SHORT COMMUNICATION

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Anatomical variations of the superficial palmar arch and its clinical relevance

Anatomske varijacije površinskog luka dlana i njihov klinički značaj

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Abstract

Background/Aim. In-depth knowledge of the vascular network of the hand is of great importance in modern medicine. The main vessel of the hand is the superficial palmar arch (SPA). As typically described in anatomical textbooks, it arises as a terminal branch of the ulnar artery, which then anastomoses with the superficial palmar branch of the radial artery. However, the SPA is characterized by remarkable variability, which has been the area of interest of many researchers so far. The aim of this study was to exert a comprehensive examination of the anatomy of the SPA. **Methods.** The research was conducted at the Institute of Anatomy "Niko Miljanić" on a total number of 14 cadavers. After careful dissection, variations of the modality of formation of the SPA and its distance of the SPA from Kaplan's cardinal line were observed on the right hands. Collected data were then analyzed statistically in SPSS 11.0 using the Mann-Whitney *U* test, with the accepted level of statistical significance of $p < 0.05$. **Results.** According to Coleman and Anson's classification, the higher incidence of the incomplete type (57.14%) of the SPA was observed compared to the complete type (42.86%). In addition to this, a statistically significant difference was discovered in the distance of the SPA from Kaplan's cardinal line between two groups with complete and incomplete types, respectively. The parameter examined in the group with the complete type took the value of 2.13 ± 0.32 cm, while in the group with the incomplete type measured 3.33 ± 0.87 cm. **Conclusion.** The present study showed a very important complexity in the domain of anatomy of the SPA with numerous clinical implications. For that reason, a thorough evaluation of the hand circulatory system should be considered while planning surgical procedures in order to avoid operative and postoperative complications.

Key words:
anatomic variation; ulnar artery; hand.

Apstrakt

Uvod/Cilj. Detaljno poznavanje vaskularne mreže šake od velikog je značaja u savremenoj medicini. Glavni krvni sud šake jeste površinski arterijski luk dlana (PLD), koji klasično nastaje anastomoziranjem lakatne arterije sa površinskom granom žbične arterije dlana. PLD odlikuje izuzetna varijabilnost koja se manifestuje različitim načinom nastanka i položajem ovog krvnog suda. Cilj rada bio je da se ispita anatomija PLD. **Metode.** Istraživanje je sprovedeno na Institutu za anatomiju „Niko Miljanić" na ukupno 14 kadavera. Nakon pažljive disekcije, na svim desnim šakama analizirane su varijacije u načinu nastanka kao i udaljenost PLD od Kaplanove kardinalne linije. Dobijeni podaci statistički su obrađeni u programu SPSS 11.0 primenom *Mann-Whitney* testa, pri čemu je prihvaćeni nivo statističke značajnosti bio $p < 0,05$. **Rezultati.** Prema *Coleman* i *Anson* klasifikaciji uočena je veća učestalost nekompletnog (57,14%) u odnosu na kompletni tip (42,86%) PLD. Takođe, utvrđena je statistički značajna razlika u rastojanju PLD od Kaplanove linije između kompletnog i nekompletnog tipa. Rastojanje kod kompletnog tipa bilo je 2,13 ± 0,32 cm, dok je kod nekompletnog tipa iznosilo 3,33 ± 0,87 cm. **Zaključak.** Sadašnja studija pokazala je veoma značajnu kompleksnost anatomije PLD, koja povlači za sobom veliki broj kliničkih implikacija. Da bi se izbegle operativne i postoperativne komplikacije neophodna je procena cirkulatornog sistema šake u toku planiranja hirurških procedura.

Ključne reči:
anatomija, varijacije; a. ulnaris; šaka.

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Introduction

From the evolutionary point of view, the human hand has become highly specialized in performing quite delicate and finely coordinated movements that have enabled us to skillfully use the objects from our surroundings. The hand, furthermore, contains numerous, densely packed tactile receptors and, therefore, plays an important role as a sensory apparatus that helps us perceive the environment [1]. Such a complex function of the hand is nothing else but a reflection of its complex anatomical structure. It is in this regard that we can analyze the vascular network of the hand, which is complicated and extremely variable. In-depth knowledge of hand vasculature is of great importance in modern medicine.

In broad terms, the two main blood vessels of the hand are the ulnar artery (UA) and the radial artery (RA). These two arteries anastomose on the anterior side of the hand and form two arterial arches – superficial and deep palmar arch [2]. The superficial palmar arch (SPA) undoubtedly occupies a central place in the hand vascular system [3]. Since the SPA presents the primary focus of our study, its origin, course, and side branches are described in more detail in the text that follows.

As standardly described in anatomical textbooks, the SPA arises from the UA, just distal to the pisiform. The vessel passes first medially around the hook of the hamate, then swings laterally, forming an arch that is convex downward [4]. The terminal part of the SPA communicates typically with the superficial palmar branch of the RA in the first web space [5]. The SPA lies in the loose connective tissue just beneath the palmar aponeurosis and above the terminal branches of the ulnar and median nerves, the long flexor tendons, and the lumbrical muscles [6].

The SPA gives rise to three or four common digital palmar arteries. At the base of the fingers, each of these arteries split into two proper digital palmar arteries. The vascular territory of proper digital palmar arteries includes the anterior surfaces of the second to the fifth finger and the posterior surfaces of these fingers at the level of the intermediate and distal phalanges. The medial side of the little finger is supplied by a separate branch that arises from the UA or represents the first side branch of the SPA [7].

Many anatomical variations of the SPA have been described by now in the literature. These variations manifest in the unusual formation and localization of the vessel and the atypical number of its side branches [8]. Variability of the SPA was the object of interest of many researchers back in the 19th century [9]. In the past century, studies were done to classify the SPA according to its formation. Important investigations in that period were conducted by Coleman and Anson [10] and Ikeda et al. [11].

In addition to having introduced detailed systematization of the SPA, scientists also tried to explain the causes of this remarkable variability. The most accepted theory is based on the ontogenetic development of the hand. This concept says that primitive vascular patterns of the hand during embryogenesis undergo many changes in terms of regression of already existing blood vessels and appearance of new ones [11]. Identification of the most common variations of SPA is very important for surgical techniques such as the use of vascularized skin flaps, synovial flaps, cardiac catheterization and bypass grafting, and wrist joint surgery [2, 12, 13].

Besides the origin of the SPA, two significant aspects in the analysis of this blood vessel are the diameters of the vessels involved in its formation and the localization of the SPA with respect to the topographic landmarks of the hand, such as Kaplan's cardinal line. Unlike the anatomical variations of the SPA, this topic has not been discussed in a huge number of research papers, so in this area, there is a need for further investigation.

The aim of this study was a comprehensive examination of the anatomy of the SPA, which included two parameters: the formation of the SPA and its localization related to the topographic landmarks of the hand.

Methods

Our research was conducted on cadaver material of the Institute of Anatomy "Niko Miljanić", Faculty of Medicine, University of Belgrade, with the approval of the Ethics Committee for the use of human and laboratory animal material, Faculty of Medicine, University of Belgrade, Serbia (Nº 325-07-01245/2014-05/2). A total number of 14 cadavers were examined in the study, of which 7 were male and 7 were female cadavers aged 67 to 79 years. At the very beginning, a visual inspection of every hand was performed to exclude the specimens with deformities and traces of trauma or surgical interventions. After fixation in 10% formalin solution, the right hands were carefully dissected, following standard protocols from dissection manuals.

In the first part of our research, the variations in the formation of the SPA were examined. Several classifications of the SPA were made in the previous period based on its formation. One of the most practical and most used is the classification into a complete and incomplete type [14]. The complete type of the SPA is defined when there is an anastomosis between the vessels involved in its formation or when the UA reaches the first web space. On the other hand, if there is no such anastomosis, the SPA is considered incomplete [15].

In the second part of our research, the focus was put on the localization of the SPA in relation to the topographic landmarks of the hand. While choosing the landmark that will be used in the study, we took into consideration two criteria – simplicity of determination and practical use in surgical procedures on the hand. Keeping that in mind, Kaplan's cardinal line was selected. According to the original definition, Kaplan's cardinal line connects the apex of the first web space with the ulnar side of the hand and runs parallel to the middle palmar crease [16]. For this study, two groups were formed – one with the complete and one with the incomplete type of the SPA, respectively. The parameter that was examined and then compared between the two groups was the vertical distance from Kaplan's cardinal line to the SPA at the level of the fourth common digital palmar artery. Measurements were taken twice on each hand, and the average of two values was recorded. The measuring instruments used in the study were the ruler and electronic digital caliper (range of 0–500 mm, resolution 0.01 mm).

The methodology of the parameters examined is shown schematically (Figure 1), while the parameters are shown in Figure 2.

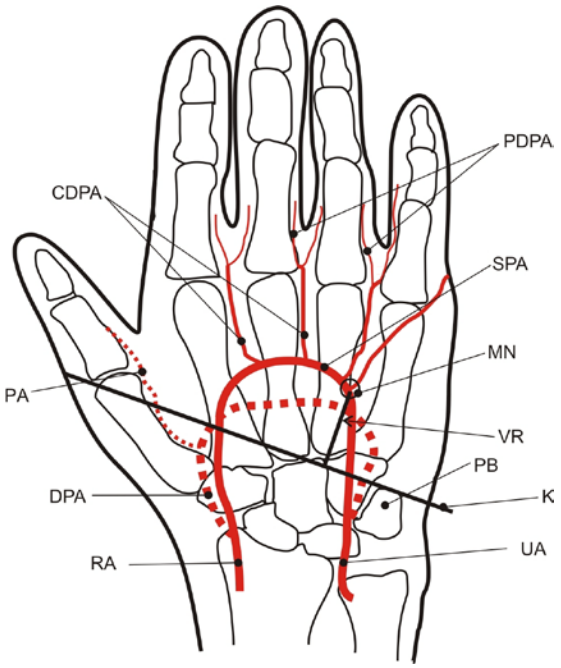

Fig. 1 – Vascular network of the hand and methodology of measurement of the parameters examined.
UA – ulnar artery; RA – radial artery; DPA – deep palmar arch; SPA – superficial palmar arch; PA – principal artery of the thumb; CDPA – common digital palmar arteries; PDPA – proper digital palmar arteries; PB – pisiform bone; K – Kaplan's cardinal line; MN – origin of the fourth common digital palmar artery in the fourth web space; VR – vertical distance between the superficial palmar arch at the level of the fourth common digital palmar artery and Kaplan's line.

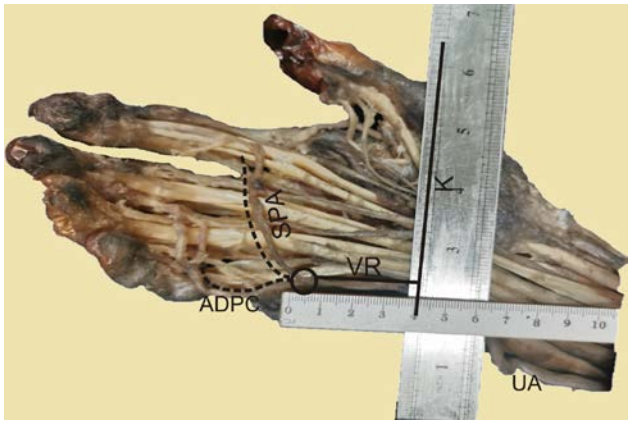

Fig. 2 – Methodology of measurement of the parameters examined in hand with incomplete type of the superficial palmar arch.
K – Kaplan's cardinal line; SPA – superficial palmar arch; UA – ulnar artery; ADPC – fourth common digital palmar artery; VR – vertical distance between the superficial palmar arch at the level of the fourth common digital palmar artery and Kaplan's line.

Statistical analysis of the data was performed in SPSS 11.0 using the Mann-Whitney *U* test, with the accepted level of statistical significance of $p < 0.05$.

Results

The results of our study are demonstrated in Tables 1 and 2. The complete type of the SPA was observed in 6 of 14 hands (42.86%), while the incomplete type was detected in 8 of 14 hands (57.14%). The average distance between the SPA (at the level of the fourth common digital palmar artery) and Kaplan's cardinal line measured 2.13 ± 0.32 cm in the group with the complete type. The same parameter took the value of 3.33 ± 0.87 cm in the group with the incomplete type of the SPA. A statistically significant difference was found by comparing the results between the two groups, with $p = 0.02$. Further investigation of data collected did not reveal a statistically significant difference between male and female cadavers, with $p = 0.65$.

Table 1

Results obtained by measuring the distance between the superficial palmar arch (SPA) and Kaplan's cardinal line

Cadaver number	SPA type	Distance between SPA and Kaplan's line (cm)
1	incomplete	3.8
2	complete	2.5
3	incomplete	3.7
4	incomplete	3.0
5	complete	2.1
6	complete	1.6
7	complete	2.0
8	incomplete	3.1
9	incomplete	3.5
10	complete	2.2
11	complete	2.4
12	incomplete	1.4
13	incomplete	4.0
14	incomplete	4.1

Table 2

Comparison of the distance between Kaplan's cardinal line and the superficial palmar arch (SPA) in groups with complete and incomplete type

SPA type	Distance between SPA and Kaplan's line (cm)	
	mean	SD
Incomplete (57.14%)	3.33	0.87
Complete (42.86%)	2.13*	0.32

SD – standard deviation.
***statistically significant decrease of the parameter examined in a group with complete type of the superficial palmar arch.**

A comparison of our results with those of other studies is shown in Table 3.

Table 3

Comparative analysis of incidence of complete and incomplete type of the superficial palmar arch (SPA) in the present and previous studies

SPA type	Coleman and Anson [10]	Janevski et al. [18]	Ikeda et al. [11]	Tagyl et al. [3]	Joshi et al. [19]	Present study
Complete	78.5%	42.4%	96.4%	75%	82%	42.86%
Incomplete	21.5%	57.6%	3.6%	25%	18%	57.14%

Discussion

The first aim of the present study was to analyze the variations in the formation of the SPA. This interesting feature of the SPA has intrigued a great number of scientists, whose first task was to describe the course, side branches, and relation of this blood vessel with adjacent elements. The development of modern medicine in the 20th and 21st century necessitated the systematization of previously collected knowledge with the purpose of its practical use in the fields of plastic, reconstructive, and microsurgery. This was how various classifications of the SPA were introduced. In the present study, the division between the complete and incomplete types was used. This classification appeared for the first time in the works of Jaschtschinski [9] at the end of the 19th century [17] and was elaborated further by Coleman and Anson [10] in the 20th century. Investigating the sample that comprised 650 hands, these two scientists observed 5 subgroups (A, B, C, D, and E) within the complete type and 4 subgroups (A, B, C, and D) within the incomplete type of the SPA [10].

The present study showed a moderately higher incidence of the incomplete type (57.14%) compared to the complete type (42.86%) of the SPA. Previous studies, however, found the opposite, i.e., the dominant occurrence of the complete type. Coleman and Anson [10] observed the complete type in 78.5% of cases and the incomplete type in 21.5% of cases, while Ikeda et al. [11] found the complete type in even 96.4% of specimens and the incomplete type in just 3.6% of specimens. On the other hand, data collected in the present study are in complete concordance with the results of the research on 500 hand angiograms conducted by Janevski et al. [18], with the recorded percentages of 42.4% for the complete and 57.6% for the incomplete type of the SPA.

The origin of the differences between the results of the present study and the results of some other studies is certainly multifactorial. At first, this discordance can be explained by the small size of our sample compared to other studies that were conducted on several hundreds of hands. Furthermore, ethnical differences in examined populations contribute for sure to the disparity of results [19]. Ultimately, because a subjective inspection of the sample was the method used in data collecting, differences in the interpretation of the complete and incomplete type of the SPA may be one of the causes of the differences in the results.

Unusual cases of the complete absence of the SPA [20] or double SPA [4] have been described in the literature. Other studies suggest that the median artery can contribute to the formation of both complete and incomplete types of SPA [21]. This blood vessel normally regresses during fetal development but sometimes persists and can be found in adults. Due to its close relationship with the median nerve, the persistent median artery can provoke the symptoms of carpal tunnel syndrome [22]. The aforementioned findings are extremely rare and were not observed in the present study.

Considering the variability of the SPA, there is a classification proposed by Gokhroo et al. [2] that is worth mentioning because it includes several criteria in the SPA typing, such as dominance, completeness, diameters of the ulnar and radial arteries, blood flow rate, and the existence of atherosclerotic lesions.

The second aim of the present study was to analyze the localization of the SPA in relation to the topographic landmarks of the hand. It is an incredibly important aspect in the examination of the SPA because topographic landmarks, such as palmar creases and Kaplan's cardinal line, are widely used to avoid injuries to this blood vessel during surgical procedures. Nevertheless, the distance between the SPA and Kaplan's cardinal line was inspected in a limited number of research papers. To the best of the author's knowledge, there is no study in which the given parameter was compared between the complete and incomplete types of the SPA.

The results of the present study revealed a greater distance between the incomplete type of the SPA and Kaplan's line (3.33 ± 0.87 cm) compared to the complete type (2.13 ± 0.32 cm). These data differ considerably from the results of the research led by Panchal and Trzeciak [23], where the average of the examined distance was measured at 1.18 ± 0.43 cm. The differences are slightly smaller when the results of the present study are compared to those of the research conducted by McLean et al. [16], in which the same parameter took the value of 1.53 ± 0.86 cm. This discordance can be explained by the differences in the interpretation of Kaplan's cardinal line, whose definition changed over time [24].

The cause of the observed differences in the distance between groups with the complete and incomplete types of the SPA is possibly found in the embryologic development of the hand vascular network, as is the case for the variations in the formation of this blood vessel [25]. It is evident that the incomplete type of the SPA, which was considered anomalous in the past, very often goes together with some other anatomical varieties, such as the absence of the palmaris longus muscle or persistent median artery [26]. Jaschtschinski [9] regarded the incomplete type of the SPA as an "atavistic feature", and it was proved that very rare variations of the SPA observed in humans represent the phylogenetic retention of the primitive vascular patterns found in other primates – chimpanzee, gorilla, orangutan, gibbon, and macaque.

The knowledge of the anatomy of the SPA has many clinical implications. On the one hand, some procedures re-

quire transradial access (TRA), e.g., cardiac catheterization and arterial cannulation. Cardiac catheterization is frequently used in the diagnosis or treatment of certain cardiovascular conditions, while radial arterial cannulation precedes hemodialysis or arterial blood gas analysis. On the other hand, the ultimate choice in some interventions may be complete removal of the radial artery, which serves as a coronary artery bypass graft (CABG), or taking part in vascularized skin flaps that are nowadays widely used in microsurgery [27]. In both cases, it is essential to assess the existence of collateral circulation in the hand before performing the procedures. The methods of evaluation include Allen's test, Doppler ultrasonography, pulse oximetry, or angiography [28]. It has been shown that people with the incomplete type of SPA are more prone to hand ischemia as one of the complications of the aforementioned procedures [29]. The same problem may occur even in persons with the complete type of SPA [30], which is explained either by the incapacity of the anastomotic vessels to ensure the needs of tissue in the newly created situation of compromised blood flow or by the existence of atherosclerotic lesions which narrow the lumen of the UA and disable adequate blood supply. Other researchers suggest that multiple anastomoses within the vascular bed of the hand increase the risk of profuse bleeding in case of traumatic injury of the blood vessel, but at the same time help faster recovery [31]. In addition to assessing the type of SPA, it is of tremendous importance to know its localization to avoid the iatrogenic injury of this blood vessel during some surgical operations on the hand, like carpal tunnel release (CTR). In this context, it is crucial to know the exact distance between the SPA and Kaplan's cardinal line, which represents the distal border of "the safe zone" in operations in the wrist area [23].

In the end, we must mention that the present study contains some limitations. Those are the small sample size which does not allow the generalization of the obtained results to the entire population, and the examination of the hands of just one side, so it was not possible to draw a conclusion about the existence of bilateral symmetry of the SPA.

Conclusion

The vascular network of the hand is organized in a very complex manner. Its dominant blood vessel is the SPA, typically formed by anastomosing of the UA and RA. However, this blood vessel is characterized by remarkable variability in its formation and localization to the topographic landmarks of the hand, such as Kaplan's cardinal line. Every surgeon should be aware of this variability while performing the interventions on hand, as it affects the course of the operation and the postoperative recovery. Our study reported a higher incidence of the incomplete type in comparison to the complete type of the SPA. It was also observed that there are differences in the distance between these two types of SPA and Kaplan's cardinal line. Because of that, the authors suggest that a thorough assessment of hand circulation should be performed prior to any invasive procedure to avoid hand ischemia as one of the possible complications. Finally, there is a need for further investigation in this field with the goal of the advancement of pre-existing knowledge. One of the directions in which future research could be taken is the examination of factors that influence the outstanding variability of the SPA.

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REFERENCES

1. *Littler JW*. The physiology and dynamic function of the hand. Surg Clin North Am 1960; 40: 259–66.
2. *Gokhroo R, Bisht D, Gupta S, Kishor K, Ranwa B.* Palmar arch anatomy: Ajmer Working Group classification. Vascular 2016; 24(1): 31–6.
3. *Tagyl SM, Cicekcibasi AE, Ogun TC, Buyukmumcu M, Salbacak A.* Variations and clinical importance of the superficial palmar arch. SDU Tip Fak Derg 2007; 14(2): 11–6.
4. *Patnaik VVG, Kalsey G, Singla Rajan K.* Palmar arterial arches – a morphological study. J Anat Soc Ind 2002; 51: 187–93.
5. *Chirag B, Candice DM, Johnson LY, Omid RB, Kar R.* Incomplete superficial palmar arch and bilateral persistent median artery. Int J Surg Case Rep 2019; 58: 205–7.
6. *Gajisin S, Zbrodowski A.* Local vascular contribution of the superficial palmar arch. Acta Anat (Basel) 1993; 147(4): 248–51.
7. *Ilic A.* Hand arteries. In: *Bogdanovic D, Mrvaljevic D,* editors. Anatomy of the upper extremity. Belgrade, Serbia: Faculty of Medicine, University of Belgrade; 1991. p. 66. (Serbian)
8. *Haladaj R, Wysiadecki G, Dudkiewicz Z, Polguj M, Topol M.* Persistent median artery as an unusual finding in the carpal tunnel: its contribution to the blood supply of the hand and clinical significance. Med Sci Monit 2019; 25: 32–9.
9. *Jaschtschinski SN*. Morphologie und topographie des arcus volaris sublimis und profundus. Anat Hefte 1897; 7: 163–88. (German)
10. *Coleman SS, Anson BJ*. Arterial patterns in the hand based upon a study of 650 specimens. Surg Gynecol Obst 1961; 113(4): 409–24.
11. *Ikeda A, Ugava A, Kazihara Y, Hamada N*. Arterial patterns in the hand based on a three-dimensional analysis of 220 cadaver hands. Am J Hand Surg 1988; 13(4): 501–9.
12. *Aragão JA, da Silva AC, Anunciação CB, Reis FP*. Median artery of the forearm in human fetuses in northeastern Brazil: anatomical study and review of the literature. Anat Sci Int 2017; 92(1): 107–11.
13. *Aktouf A, Auquit-Auckbur I, Mebtouche N, Mouilhade F, Le Moulec YP, Milliez PY*, et al. Anatomical study and clinical relevance of the flexor superficialis synovial flap: an assessment of 31 hand dissections. Surg Radiol Anat 2012; 34(6): 493–8.
14. *Gellman H, Botte MJ, Shankwiler J, Gelberman RH*. Arterial patterns of the deep and superficial palmar arches. Clin Orthop Relat Res 2001; (383): 41–6.
15. *Singh S, Lazarus L, De Gama BZ, Satyapal KS*. An anatomical investigation of the superficial and deep palmar arches. Folia Morphol (Warsz) 2017; 76(2): 219–25.

16. *McLean KM, Sacks JM, Kuo YR, Wollstein R, Rubin JP, Andrew Lee WP.* Anatomical landmarks to the superficial and deep palmar arches. Plast Reconstr Surg 2008; 121(1): 181–5.
17. *Gnanasekaran D, Veeramani R.* Newer insights in the anatomy of superficial palmar arch. Surg Radiol Anat 2019; 41(7): 791–9.
18. *Janevski BK.* Anatomy of the arterial system of the upper extremities. In: *Landsmeer JMF, Terpstra JL*, editors. The Angiography of the upper extremity. Hague, Netherlands: Martinus Nijhoff 1982; p. 120.
19. *Joshi SB, Vatsalaswamy P, Bahetee BH.* Variation in formation of superficial palmar arches with clinical implications. J Clin Diagn Res 2014; 8(4): AC06–9.
20. *Ozkus K, Peştelmaci T, Soyluoğlu AI, Akkin SM, Ozkus HI.* Variations of the superficial palmar arch. Folia Morphol (Warsz) 1998; 57(3): 251–5.
21. *Rodríguez-Niedenführ M, Sañudo JR, Vázquez T, Nearn L, Logan B, Parkin I.* Median artery revisited. J Anat 1999; 195(Pt 1): 57–63.
22. *Barfred T, Højlund AP, Bertheussen K.* Median artery in carpal tunnel syndrome. J Hand Surg Am 1985; 10(6 Pt 1): 864–7.
23. *Panchal AP, Trzeciak MA.* The clinical application of Kaplan's cardinal line as a surface marker for the superficial palmar arch. Hand 2010; 5: 155–9.
24. *Vella JC, Hartigan BJ, Stern PJ.* Kaplan's cardinal line. J Hand Surg 2006; 31(6): 912–8.
25. *Singer E.* Embryological pattern persisting in arteries of the arm. Anat Rec 1933; 55(4): 403–9.
26. *O'Sullivan E, Mitchell B.* Association of the absence of palmaris longus tendon with an anomalous superficial palmar arch in the human hand. J Anat 2002; 201(5): 405–8.
27. *Tan RES, Lahiri A.* Vascular anatomy of the hand in relation to flaps. Hand Clin 2020; 36(1): 1–8.
28. *Ruengsakulrach P, Eizenberg N, Fahrer C, Fahrer M, Buxton BF.* Surgical implications of variations in hand collateral circulation: Anatomy revisited. J Thorac Cardiovasc Surg 2001; 122(4): 682–6.
29. *Nunoo-Mensah J.* An unexpected complication after harvesting of the radial artery for coronary artery bypass grafting. Ann Thorac Surg 1998; 66(3): 929–31.
30. *Doscher W, Viswanathan B, Stein T, Margolis IB.* Hemodynamic assessment of the circulation in 200 normal hands. Ann Surg 1983; 198(6): 776–9.
31. *Lockhardt RD, Hamilton GF, Fyfe FW.* Vascular system – Systemic arteries. In: Anatomy of the human body. London, United Kingdom: Faber & Faber Ltd. 1959; p. 612.

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