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Formation and branching patterns of deep palmar arch

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ABSTRACT

Objective: The present study is to document and provide information about both normal and variable morphology of the deep palmar arch (DPA) in adult human cadavers by the dissection method.

Materials and Methods: We examined 12 upper extremities (6 cadavers). After the classification of the vascular patterns of DPA and its branches, measurements of the vessel diameters were carried out using a digital compass.

Results: Deep palmar arch was found as a completed arch (100%) in all cases. The anastomosis between the distal deep palmar branch of the ulnar artery (DPBUA) and the terminal branch of the radial artery (RA) was the most common type in our study. The incidence of the DPA was reported as a complete arch ranging from 54.9% to 100%. Palmar metacarpal arteries (MPAs) originating from the DPA were divided into four branches (25%) in three cases and three branches (75%) in nine cases. The mean diameter of the MPAs at the point of origin at the DPA was between 0.3 mm and 0.6 mm.

Conclusion: A comprehensive understanding of the DPA branching diameters in the hand will facilitate surgical and radiological approaches and contribute to a constantly expanding knowledge base in literature.

Keywords: Anatomy, Deep palmar arch, Hand, Radial artery, Ulnar artery

1. INTRODUCTION

Arterial blood supply to the hand is vital, comprising the vascular networks that provide anastomosis between the superficial palmar arch (SPA) and the deep palmar arch (DPA) [1-5]. These arches and their branches form an abundant network of blood vessels that provide oxygenated blood to all parts of the hand and fingers. The SPA is generally formed by the ulnar artery (UA) and the superficial palmar branch of the radial artery (SPBRA) [5,6]. The radial artery (RA) then continues its course, curving around to enter the dorsal aspect of the hand, passing the scaphoid and trapezium, and passing through the floor of the anatomical snuff box [7]. After reaching the snuff box, the RA passes between the two heads of the first dorsal interosseous muscle and proceeds to the palm, and shows continuity as the DPA (Figure 1). The DPA is dominated by the RA in the palm and is formed by the anastomosis of the distal deep palmar branch of the ulnar artery (DPBUA) and RA [6]. The DPA is localized deep in the flexor tendons of the hand. The palmar metacarpal arteries (MPAs), which anastomose with the common palmar digital arteries, emerge from the convexity of the DPA [8]. It is known that proximal and distal perforating branches, as well as MPAs, originate from the DPA (Figure 1). The DPA is located more proximally than the SPA [9]. The DPA supplies blood to the thumb and the lateral side of the index finger [7]. Injury to this area can cause considerable bleeding, but healing is rapid due to anastomoses. These two arches balance the circulation with some compensatory variations [10].

A thorough examination of hand function is the basic requirement of all hand surgeons during interventions. The vascular anatomy of the hand is a complex and challenging field, and has been the subject of many classification studies. One of the first classifications of the palmar arches was made by Coleman and Anson [11]. The human hand is highly developed in terms of its complexity and variation, which stems from embryologic development [12]. It is

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important to note that in a careful long-term analysis of arterial variations based on homogeneous criteria, these variations occurred with very similar incidences each year [13]. In previous studies, the completeness of the SPA ranged from 31.8% [14] to 100% [4], whereas the completeness of the DPA was reported to range from 54.9% [1] to 100% [7,15,16].

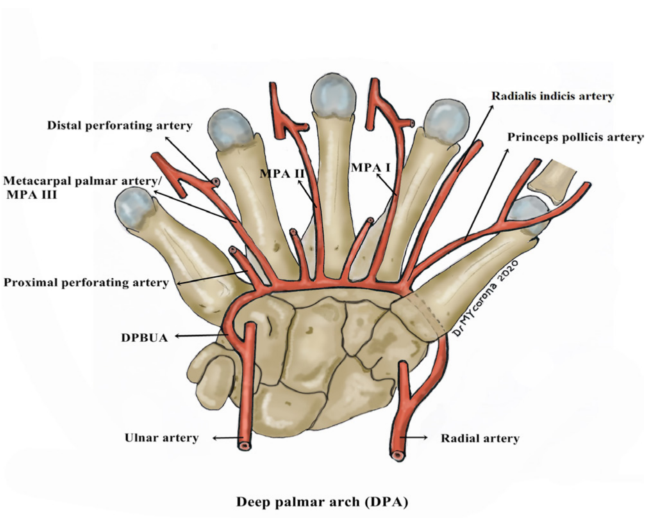

Figure 1. Schematic representation of the deep palmar arch. (DPBUA: Deep palmar branch of the ulnar artery; MPA: Palmar metacarpal arteries)

Aside from the well-known SPA, recent studies have shown that DPA and its branches are of sufficient size for some microvascular reconstruction procedures [7]. van Leeuwen et al. [17] recently concluded that although the incompleteness of the SPA is common, the digital blood supply is always preserved by a complete DPA. The ischemia potential and the variability of vascular formation are the most significant difficulties faced in these surgical procedures [18,19].

It is beyond doubt that an awareness and identification of the DPA variations in the hand are particularly important for the reconstruction of congenital anomalies, post-traumatic lesions and the use of the RA as an arterial by-pass graft [1-3,8,10]. Physical examinations, diagnostic studies and an evaluation of surgical interventions for the restoration of blood flow are necessary to prevent irreversible damage. Angiography, ultrasonography, and Doppler studies have been carried out as well as gross dissections and casting techniques with the aim of gaining an understanding to the complex and thin vascular structures in the palmar region [18,20,21].

The present study aimed to establish the morphometric parameters and the anatomical branching pattern of the DPA in human cadaver. To the best of our knowledge, there have been few studies to date focusing on the morphometry of the DPA branches in terms of surgical and anatomical relevance. Such information defining the DPA morphology could be substantially beneficial to the clinical and anatomical fields.

2. MATERIALS and METHODS

We examined 12 upper extremities (6 cadavers). The cadavers were both female and male (female 1/male 5), aged 30–70 years and had no orthopedic defects. All cadavers were fixed using phenol and formol, and routinely dissected by first-year medical students.

Measurements were repeated three times to minimize measurement error, and the average of the data obtained from different cases was used as the study data. The measurements were made using a digital caliper with a 0.01 mm accuracy.

The study was conducted to document and inform both the normal and variable morphology of the DPA. A skin incision was made to the dissected areas extending to the distal phalanxes, and the skin and fascia were then cut off. The RA and UA were dissected in the wrist region, and their branches were identified in the distal third part of the forearm (Figure 2). After the branch of the SPBRA that participates in the SPA and the proximal (distal, if any) DPBUA that joins the DPA, the superficial palmar region was dissected (Figure 2). The palmar aponeurosis was revealed, separated from the flexor retinaculum and divided proximally, and the septae were removed. The neurovascular structures were protected from the beginning of the flexor retinaculum with curved-tip dissecting scissors. Then the flexor retinaculum was dissected on both sides with a central incision down the middle of the retinaculum. The branches of the median nerve passing through the carpal tunnel, and the tendons of the flexor digitorum superficialis and the flexor digitorum profundus were carefully dissected.

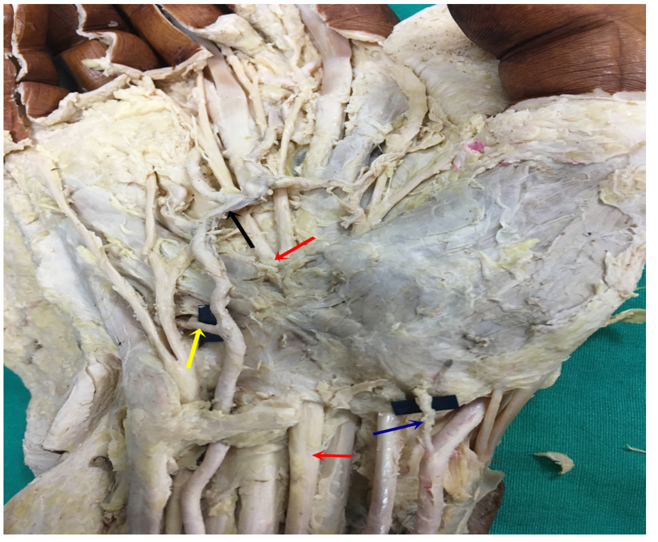

Figure 2. Appearance of the vessels, nerves, and their branches in the palmar region of the hand (case-4). (Yellow arrow: Distal deep palmar branch of the ulnar artery; Blue arrow: superficial palmar branch of the radial artery; Black arrow: superficial palmar arch; Red arrow: median nerve)

The dorsal course of the RA was examined before reaching the palmar region. The RA was dissected to reveal the course and branching of the first interosseous space in the anatomical snuffbox (Figures 3,4).

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***Figure 3.** Branches are given by the radial artery after passing through the snuff box (A: case-2; B: case-5). (Yellow arrow: Deep palmar arch; Blue arrow: Princeps pollicis artery; Red arrow: radialis indicis artery; Green arrow: dorsal metacarpal artery I)*

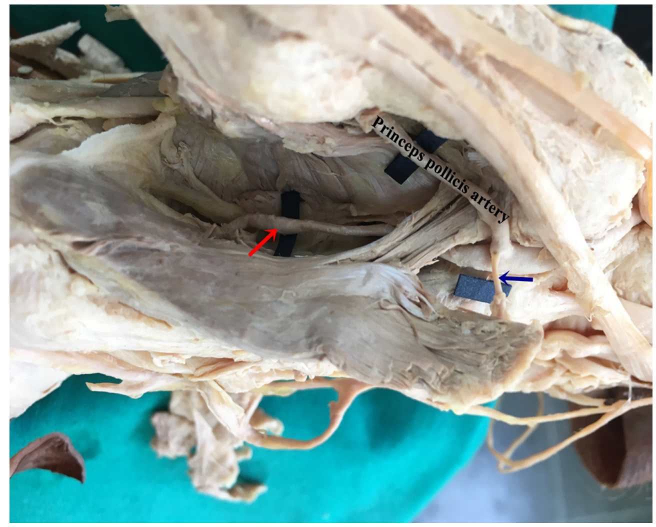

***Figure 4.** The appearance of a perforating branch feeding the oblique head of the interosseous muscle and princeps pollicis and radialis indicis arteries originating from the radial artery (case-1). (Blue arrow: perforating branch; Red arrow: radialis indicis artery)*

***Table I.** The mean diameters of vessels (mm) and number of MPAs originating from the DPA.*

Specimen	Case	Sex	R/L	RA	UA	Deep branch of ulnar artery		PPA	RIA	Dorsal metacarpal artery I	DPA (Origin)	DPA (Termination)	Number of palmar metacarpal arteries
						Proximal	Distal						
1	1	M	L	2.82	2.4	*	0.15	1.47	1.55	*	1.38	0.96	3
	2	M	R	3.57	2.55	*	1.5	2.37	1.46	*	1.1	0.9	4
2	3	M	L	3	3.5	*	0.17	1.8	1.8	*	1.7	1.7	3
	4	M	R	4.6	3.1	*	0.20	2.0	2.3	0.95	1.8	1.0	3
3	5	M	R	2.05	1.57	0.6	1.13	1.0	0.35	0.26	0.96	1.08	3
	6	M	L	2.1	1.9	*	1.22	1.2	0.9	*	1.21	0.9	3
4	7	F	R	2.59	1.75	0.63	1.14	1.31	1.11	*	1.02	0.4	4
	8	F	L	2.91	2.45	*	0.69	1.62	1.45	*	1.3	1.0	3
5	9	M	R	2.35	2.38	*	1.24	1.35	1.37	0.85	0.98	0.95	4
	10	M	L	2.85	2.33	*	0.99	1.5	1.2	*	1.22	0.96	3
6	11	M	R	2.82	2.34	*	1.1	1.45	1.38	*	1.13	1.07	3
	12	M	L	2.94	2.44	*	0.58	1.67	1.32	*	1.39	0.89	3
	Total Average	n=12	Right=6 Left=6	**2.88 mm**	**2.39 mm**		**0.84 mm**	**1.56mm**	**1.35mm**		**1.26 mm**	**0.98 mm**	**0.3-0.6 mm**
	Avarage males	n=10		**2.91 mm**	**2.45 mm**		**0.82 mm**	**1.58 mm**	**1.36 mm**		**1.28 mm**	**1.04 mm**	**0.53 mm**
	Avarage females	n=2		**2.75 mm**	**2.1 mm**		**0.91 mm**	**1.46 mm**	**1.28 mm**		**1.16 mm**	**0.7 mm**	**0.49 mm**

*(**RA:** the diameter of the radial artery before giving the superficial palmar branch; **UA:** Ulnar artery; **PPA:** princeps pollicis artery; **RIA:** radialis indicis artery; **DPA:** deep palmar arch; *: not observed)*

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To obtain a clear field of visualization of the DPA, the lateral head of the interosseus dorsalis-I and the oblique head of the adductor pollicis were removed, as well as the skin and fascia. Changes in all dissected regions were observed, recorded and visualized. When possible, we measured the diameters of RA, UA, proximal and distal deep palmar branch of the ulnar artery, PP, RI, dorsal metacarpal artery I as well as the distance from the origin of the DPA to its termination. The average diameters of the vessels are presented in Table I.

The experimental protocols were approved by the Clinical Research Ethics Committee (approval no: 02-280097).

Statistical Analysis

Data analysis was performed using SPSS 23.0 program. Measurements were considered to be significant when $p< 0.05$.

3. RESULTS

The DPA was found as a completed arch in all 12 hands (100%). At least one of the DPBUA (proximal or distal) was present in all samples. It was determined that the terminal part of the RA was anastomosed with distal DPBUA in all cases (100%). Proximal DPBUA emerged in only two cases (case-5 and case-7) (16%), but were not involved in any form of the DPA (Figure 5).

Figure 5. *Proximal and distal deep palmar branch emerged from the ulnar artery and formation of deep palmar arch with distal deep palmar branch of the ulnar artery (case-5). (Green arrow: Proximal deep palmar branch of the ulnar artery; Red arrow: Distal deep palmar branch of the ulnar artery; Blue arrow: perforating branches; Black arrow: palmar metacarpal arteries; Yellow arrow: deep palmar branch of ulnar nerve)*

The MPAs branching from the DPA numbered four (25%) in three cases and three (75%) in nine cases (Table I). In 11 cases, the MPAs were found to originate separately from the DPA. In contrast, in one case (case-4), it was observed that palmar metacarpal II and III, which were closer to DPBUA, first emerged as a common trunk after a short course, bifurcated into two, and then continued the course of these two branches. These branches were then anastomosed with the common palmar digital arteries originating from the SPA (Figure 6). In addition to the MPAs, perforating branches (cases-1, – 2, – 4, and – 5) emerged from the DPA proximally. In some cases, the perforating branches (case-1 and case-4) were involved in this arch formation (Figures 6,7).

Figure 6. *Extraction of the second and third palmar metacarpal arteries from the arcus palmaris profundus in a common trunk and atypical course of the deep branch of the ulnar nerve (case-2). (Blue arrow: perforating branches; Yellow arrow: perforating branches; Black arrow: palmar metacarpal arteries; Green arrow: distal deep palmar branch of the ulnar artery; Red arrow: deep branch of ulnar nerve)*

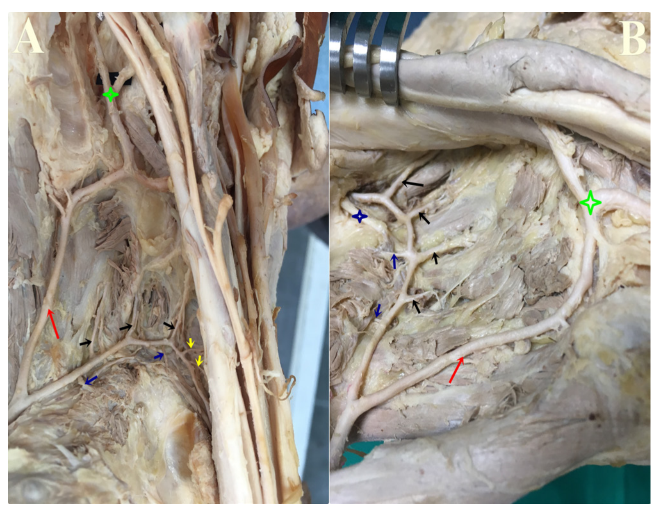

Figure 7. *Four palmar metacarpal arteries originating from the deep palmar arch and atypical course of radialis indicis artery at hand and anastomosis with common palmar digital arteries (A: case-1; B: case-4). (Black arrow: palmar metacarpal arteries; Yellow arrow: perforating branches originating from the deep palmar arch; Red arrow: radialis indicis artery; Blue arrow: perforating branches; Green asterix: bifurcation of radialis indicis artery and anastomosis with common palmar digital arteries; Blue asterix: deep branch of ulnar nerve)*

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The dorsal metacarpal artery-I appeared in only three of the 12 upper extremities (Figures 3,6). It was observed that the RA often made perforating branches in the absence of the dorsal metacarpal artery-I (Figure 4). In one case, the princeps pollicis artery (PPA) emerged from the RA after the radialis indicis artery (RIA). RIA was observed to take a different course in two cases (case-1 and case-2). After the RIA originated from the RA, it was observed to be oblique in the distal direction. Before reaching the second metacarpophalangeal joint, it directed toward the medial side and was bifurcated in two. One branch continued its course distally to the medial depth of the second finger and was soon bifurcated again; and the other branch was found to anastomose with the common palmar digital arteries, which is one of the branches of the SPA (Figure 7).

It was determined that the deep palmar branch of the ulnar nerve (DPBUN), which was adjacent to the DPA, proceeded along a different course in the right hand of two different cadavers and reached the adductor pollicis. In one cadaver (case-4), the DPBUN was observed to pass through the dorsal of MPA II and III, where they first separated from the DPA as a common trunk and bifurcated, and then crossed the first MPA in a palmar direction to reach the adductor pollicis (Figure 6).

After explaining and correlating the vascular patterns of the DPA and its branches, as well as other vessels, the diameters of the vessels were measured with a digital compass. The mean diameters of the vessels are presented in Table I. In a comparison of the arterial diameters, the terminal branch of the RA was found to be more dominant than the DPBUA.

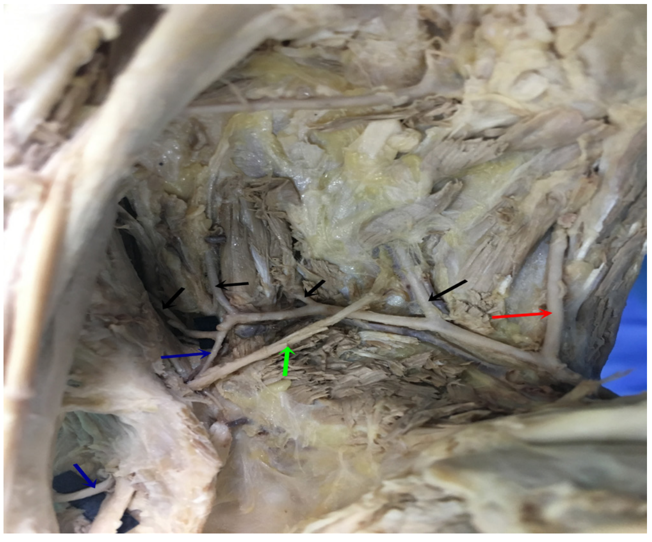

Figure 8. Four palmar metacarpal arteries originating from the deep palmar arch and the course of deep branch of ulnar nerve (case-6) (Blue arrow: distal deep branch of the ulnar artery; black arrow: palmar metacarpal arteries; red arrow: radialis indicis artery; green arrow: deep branch of ulnar nerve)

4. DISCUSSION

In modern surgical and anatomical procedures, the recognition of morphometric data and anatomic vascular variations in the branching pattern of the DPA has become of considerable importance. In the present study, the proximal DPBUA was observed in two cases (16.6%), whereas the most common variant observed was the distal DPBUA together with the terminal branch of the RA, which was noticed in all cases. It was further noted that in no case did the proximal and distal branches contribute to DPA formation at the same time. In addition to the contribution of these branches to the formation of the arch, we found that the perforating branches, as well as the MPAs, originated from the DPA. Another important finding was that, in addition to MPAs, RIA was directed toward the medial side, and anastomosed with the common palmar digital arteries before reaching the second metacarpophalangeal joint in two cases.

The classification of the DPA has been demonstrated by many researchers. The most commonly described variant of the DPA is the radio-ulnar type in literature [15]. The few noteworthy studies are as follows. Loukas et al., studied the palmar arterial arch on 120 specimens, and found the DPA to be formed by the RA in all extremities, and classified the DPA into three groups in their study [15]. Type D-I (60%) referred to anastomosis of the DPBRA and the distal DPBUA. Gellman et al., reported that the DPA was formed by the DPBRA in 100% of the samples, and divided the DPA into three groups in their study [18]. They found the DPA to be an anastomosis between the DPBRA and the distal DPBUA in Type-A (44.4%). Coleman and Anson, identified a completed arch in 97% of the cases, which they divided into four groups in their study, among which they observed the anastomosis between the RA and the distal DPBUA to the most common type, accounting for 49% of the total (Type-B) [11]. Bigler et al., determined that one patient had an incomplete SPA, whereby only the SPBRA and a complete DPA were present [22]. In the present study, the DPA was defined as an anastomosis between the RA and distal DPBUA in all cases (100%). RA was found to be more dominant than the DPBUA in most cases. It can be concluded from these results that the distal DPBUA plays a more significant role in arch formation than the other branches. The results of the current study concur with those of previously published studies [11,15,18,22], however it was a remarkable finding that the second and third MPAs first emerged as a common trunk and then bifurcated. No other studies have been found identifying MPAs originated from the DPA as a common trunk. There are some minor differences in the frequency of the anastomotic patterns when compared to previous studies, which may be due to the relatively small sample size (the sample in the current study was only 12 specimens) or the techniques used.

In some studies, it has been determined that the DPA is more variable than the SPA [7,16]. Patnaik et al., reported that the DPA was observed to be completed in all dissections, while also being more variable [16]. The authors found that the UA yielded two deep palmar branches (proximal and distal) in all cases, but both contributed to the formation of DPA by only

10%. They determined that the distal DPBUA formed the DPA in 52% of the samples. Singh et al., also found that DPA showed more variability than the SPA, and classified the DPA into five types depending on its formation in their study [7]. They went on to report that the DPA consisted of anastomosis between the DPBUA and the DPBRA in 72% (36/50) of the samples, and that only one of the proximal and distal DPBUA had anastomosed with the DPBRA in 4% (2/50) of the samples. Dhar and Lall, however, reported that the DPA was less variant than the SPA, and that the predominant type of DPA was formed by anastomosis (60%) of the DPBRA and the distal DPBUA [23]. Zarzecki et al., found the DPA to be a complete arch in 95.2% of cases [5]. They determined that the DPA was less variable than the SPA in 12 studies (n=1093) included in this meta-analysis, but mentioned that it was impossible to carry out a detailed meta-analysis on this trait due to the scarcity of studies reporting its specific variations. In the present study, the proximal DPBUA was observed in two cases (16.6%), while only the distal DPBUA was involved in the arch formation. This study was carried out to in response to the scarcity of macroscopic and morphometric studies on the DPA.

The present cadaveric study makes a morphometric assessment of the DPA and its main branches. The external diameters, branches and corresponding vessels of the DPA have rarely been described in literature. Bilge et al. [24] measured the mean diameter of the introduced terminal portion of the RA, and the proximal and distal DPBUA as 2.60 (± 0.47) mm, 1.77 (± 0.44) mm and 1.63 (± 0.52) mm, respectively. Evaluating the diameter of the MPAs individually, they reported that the mean diameter of the first MPA was 1.50 (± 0.38) mm, the second was 1.41 (± 0.35) mm and the third was 1.45 (± 0.33) mm. Gellman et al. [18] stated that the mean diameter of the MPAs was 1.20 mm, while Gokhroo et al. [1] measured the mean diameter of MPAs as 1.44 (±0.39) mm. In the present study, the mean diameters of the RA and UA before joining the arch were 2.88 (±0.78) mm and 2.39 (±0.64) mm, respectively. Concerning the external diameter of the DPA, the mean diameter of the terminal branch of the RA (at its origin) and the distal DPBUA (at its termination) were 1.26 (±0.65) and 0.98 (±0.73) mm, respectively, while the mean diameter of the MPAs at the point of origin at the DPA was between 0.3 and 0.6 (±0.59) mm. There were no statistically significant differences between group means for right and left sides and for gender ($p>0.05$). A cadaveric assessment of the DPA diameters in the present study revealed comparable figures. A few compatible results have been reported previously [1,18,24]. Based on the findings of the present study, it could be said that the RA is the dominant artery in the arch formation, although the average diameter of the MPAs is thinner than in other studies. The morphometric diameters on the left hand were measured thicker than in the right hand in many cases (Table I). As a result of our study, we clearly stated the importance of keeping the palmar arch and its variations in mind due to the risk of ischemic hand complications before clinical applications.

In the present study, the position of the DPBUN was evaluated. Bilge et al., evaluated the position of the DPBUN as a structure adjacent to the DPA, and reported that the DPBUN passed through the DPA obliquely and dorsally in 38 (76%) specimens, and through the palmar direction in 12 (24%) specimens [24]. Olave and Prates, reported the dorsal neighborhood of the DPBUN in 50% of the cases [25]. Bini and Leclercq, determined that the DPBUN crossed the DPA superficially in 43% of cases, and deeply in 57% cases in 21 hands [26}. In the present study, it was worthy of note that the DPBUN passed through both the dorsal and palmar aspects of the MPAs in the same case (Figure 6, Figure 8). The DPBUN was observed obliquely in the dorsal direction of the DPA and its branches, and reached the muscle in all other cases. It is very important for surgeons engaged in surgeries in this region that the DPBUN and DPA be well known in terms of their interrelations and variations. The DPBUN lies in an area that is not often approached by hand surgeons [27,28], where the anatomy is complex, and where the anatomical studies of the ulnar nerve are often restricted to Guyon's canal [26,29].

Conclusion

Surgical interventions to the hand require more detailed information on the complex anatomical structures of the hand and the upper extremity every day to fulfill the need to verify the validity of the various procedures in practice, and to make new definitions [2,30]. This considerable dissection-based study has presented some significant findings regarding the branching pattern and formation of the DPA, and has added new information on the diameter of these vessels to correlate the findings with literature. These variations can be detected in a modified Allen's test, a Doppler ultrasonography, a pulse oximetry and an arterial angiography before the clinical implications can be understood. A comprehensive understanding of the DPA branching diameters in the hand is important in clinical procedures to support the lack of knowledge in literature. It is clear that this study will contribute to hand surgery and radiological anatomy in the future.

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Compliance with Ethical Standards

Ethical Approval: The experimental protocols were approved by the Istanbul University, Cerrahpasa Medical School Clinical Research Ethics Committee (approval no: 02-280097). All authors were well versed in the WMA Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects – and confirmed that the present study was in full compliance with the declaration.

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Conflict of Interest: The authors report that they have no conflict of interest.

Authors' Contribution: RH: Literature search, experimental studies, data analysis, STP and MY: Concept, experimental studies, data analysis, manuscript editing.

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