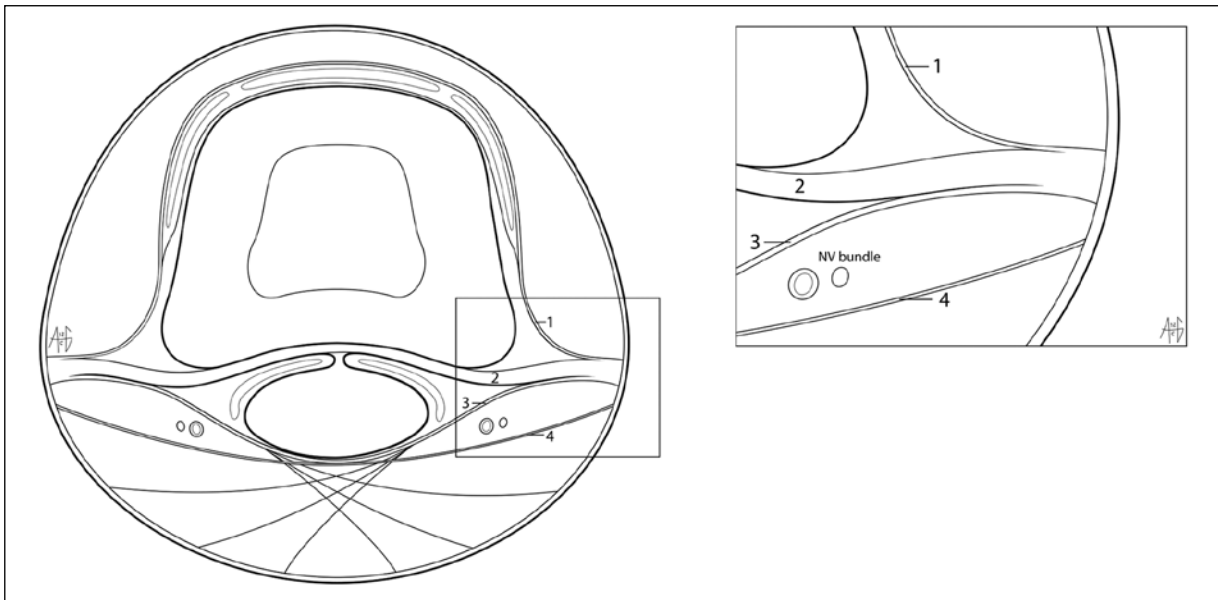
Figure 4. Cross-section of the finger, just proximal to the PIP-joint. The three layers of Cleland are shown. Layer 1 consists of the dorsal fibres originating from the extensor tendon adventitia. Layer 2 shows the middle fibres, originating from the floor of the flexor tendon sheath, in which the artery of the vinculum longum is embedded. Layer 3 originates from the fascia covering the flexor tendon sheath. Grayson's trabecular network of fibres is shown in different layers. Layer 4 is the most visible and thickest layer of Grayson which covers the volar side of the neurovascular bundle.

designated the lateral digital sheet. The length of insertion in a proximal-to-distal direction was in all cases significantly ($p < 0.001$) greater than the origin of any of its layers, the fibres fanning out from their origins.

Cleland's ligaments at the DIP joint

Cleland's ligaments' DIP-P and DIP-D were found to originate from the distal part of the middle phalanx and DIP joint, both at approximately the same proximo-distal level and in a fashion comparable to the origins of the PIP ligaments. The A5 pulley was the main origin of the DIP-P ligament, and the C3 pulley for Cleland's DIP-D.

In comparison with the proximal ligaments, the layer originating from the extensor tendon sheath was absent. The fibres originating from the palmar side of the flexor tendon sheath contributed most to the ligaments. Cleland DIP-P and DIP-D also fanned out towards their insertion and had significantly smaller origins than insertion ($p < 0.001$)

Dynamics of Cleland's ligaments

The proximal and distal ligaments arising from either the PIP or DIP areas on the same side of the digit were found to slide over each other as the angle between them altered during flexion and extension. The tension in the fibres of each ligament varied with the degree of flexion. In extension, the distal fibres of each ligament were under tension, while in flexion, the proximal fibres were tight.

Function of Cleland's ligament

In general, the orientation of the ligaments was found to help anchor and suspend the skin during both flexion and extension, and prevent it from bagging.

The most dorsal part of ligament PIP-D was found to act as a sliding path for the lateral bands of the extensor apparatus at the PIP-level during flexion of the finger.

The function of the palmar part of PIP-P and PIP-D was related to its origin on the surface of the flexor tendon sheath between the A2 and A4 pulley, which are partly in continuity with the fibres of the cruciate ligaments. During flexion of the finger, this part of the flexor tendon sheath could be seen to 'telescope', as the distance between the annular pulleys shortened. As a result, the orientation of the fibres of PIP-P and PIP-D became more transverse, allowing the skin to bulge in a controlled manner to the lateral sides of the fingers proximal and distal to the joint creases. Because the skin anchoring points of the ligaments remained at a fixed distance from the joint axis, PIP-D
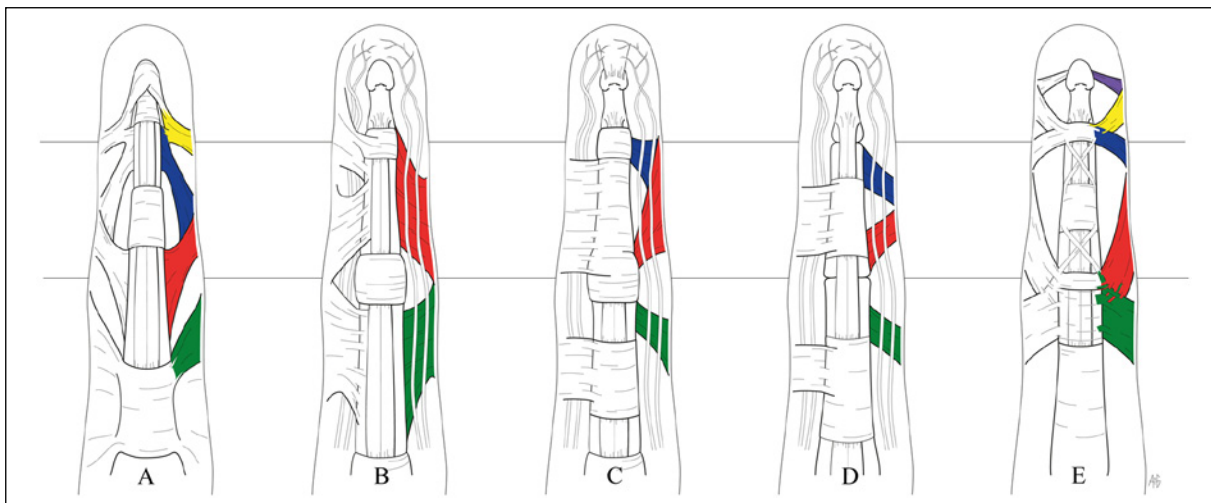
Figure 5. This illustration consists of redrawn copies of the most important historical drawings of Cleland's ligaments. The differences between the authors are more visible in accordance with our findings (E). From left to right: Cleland (A), Grayson (B), Milford (C), McFarlane (D), and Zwanenburg (E). Each ligament is given a different colour; the same colour refers to the same ligament, in the authors' opinion. Red: PIP-D; green: PIP-P; yellow: DIP-D; blue DIP-P; purple: a possible fifth ligament of Cleland (Cleland, 1878; Grayson, 1941; McFarlane, 1990; Milford, 1968).

and DIP-D were observed to prevent undue movement of the skin distally, and PIP-P and DIP-P limit proximal skin displacement. These anchors acted regardless of the degree of flexion or extension of the digit.

Discussion

For the purpose of clarity, we proposed a refinement of the nomenclature relating the ligaments to their region of origin (PIP or DIP) with an extension -P (proximal) or -D (distal), depending on their orientation.

We found Cleland's ligaments to be multilayer ligamentous structures arising from the regions of the interphalangeal joints and passing proximally and distally to insertions in the skin on either side. Each ligament consisted of different layers (three at the PIP level and two at the DIP level) that seemed to arise from fascial structures enveloping the bone, joint, and tendon sheath, merging laterally and running towards their insertions into the skin. The ligaments at and about the PIP joint were the largest and also the best developed and most obliquely orientated ligaments. The Cleland's ligaments at and about the DIP joint were two smaller ligaments, originating mainly from the distal part of the middle phalanx and consisting of two laminations instead of three. The absence of a third layer can be explained by the absence of an extensor expansion at this level. The distal ligaments were much smaller because the distance between bone and skin is smaller.

Our measurements in general match the description of de Ary-Pires et al. (2007). The description of our PIP-D is also in concordance with the original description of Cleland. This is not the case for what we call PIP-P. Its origin is mainly from the proximal phalanx at the same level as PIP-D, although it is smaller in width and length, and more transversely orientated than PIP-D. This finding, in fact, differs quite substantially from the currently generally accepted picture that was proposed by McFarlane in 1974 and was based on Milford's findings (Figure 5) (McFarlane, 1974; 1990; Milford, 1968).

Our findings differ from those of Zancolli in that he divided the PIP-associated ligaments of Cleland into proximal, middle, and distal parts (Figure 6) (Zancolli and Cozzi, 1992). Our Cleland PIP-P corresponds to his proximal fibres, and our Cleland PIP-D, to his distally orientated fibres. The middle fibres he mentioned run in a different plane, and in our view, may better be considered part of the transverse band of Landsmeer (transverse retinacular ligament).

There is also disparity with respect to the aspects of the ligaments in a cross-sectional overview (Figure 4). We, in agreement with Zancolli and de Ary-Pires et al., found fibres to originate from three different levels converging as they passed laterally to insert around the mid-lateral line of the digit into the skin (de Ary-Pires et al., 2007; Zancolli and Cozzi, 1992). This is in agreement with the original description of Cleland, but not with the drawing made by Chrysopoulo, which showed fibres fanning out from
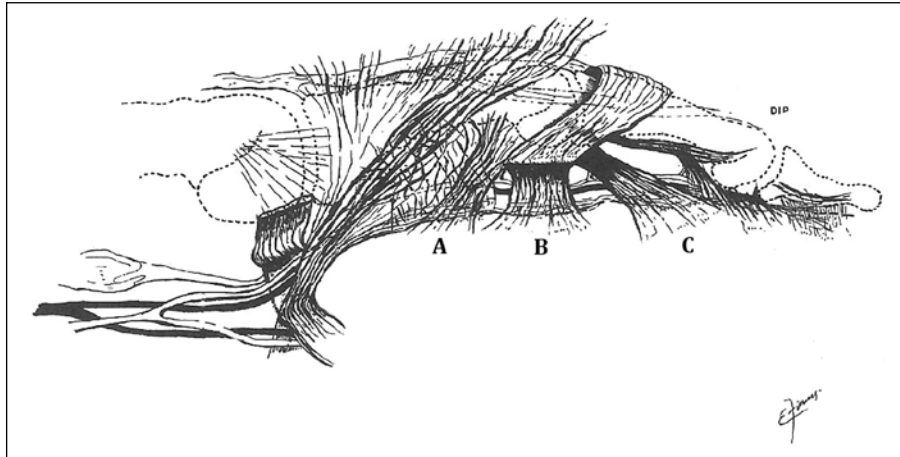
Figure 6. A detailed figure from Zancolli and Cozzi's Atlas of Surgical Anatomy of the Hand (4). (A–C) show respectively the proximal fibres (A), middle fibres (B), and distal fibres (C) of Cleland's ligaments. The "middle" fibres (B) are shown attached to Landsmeer's transverse band. The distal ligaments of Cleland are not shown (Zancolli and Cozzi, 1992).

their origin to the dorsal and ventral aspects towards the skin (Cleland, 1878; Chrysopoulo et al., 2002) (Figure 2).

Zancolli has drawn the level of insertion of the different layers of Cleland volar to the mid-lateral line in his cross-section (Figure 2). Our dissections suggest this insertion being more dorsal than Zancolli's description, in the mid-lateral position.

Several functions have been postulated for Cleland's ligaments, however, always without firm proof, and one as a stabilizer of the digital nerves and vessels. Another was the prevention of the skin from bagging, by keeping the skin in place during digital movement. We have been able to show that the PIP ligaments make a movement like a pair of scissors during flexion and extension and that the PIP-P ligaments at all angles limit skin movement proximally, whereas the PIP-D fibres limit distal migration. Acting together, they stabilize the skin relative to the joints, but this action is independent of the joint's position.

A further function that we can now attribute to Cleland's PIP-D and PIP-P ligaments is the creation of a gliding path for the lateral slip of the extensor tendon during flexion. This sliding function of the lateral slip of the extensor tendon has been well described by Zancolli, but he attributed this function only to the transverse retinacular ligament (Zancolli, 1968). In our opinion, it is the transverse retinacular ligament that keeps the different parts of the extensor tendon together, but Cleland's PIP-D limits the amount of palmar displacement by creating a gliding path ending at its insertion into the skin dorsal to the virtual joints axis. The small amount of gliding is likely to be vulnerable to adhesions in joint trauma.

As we hypothesized at the start of this study, the inconsistencies in previous reports may have been caused, at least in part, by the use of suboptimal conservation methods of the cadavers. In a pilot study, we performed dissections in formalin-fixed specimens, and found these difficult to execute and their findings unreliable. We had the option to change to fresh frozen/thawed specimens and specimens fixed with Thiel's method (Thiel, 1992). Our intact fresh frozen hands had been frozen immediately with straight fingers making manipulation before dissection (with potential damage to delicate tissues, such as the cutaneous ligaments) unnecessary and therefore ideal for anatomical studies. Tissues fixed by Thiel's method retain near natural flexibility and allow passive joint motion, making them our preferred choice for functional studies. We look upon this as a strength of this study. Moreover, the micro-dissection methodology we used allowed us to disclose detail previously unnoticed consistently. This compensates in part for the relative limited number of dissected fingers, which we believe is the main weakness of this study.

The relevance of this work is becoming greater, especially now it has been clearly shown that this ligament, in contrast to what has been long stated, is also affected in Dupuytren's disease (Shewring and Rethnam, 2013). Further study is necessary to investigate if any specific part of the redefined anatomical structure is more prone to be affected than others.

The anatomy and function of Cleland's ligaments is more complex than previously described, and it is now clearer than before that they play an important role in maintaining skin stability in all positions of the finger. The new insights gained into the anatomy and

function of Cleland's ligaments will help in further understanding its exact role in Dupuytren's disease.

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