Krupa et al.
Medical Journal of Cell Biology 2023
DOI: 10.2478/acb-2023-0005
Received: 20.02.2023
Accepted: 08.04.2023

Minireview of connective tissue features and selected forearm structures

Robert Krupa[1], Andrzej Mrozek[2], Jagoda Urbanska[3], Małgorzata Suchanecka[4], Katarzyna Siwek[4]

Abstract

Connective tissue is an extremely divaricated structure and, unlike other tissues, made up of proteins combined in various configurations. This construction is characterized by high variability and the ability to adapt through the appropriate selection of synthesized matrix components. That feature helps properly stabilize the body's joints. The content of receptors enables information transfer about stimuli acting on itself and on neighboring structures.

This work aims are to collect information about selected forearm structures, its features, functions and receptors content. One of the objectives is to improve the knowledge organization, indicate possible areas to expand and to inspire exploration diversity of connective tissue.

Structures described in the article include the transverse carpal ligament, the superficial and deep fascia of the forearm, the interosseous membrane, the flexor retinaculum system and the palmar aponeurosis. These structures are well-known even to inexperienced science students. However, acquired knowledge is still incomplete and possible to explore.

Running title: Connective tissue features

Keywords: fascia, CTS, flexor retinaculum, palmar aponeurosis

[1]Faculty of Physiotherapy, Wroclaw Medical University, Wroclaw, Poland
[2]Clinical and Dissecting Anatomy Students Scientific Club, Faculty of Medicine, Wroclaw Medical University, Wroclaw, Poland
[3]Faculty of Dentistry, Wroclaw Medical University, Wroclaw, Poland
[4]Department of Human Morphology and Embryology, Division of Anatomy, Wroclaw Medical University, Wroclaw, Poland
***Correspondence:** robert.krupa@student.umw.edu.pl
Full list of author information is available at the end of article

sciendo

Introduction

Musculoskeletal system, which allows for precise hand movements, has an extremely composite structure. It consists of muscles, bones and supporting connective tissue, which is part of i.e., fasciae, retinacula or ligaments. Connective tissue originates from mesenchyme during embryogenesis [1] and is considered as a unique type of tissue. Unlike other tissues, connective tissue is not formed by cell systems, but built by the relationships of protein structures. Thanks to this structure, it can behave as a scaffold for the human body. Groups of proteins ensuring whole tissue are: collagen, proteoglycans, types of various glycoproteins. Fibroblasts are responsible for the synthesis of these ingredients.

This article is about to show and compare the features of connective tissue resulting from its structure. Examples of selected connective tissue structures of the forearm are: transverse carpal ligament, superficial and deep fascia, interosseous, flexor retinaculum and palmar aponeurosis.

Mystery of collagen

First, the specifics of collagen should be presented. The type and arrangement of collagen bundles, as well as the content of glycoproteins makes up a response to mechanical strains and helps with maintenance of homeostasis [2].

Further, the appropriate arrangement of the connective tissue components and location makes it possible to distinguish it between structures e.g., ligaments and tendons. Thus, conclusion can be made that the ligaments are rich in collagen I, II, III, V and XI [2].

An interesting feature of connective tissue is its ability to adapt under the influence of a mechanical stimulus e.g., the thickening of the flexor retinaculum in climbers. It has been proven that exercise training affects the morphology and biomechanical characteristic of connective tissue [3].

Stimulated by tension, pressure or stretching fibroblasts starts synthetizing components of extracellular matrix [4,5].

It is assumed that one of the main functions of regular connective tissue is the stabilization of movable anatomical systems, such as joints. Ligaments, joint capsules, interosseous membranes and retinacula are designed to keep the system concrete. Other researchers, due to far-reaching effects resulting from this connection, eagerly use the term "fascial system" [6].

Despite the organization presented by collagen together with other connective tissue elements as described above, one more component has been selected in the connective tissue elements, giving them a specific feature – sensory receptors, specifically mechanoreceptors. Stained in connective tissue structures help determine role of studied structure.

Sensitive to high-frequency vibrations, Pacini bodies were located in the connective tissue of the forearm. Ruffini bodies, which respond to skin stretching, have been found in fascial layers and connective tissues. Golgi-Mazzoni bodies, which respond to pressure and free nerve endings, have been shown in the tissues selected for this article [7,8].

Proprioception is a sensory specialization, allows to constantly monitor position and movements of the body. It is a known fact that the neuromuscular spindles and Golgi bodies located in the muscles are responsible for proprioception [9].

Mechano-sensitive receptors have a defensive and warning function. They fulfilling protective role – thanks to them it is possible to dodge injuries [10].

Because of that the theory was developed that the connective tissue building the forearm stabilize it, protect the underlying muscular, nervous and vascular structures and, through the content of receptor cells, perform a proprioceptive function [11,12].

Pathologies

Environmental changes can negatively affect the connective tissue, because of influence of mechanical stress. It forces tissue to adapt, leading to pathological conditions of collateral tissues [13].

It is possible that inflammatory symptoms are not present. An example is the carpal tunnel syndrome (CTS), when the stiffening of the transverse carpal ligament increases pressure on the median nerve [14].

Stiffening and thickening of connective tissue structures are associated with a change in their metabolic activity, which influences production of tissue components. Environmental triggers, genetic predisposition and hormonal changes (especially in post-menopausal women) can lead to this type of changes [15].

Also, the content and shape of receptor cells in pathologically changed organs are rearranged [16].

Flexor retinaculum

The flexor retinaculum (FR) is an extension of the fascia of the forearm flexors [17].

It is a fibrous band that closes the carpal groove. The flexor muscles of the forearm, the median nerve and the vessels of the radial side of the wrist are localized in its proximity [18]. Its attachment points are located on the carpal bones: the palmar surface of the scaphoid, trapezius, pisiform and hook of the hamate [15].

Four types of fiber arrangement in FR have been described. The authors noticed a tendency to form "lamellae" that followed a characteristic bundled pattern. The classical division is as follows [19]:

- TYPE I – the most common arrangement of the bundle, distal-transverse and elbow-oblique lamina;

- TYPE II – distal-transverse and oblique-ulnar laminae were visible in the superficial layer, and proximal-transverse and radial-oblique laminae in the deep layer;
- TYPE III – in the superficial layer, distal-transverse and oblique-ulnar laminae and both types of transverse laminae into deep layer;
- TYPE IV – had transverse laminae at any depth and no distinct oblique laminae.

A correlation between the proximo-distal length of the flexor retinaculum and the arm's length was demonstrated. This proportion is shorter for women. Averagely, the length of the flexor retinaculum was 14% for the right arm and 15% for the left arm. Nevertheless, studies show a gender difference [20], which may affect the incidence of CTS in the female population. It has also been shown that females have a smaller carpal arch than males, as well as a lower distal arch height, resulting in reduced hand flexion and a smaller arch area [21]. Less compliance has also been demonstrated [22]. Characteristic changes in thickness have been observed in patients suffering from CTS [23,24].

Other studies report that the ligament is thicker proximally than distally, and the radial and ulnar segments are thicker than the medial one [25].

When it comes to stiffness, adaptability of the connective tissue under the influence of demanding mechanical conditions and forces applied to the tissue should be concerned. [26].

Staining FR fragments gives possibility to localize structures that may be responsible for proprioception. Ruffini, Pacini and Golgi-Mazzoni bodies have been observed [11,27,28].

Antebrachial fascia

The fascial system and the fascia itself have been causing problems for many years when it comes to its precise classification, functional division or clinical application. [29].

The fascia can be divided into parts: superficial, which lies closest to the skin and separates the subcutaneous tissue, and deep, which covers the muscles. [30]. Interestingly, the superficial fascia contains the nerves and vessels that supply the skin and provides mobility to the skin thanks to multiple layers of collagen fibers [31].

According to the work of Stecco et al. [27] the innervation of the deep fascia should be considered inseparably from the innervation of the muscles that this fascia covers.

Deep fascia is built by two/three layers of collagen fibers and divided by a thin layer of connective tissue. Fede et al. in 2021 [32] proved that deep fasciae can be innervated regardless of the location, but can be differentiated due to density of innervation. Moreover, these deep fascia layers can be shown under USG examination [33].

Interosseous membrane (IOM)

Highly functional specialization of the forearm entails a lot of complicated structures. The ulna and radius provide the insertion for a large number of ligaments and muscles. However longitudinal and transverse stabilization is strictly connected to the interosseous membrane (IOM) of the forearm [34].

The IOM origins below the radial tuberosity and ends just anterior to the distal radioulnar joint. It plays an important anatomical role because it prevents the radius from moving in relation to the ulna [35].

Anatomists have divided the IOM into distal, middle, and proximal parts. Researchers also distinguished the structures that build the IOM. The proximal oblique chord (POC), also known as Weitbrecht's ligament, can be observe close to the elbow [36].

In the middle central band (CB) is visible – the widest and thickest part of the IOM. In the distal part the Distal Oblique Band (DOB), the Distal Accessory Band (DAB), and the dorsal oblique accessory cord (DOAC) can be found [34,37].

The vascularization and innervation come from the anterior and posterior interosseous nerves and arteries [38].

Research was focused on the course of collagen fibers and the presence of other substances that could affect the mechanics of the structure. The presence of collagen, which in cross-section was parallel and perpendicular to the cutting plane, was demonstrated. The fibers were divided into bundles defined by their sheaths. The hematoxylin-eosin and Verhoeff-van Gieson stains showed that the sheath is mainly composed of elastin. This component ensures appropriate mechanical resistance to high tensile loads [39].

The absence of interstitial septa and elastic fibers in the central part of the IOM was also demonstrated. The dense packing of collagen and the increased amount of elastin in the DOB and POC provide greater flexibility during rotation of the forearm, and thus a better fit to the biomechanical requirements [34].

Nervous structures are also noteworthy. Research showed the presence of sensory cells as Ruffini, Paccini, Golgi and free nerve endings inside IOM. DOB had the highest number of Paccini bodies. Ruffini endings have been found in DOB, DAB, PAB and POC. Greater density of free nerve endings correlated significantly with more Ruffini endings. DOB and POC had significantly higher density of sensory nerve endings than any other IOM structure. CB and DOAC had the lowest innervation.

It was shown that the main sensory receptors are free nerve endings. This fact may indicate the important role played by nociception in the rotation of the forearm and receiving stimuli from the IOM surrounding.

The presence of different types of receptors allows them to complement each other in their physiological activities, thus enabling sensory-motor control in all complex movements [12].

Palmar aponeurosis (PA)

It is a connective tissue, fan-shaped looking structure extending on the palmar side of the hand. It consists of two layers: The deep layer, which is made up of transversely running bundles of fibers. The superficial layer, which is formed by longitudinal, most visible fibers. They are extended between the metacarpophalangeal joints to the superficial transverse ligament of the wrist. This arrangement of fibers brings to mind a triangular structure resembling a plate. Some of the fibers are attracted to the skin as Grapow fibers [35,40].

The connection between the PA and the deep transverse metacarpal ligament, the palmar interosseous fascia and the adductor fascia was also demonstrated. It is formed by nine septa at the tendons – two marginal and seven intermediate.

In addition, there are a number of partitions between the PA bundles and the deep fascia of the hand. These partitions divide the distal portion of the PA central compartment into eight secondary compartments. Four of them consist of the flexor tendons, and in the remaining four vessels and nerves are present [41].

The fibers of the palmaris longus tendon intertwine with the fibers of the palmar aponeurosis. Contraction of the muscle affects the PA and improve its stability [42].

The most common nerve structures were free nerve endings. Researchers state that the PA is innervated in a similar way to the proprioceptive structure. Innervation by nociceptive receptors significantly emphasizes the role of the connective tissue in pain perception [11,16].

Flexor pulley system of the hand

The flexor retinaculum system consists of two structures – the inner synovial sheath and the outer rim – the retinaculum. This fibrous tissue that encircles the superficial or deep digital flexor tendon, creating a tunnel intended for a flexor tendon. The retinaculum is ascending in the distal direction. There are 5 pulleys [43]:

- A1 – over the metacarpophalangeal joints,
- A2 – over the proximal phalanx,
- A3 – over the proximal interphalangeal joints,
- A4 – above the middle phalanx,
- A5 – above the distal interphalangeal joints.

The function of the annular pulleys is to enhance effective flexor tendon function by holding the tendons close to the phalanges. That is a prevention from "bowstringing" when the digits are flexed. Although the flexion component of the tendon is increased when pulleys are absent, due to a higher approach angle, a given angular motion requires greater tendon excursion. Functionally A2 was the most important pulley, followed by A4. On the other hand, loss of the A pulley was not associated with a significant change in tendon excursion. However, both the A2 and the A4 pulley have to be present for optimal excursion. [44].

According to the research, the structure of the pulleys is formed already in the 9th week of pregnancy, and their separation can be distinguished in the 12th week. There are formed by three layers. Inner one consists cells with large nuclei, forming flat shape and resembling tendon cells. They are separated by the future synovial cavity from the outer layer of the tendon. The middle layer is rich in fibroblasts lying along the collagen fibers. Collagen bundles surround the flexor tendon and attach to the perichondrium. The outer layer is formed by a richly vascularized mesenchymal tissue, which on the dorsal side surrounds the tendons of the flexors, extensors and the cartilage model of the bone [45].

Comparison of the pulleys of each finger showed that the ring finger is usually the weakest and least stiff, while the index finger is stronger and stiffer than the others. This is probably the reason why injuries most commonly affect the ring finger [46]. Injuries are most often the result of overuse during rock climbing. Most often they concern the A2 pulley, which has the greatest tension during tightening the grip [47].

Conclusions

Our work deals with issues related to the connective tissue structures of the forearm, its features and functions related to them. They are related to the fascial system of the and its function. Another feature is the importance for the functioning of the forearm, wrist and hand. It is forming sheaths and tissue barriers that allow the passage of tendons, muscles, nerves and vessels, and at the same time protect them or prevent excessive rotation in joints [10,48]. Durability resulting from its organization [2] and sensory functions [10] give a completely different outlook of the connective tissue of the forearm. It is no longer just a passive structure, but a kind of proprioceptive organ.

Accurate knowledge of the microanatomy and content of sensory cells will determine their suitability for potential transplants. It will also answer the question of whether biomechanical and proprioceptive function will be preserved after such an autograft [12]. This is important in the duration of postoperative rehabilitation recovery time after surgery [49].

It cannot be denied that anatomy, although it seems to be a well-known science, can be surprising. Not only the morphological diversity of structures [50,51], but also the discovery of new, previ-

ously poorly studied structures. Perfect example is structure called by the authors as "Annular Pulley of the Wrist" [52].

This makes current and future researchers realize about still existing discovering potential inside the human body.

Ethical approval
The conducted research is not related to either human or animal use.

Acknowledgments
Not applicable.

Corresponding author
Robert Krupa, Faculty of Physiotherapy, Wroclaw Medical University, Wroclaw, Poland, e-mail: robert.krupa@student.umw.edu.pl.

Conflict of interest
The authors declare no conflict of interest.

References

1. Hita-Contreras F, Martínez-Amat A, Ortiz R, Caba O, Alvarez P, Prados JC, Lomas-Vega R, Aránega A, Sánchez-Montesinos I, Mérida-Velasco JA. Development and morphogenesis of human wrist joint during embryonic and early fetal period. J Anat. 2012;220(6):580-90; DOI:10.1111/j.1469-7580.2012.01496.x.
2. Halper J, Kjaer M. Basic components of connective tissues and extracellular matrix: elastin, fibrillin, fibulins, fibrinogen, fibronectin, laminin, tenascins and thrombospondins. Adv Exp Med Biol. 2014;802:31-47; DOI:10.1007/978-94-007-7893-1_3.
3. Schreiber T, Allenspach P, Seifert B, Schweizer A. Connective tissue adaptations in the fingers of performance sport climbers. Eur J Sport Sci. 2015;15(8):696-702; DOI:10.1080/17461391.2015.1048747.
4. Chiquet M, Gelman L, Lutz R, Maier S. From mechanotransduction to extracellular matrix gene expression in fibroblasts. Biochim Biophys Acta. 2009;1793(5):911-20; DOI:10.1016/j.bbamcr.2009.01.012.
5. Bordoni B, Zanier E. Understanding fibroblasts in order to comprehend the osteopathic treatment of the fascia. Evid Based Complement Alternat Med. 2015;2015:860934; DOI:10.1155/2015/860934.
6. Blasi M, Blasi J, Domingo T, Pérez-Bellmunt A, Miguel-Pérez M. Anatomical and histological study of human deep fasciae development. Surg Radiol Anat. 2015;37(6):571-8; DOI:10.1007/s00276-014-396-1.
7. Silverthorn DU. Human physiology: an integrated approach. 8ht ed. London:Pearson; 2018. 984 p.
8. Grigg A, Hoffman AH, Fogarty KE. Properties of Golgi-Mazzoni afferents in cat knee joint capsule, as revealed by mechanical studies of isolated joint capsule. J Neurophysiol. 1982;47(1):31-40; DOI:10.1152/jn.1982.47.1.31.
9. Moon KM, Kim J, Seong Y, Suh BC, Kang K, Choe HK, Kim K. Proprioception, the regulator of motor function. BMB Rep. 2021;54(8):393-402; DOI:10.5483/BMBRep.2021.54.8.052.
10. Cavalcante ML, Rodrigues CJ, Mattar R Jr. Mechanoreceptors and nerve endings of the triangular fibrocartilage in the human wrist. J Hand Surg Am. 2004;29(3):432-5; DOI:10.1016/j.jhsa.2004.01.001.
11. Stecco C, Macchi V, Barbieri A, Tiengo C, Porzionato A, De Caro R. Hand fasciae innervation: The palmar aponeurosis. Clin Anat. 2018;31(5):677-683;DOI:10.1002/ca.23076.
12. Rein S, Esplugas M, Garcia-Elias M, Magin TM, Randau TM, Siemers F, Philipps HM. Immunofluorescence analysis of sensory nerve endings in the interosseous membrane of the forearm. J Anat. 2020;236(5):906-915; DOI:10.1111/joa.13138.
13. Logerstedt DS, Ebert JR, MacLeod TD, Heiderscheit BC, Gabbett TJ, Eckenrode BJ. Effects of and response to mechanical loading on the knee. Sports Med. 2022;52(2):201-235; DOI:10.1007/s40279- 021-01579-7.
14. Kim PT, Lee HJ, Kim TG, Jeon IH. Current approaches for carpal tunnel syndrome. Clin Orthop Surg. 2014;6(3):253-7; DOI:10.4055/cios.2014.6.3.253.
15. Rodriguez P, Casado A, Potau JM. Quantitative anatomical analysis of the carpal tunnel in women and men. Anna Anat. 2022;243:151956; DOI:10.1016/j.aanat.2022.151956.
16. García-Martínez I, García-Mesa Y, García-Piqueras J, Martínez-Pubil A, Cobo JL, Feito J, García-Suárez O, Vega JA. Sensory innervation of the human palmar aponeurosis in healthy individuals and patients with palmar fibromatosis. J Anat. 2022;240(5):972-984; DOI:10.1111/joa.13609.
17. Pacek CA, Chakan M, Goitz RJ, Kaufmann RA, Li ZM. Morphological analysis of the transverse carpal ligament. Hand (NY). 2010;5(2):135-40; DOI:10.1007/s11552-009- 9219-2.
18. Bochenek A, Reicher M. Anatomia człowieka. Tom 2. 10th ed. Warszawa: PZWL Wydawnictwo Lekarskie; 2010. 800 p.
19. Isogai S, Murakami G, Wada T, Akita K, Yamashita T, Ishii S. Laminar configuration of the transverse carpal ligament. J Orthop Sci. 2002;7(1):79-83; DOI:10.1007/s776-002- 8424-2.
20. Fochtmann-Frana A, Pretterklieber B, Dorfmeister K, Pretterklieber ML. A ratio to approximate the proximodistal extent of the flexor retinaculum in relation to the hand length. Ann Anat. 2021;234:151659; DOI:10.1016/j.aanat.2020.151659.
21. Lakshminarayanan K, Shah R, Li ZM. Sex-related differences in carpal arch morphology. PLoS One. 2019;14(5):e0217425; DOI:10.1371/journal.pone.0217425.
22. Zong-Ming Li. Gender difference in carpal tunnel compliance. J Musculo-skelet Res. 2005;09(03):153-159; DOI:10.1142/S0218957705001527.
23. Marquardt TL, Gabra JN, Evans PJ, Seitz WH Jr, Li ZM. Thickness and stiffness adaptations of the transverse carpal ligament associated with carpal tunnel syndrome. J Musculoskelet Res. 2016;19(4):1650019; DOI:10.1142/S0218957716500196.
24. Goitz RJ, Fowler JR, Li ZM. The transverse carpal ligament: anatomy and clinical implications. J Wrist Surg. 2014;3(4):233-4; DOI:10.1055/s-0034- 1394150.
25. Holmes MW, Howarth SJ, Callaghan JP, Keir PJ. Biomechanical properties of the transverse carpal ligament under biaxial strain. J Orthop Res. 2012;30(5):757-63; DOI:10.1002/jor.21583.
26. Woo SL, Gomez MA, Woo YK, Akeson WH. Mechanical properties of tendons and ligaments. II. The relationships of immobilization and exercise on tissue remodeling. Biorheology. 1982;19(3):397-408; DOI: 10.3233/bir-1982-19302.
27. Stecco C, Gagey O, Belloni A, Pozzuoli A, Porzionato A, Macchi V, et al. Anatomy of the deep fascia of the upper limb. Second part: study of innervation. Morphologie. 2007 Mar;91(292):38-43; DOI: 10.1016/j.morpho.2007.05.002.
28. Krupa R, Suchanecka M, Mrożek A, Siwek K. Features of the flexor retinaculum and its individual variation in carpal tunnel syndrome predisposition-a systematic review. Med J Cell Biol. 2022:10(3), 97-101; DOI: 10.2478/acb-2022-0015.
29. Kumka M, Bonar J. Fascia: a morphological description and classification system based on a literature review. J Can Chiropr Assoc. 2012;56(3):179-91.
30. Stecco C, Tiengo C, Stecco A, Porzionato A, Macchi V, Stern R, De Caro R. Fascia redefined: anatomical features and technical relevance in fascial flap surgery. Surg Radiol Anat. 2013;35(5):369-76; DOI:10.1007/s00276-012-1058-0.
31. Benjamin M. The fascia of the limbs and back – a review. J Anat. 2009;214(1):1-18; DOI:10.1111/j.1469-7580.2008.01011.x.
32. Fede C, Petrelli L, Guidolin D, Porzionato A, Pirri C, Fan C, De Caro R, Stecco C. Evidence of a new hidden neural network into deep fasciae. Sci Rep. 2021;11(1):12623; DOI: 10.1038/s41598-021-92194-z.
33. Stecco C, Stern R, Porzionato A, Macchi V, Masiero S, Stecco A, De Caro R. Hyaluronan within fascia in the etiology of myofascial pain. Surg Radiol Anat. 2011 Dec;33(10):891-6; DOI: 10.1007/s00276-011-0876-9.
34. Rein S, Kremer T, Houschyar KS, Siemers F, Philipps H. Structural topography of the interosseous membrane of the human forearm. Anna Anat. 2020;231:151547; DOI:10.1016/j.aanat.2020.151547.
35. Hochschild J. Anatomia functional para fisioterapas. Mexico: Editorial El Manual Moderno; 2017. 1340 p.
36. Kapandji A. Biomechanics of pronation and supination of the forearm. Hand Clin. 2001;17(1):111-22.
37. Matthias R, Wright TW. Interosseous membrane of the forearm. J Wrist Surg. 2016;5(3):188-93; DOI:10.1055/s-0036- 1584326.
38. Wright TW, Glowczewskie F. Vascular anatomy of the ulna. J Hand Surg Am. 1998;23(5):800-4; DOI:10.1016/S0363- 5023(98)80153-6.
39. McGinley JC, Heller JE, Fertala A, Gaughan JP, Kozin SH. Biochemical composition and histologic structure of the forearm interosseous membrane. J Hand Surg Am. 2003;28(3):503-10; DOI:10.1053/jhsu.2003.50059.
40. Langer MF, Grünert J, Unglaub F, Wieskötter B, Oeckenpöhler S. Das fibröse Skelett der Hand: Veränderungen bei der Dupuytren-Kontraktur [The fibrous skeleton of the hand: changes with Dupuytren's contracture]. Orthopedic. 2017;46(4):303-314; DOI:10.1007/s00132-017- 3406-6.
41. Manske PR, Lesker PA. Palmar aponeurosis pulley. J Hand Surg Am. 1983;8(3):259-63; DOI:10.1016/s0363- 5023(83)80154-3.
42. Cooper DW, Burns B. Anatomy, shoulder and upper limb, hand palmaris tendon [Internet]. Treasure Island (FL): StatPearls Publishing; 2022

[cited 2023 Feb 16]. 10 p. Available from: https://pubmed.ncbi.nlm.nih.gov/30137801/.
43. Zafonte B, Rendulic D, Szabo RM. Flexor pulley system: anatomy, injury, and management. J Hand Surg Am. 2014;39(12):2525-32; DOI:10.1016/j.jhsa.2014.06.005.
44. Peterson WW, Manske PR, Bollinger BA, Lesker PA, McCarthy JA. Effect of pulley excision on flexor tendon biomechanics. J Orthop Res. 1986;4(1):96-101; DOI:10.1002/jor.1100040112.
45. Peterson WW, Manske PR, Bollinger BA, Lesker PA, McCarthy JA. Effect of pulley excision on flexor tendon biomechanics. J Orthop Res. 1986;4(1):96-101; DOI:10.1002/jor.1100040112.
46. Mallo GC, Sless Y, Hurst LC, Wilson K. A2 and A4 flexor pulley biomechanical analysis: comparison among gender and digit. Hand (N Y). 2008;3(1):13-6; DOI:10.1007/s11552-007-9057-z.
47. Miro PH, vanSonnenberg E, Sabb DM, Schöffl V. Finger flexor pulley injuries in rock climbers. Wilderness Environ Med. 2021;32(2):247-258; DOI:10.1016/j.wem.2021.01.011.
48. Deak N, Bordoni B. Anatomy, shoulder and upper limb, wrist flexor retinaculum. [Internet]. Treasure Island (FL): StatPearls Publishing; 2021 [cited 2022 Sep 20]. 12 p. Available from: https://www.ncbi.nlm.nih.gov/books/NBK545198/.
49. Kaya D, Guney-Deniz H, Sayaca C, Calik M, Doral MN. Effects on lower extremity neuromuscular control exercises on knee proprioception, muscle strength, and functional level in patients with ACL reconstruction. Biomed Res Int. 2019;2019:1694695; DOI:10.1155/2019/1694695.
50. Olewnik Ł, Waśniewska A, Polguj M, Podgórski M, Łabętowicz P, Ruzik K, Topol M. Morphological variability of the palmaris longus muscle in human fetuses. Surg Radiol Anat. 2018;40(11):1283-1291; DOI:10.1007/s00276-018-2069-2.
51. Suchanecka M, Siwek K, Ciach J, Eicke K, Tarkowski V. Typology of flexor carpi radialis muscle in human fetuses. Folia Med Cracov. 2022;62(1):5-17; DOI:10.24425/fmc.2022.141687.
52. Simovitch R, Abel M, Arslan O, Frank C. Pulley anatomy for the radial side of the wrist. Clin Anat. 2001;14(4):246-7; DOI:10.1002/ca.1041.