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Persistent Median Artery as an Unusual Finding in the Carpal Tunnel: Its Contribution to the Blood Supply of the Hand and Clinical Significance

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Manuscript Preparation E
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Background: Knowledge of the variable relation of the persistent median artery (PMA) to the median nerve and its contribution to the formation of the superficial palmar arch is of great clinical significance. This study presents a proposal of specific variables which might be introduced to characterize the PMA in the wrist region.

Material/Methods: One hundred and twenty-five randomly selected, isolated upper limbs fixed in 10% formalin solution were subjected to anatomical dissection.

Results: Of the 125 upper limbs, PMA was found in 5 specimens (4% of the total number of limbs). In the carpal tunnel, the artery occupied the anterolateral position (2 cases), the anterior position (2 cases) or the anteromedial position (1 case) in relation to the median nerve. Two types of superficial palmar arches with significant contributions from the PMA were observed in the studied material: complete medio-ulnar arch and an incomplete arch without a connection between the territories of the ulnar and median arteries. The mean ratio of the diameter of the PMA to the diameter of ulnar artery at the level of the wrist was 0.59 (min.=0.38, max=0.83, SD=0.19).

Conclusions: Orthopedic and hand surgeons should be aware of the probability of occurrence of the PMA in both planning and conducting surgeries within the wrist region and within the carpal tunnel, as this anomalous vessel might present significant contributions to the arterial blood supply of the hand and might potentially play an important role in the presence of notable clinical symptoms and presentations.

MeSH Keywords: **Anatomic Variation • Anatomy, Regional • Carpal Tunnel Syndrome • Median Nerve**

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Background

There are numerous clinically important anatomical variations of the arterial pattern within the upper limb. Anatomical variations might refer to the atypical number, origin, course or territory of individual arteries [1–8]. Occasionally, supernumerary arterial trunks might be observed as residues of the early stages of morphogenesis. The latter situation concerns, in particular, the presence of a persistent median artery (PMA), which represents a preserved part of the embryonic arterial axis of the upper extremity [9,10]. The median artery usually atrophies in the second month of intrauterine life [11]. However, it might occasionally persist after birth and not regress. In those cases, the PMA accompanies the median nerve. The PMA might also appear as 2 types: an antebrachial type (in which the artery provides blood supply to the median nerve but does not reach the hand) and a palmar type (in which the PMA contributes to the arterial supply of the hand) [10,12,13].

Typically, the hand receives its blood supply from 2 main sources: the ulnar and radial arteries. The ulnar artery together with the ulnar nerve enters the hand on the medial side of the wrist. This artery plays a predominant role in forming the superficial palmar arch, which is its primary extension. The deep palmar arch is formed predominantly by the radial artery [14]. Occasionally, the PMA might also reach the palm and contribute to formation of the superficial palmar arch [12,15]. In those cases, the PMA has a superficial course in the carpal tunnel with a close relationship to the transverse carpal ligament [16]. Such an artery might present as a contributing factor in pain related to carpal tunnel syndrome, pronator syndrome, or compression of the anterior interosseous nerve [11,17–20]. Moreover, in the wrist region, the PMA, when present, accompanies the corresponding nerve and remains in close topographical relations to the tendon of palmaris longus muscle. Since the palmaris longus tendon is routinely harvested for reconstruction of other tendons [21], its relations to the median nerve and the possible presence of the PMA should be taken into account by surgeons performing procedures in this region.

Thus, it is of great clinical significance to know the possible anatomic variations of the PMA, including its variable relation to the median nerve in the wrist region and within the carpal tunnel, its contribution to the formation of the superficial palmar arch and the vascular territory in the hand. The study aims to summarize current knowledge of the anatomy of the PMA, based on topographical morphometric studies. A proposal of specific measurements which could be introduced to characterize the PMA in the wrist region is also presented.

Material and Methods

One hundred and twenty-five randomly selected, isolated upper limbs fixed in 10% formalin solution were submitted to an anatomical dissection. The limbs were obtained from adult male cadavers (total 68 limbs, right 37, left 31) and from adult female cadavers (total 57 limbs, right 28, left 29). The study was approved by the Local Bioethics Committee. Prior to each dissection, a thorough visual external inspection was performed to exclude specimens with deformations and traces of traumas or surgeries. The procedure included antebrachial, carpal, and metacarpal regions. Stratigraphic dissection of neurovascular structures was performed with regards to previously described protocols [22,23].

The presence of a persistent median artery was also checked. We took only into account the incidence of a palmar type of persistent median artery (PMA), defined as the vessel which accompanies the median nerve on its course through the forearm and carpal tunnel and which participates in the arterial blood supply of the hand. The preparation of blood vessels was performed using microsurgical instruments at a magnification of 2.5×; these procedures were performed using HEINE® HR 2.5 X High Resolution Binocular Loupe (HEINE Optotechnik GmbH & Co., KG, Herrsching, Germany). A Digimatic Calliper (Mitutoyo Corporation, Kawasaki-shi, Kanagawa, Japan) was used to take the measurements of external diameters and distances to the selected structures and topographical landmarks. Each measurement was taken twice; the average of both measurements was accepted as the final result. Basic descriptive statistics were applied to structure the raw data. The following data related to the PMA was collected: the diameter of the PMA measured at the level of the wrist; the ratio of the diameter of the PMA to the diameter of ulnar artery at the level of the wrist; the ratio of the diameter of the PMA to the diameter of radial artery at the level of the wrist; the location of the PMA (anterolateral, anterior, or anteromedial) to the median nerve observed in the carpal tunnel; the distance from the midpoint of the interstyloid line (a line drawn between the styloid processes of the radius and the ulna) to the crossing point of the PMA and the tendon of the palmaris longus muscle; the distance to the ulnar neurovascular bundle.

Results

Of the examined material including 125 upper limbs, the PMA was found in 5 specimens (5 out of 125; or 4% of the total number of limbs): 3 male limbs (3 out of 68; or 4.4% of male limbs) and in 2 female limbs (2 out of 57; or 3.5% of female limbs). Moreover, the presence of the PMA was found on the right side in 3 cases (3 out of 65; or 4.6% of right limbs) and on the left side in 2 cases (2 out of 60; or 3.3% of left limbs).

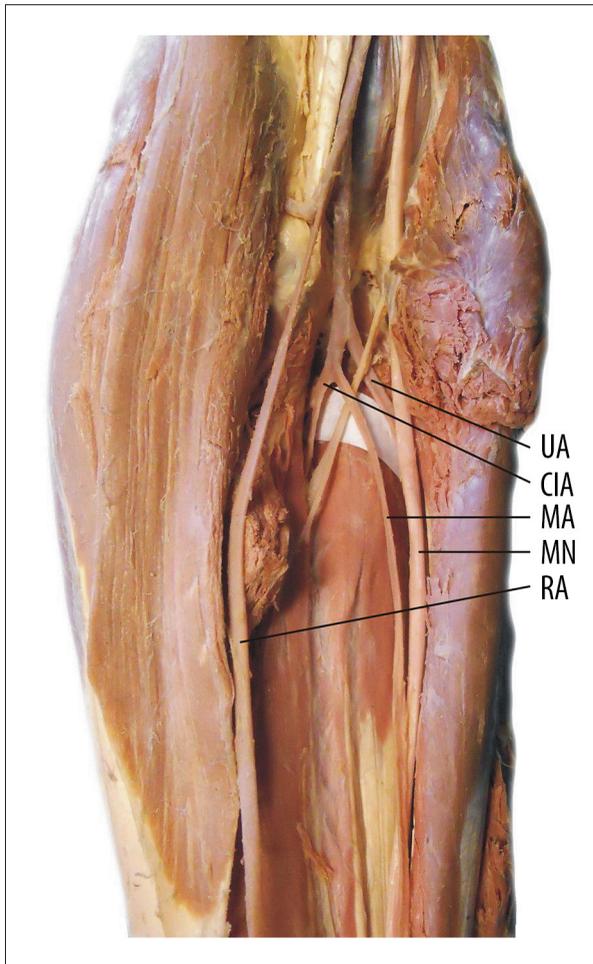


Figure 1. The persistent median artery originating from the common interosseous artery. The median artery arises posterior to the pronator teres muscle, whereupon it turns medially to accompany the median nerve along its course in the distal two-thirds of the forearm, where it travels between flexor digitorum superficialis and flexor digitorum profundus. CIA – common interosseous artery; MA – median artery; MN – median nerve; RA – radial artery; UA – ulnar artery.

The PMA took origin from the common interosseous artery in 3 out of 125 dissected upper limbs (i.e., 2.4% of all limbs and 60% of limbs with PMA; Figure 1). In 1 specimen, the PMA arose from the ulnar artery. In another case, the PMA branched off the initial part of the anterior interosseous artery. In all cases, the PMA accompanied the median nerve along its course on the distal two-thirds of the forearm, where it traveled between flexor digitorum superficialis and the flexor digitorum profundus.

The characteristics of the PMA, including results of measurements of its diameter and distance to selected reference points, are shown in Table 1. At about 5 cm above the flexor retinaculum, the PMA emerged between the flexor digitorum superficialis (medially) and flexor carpi radialis (laterally) into the hand. The mean distance of this point to the interstyloid line was 46.4 mm (from 38.1 mm to 57.5 mm, SD=8.3 mm; Table 1). The mean distance from the interstyloid line to the crossing point between the PMA accompanying the median nerve and the palmaris longus tendon was 32.2 mm (from 26.3 to 38.5, SD=5 mm; Table 1). In 1 case, the palmaris longus muscle was

Table 1. The characteristics of PMA, including results of morphometric measurements* and its relation to selected reference points.

Specimen number	Side/sex	PMA diameter ¹	PMA/UA ratio ²	PMA/RA ratio ³	Relation to MN ⁴	Emerging point ⁵	Crossing point with PL tendon ⁶	Distance to UNVB ⁷	Type of SPA
1	R/F	2.21	0.83	0.86	Anterior	57.5	38.5	19	Complete
2	R/F	1.14	0.42	0.56	Anterior	38.1	32.7	22	Incomplete
3	L/M	1.04	0.38	0.24	Antero-Medial	43.8	Absence of PL	28	Complete
4	R/M	1.9	0.62	0.61	Antero-Lateral	52.5	31.2	24	Complete
5	L/M	1.72	0.71	0.53	Antero-Lateral	40.2	26.3	21	Incomplete

* All Measurements are given in millimeters. ¹ PMA diameter was measured at the level of the wrist; ² ratio of the diameter of the PMA to the diameter of ulnar artery at the level of the wrist; ³ ratio of the diameter of the PMA to the diameter of radial artery at the level of the wrist; ⁴ location of PMA (antero-lateral, anterior or antero-medial) to the median nerve observed in the carpal tunnel; ⁵ distance from the point where the PMA emerged (from between flexor digitorum superficialis and flexor carpi radialis) to the interstyloid line (a line drawn between the styloid processes of the radius and the ulna); ⁶ distance from the midpoint of the interstyloid line and the crossing point of the PMA and the tendon of the palmaris longus muscle (PL); ⁷ distance to the ulnar neurovascular bundle.

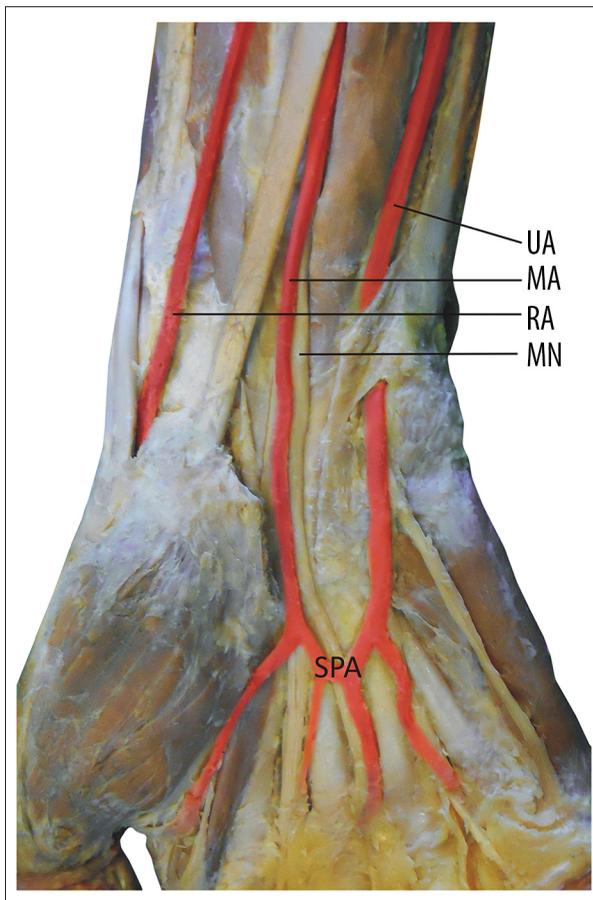


Figure 2. Specimen of the hand with a persistent median artery. Anterior aspect of the right hand. The wrist region, carpal tunnel and the metacarpal regions were exposed. The flexor retinaculum was removed. In the wrist and carpal tunnel, the median artery (MA) is located anterior to the median nerve. The median artery (MA) and the ulnar artery (UA) contribute to formation of the complete superficial palmar arch (SPA). MN – median nerve; RA – radial artery.

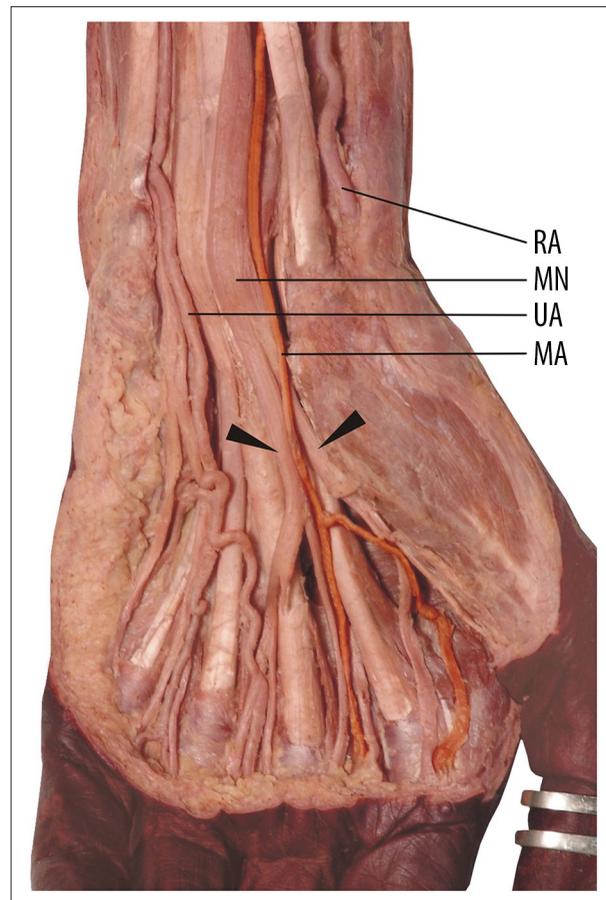


Figure 3. Specimen of the left hand with a persistent median artery. Anterior aspect of the left hand. The wrist region, carpal tunnel and the metacarpal regions were exposed. The flexor retinaculum was removed. In the wrist the median artery (MA) occupies anterolateral position in relation to the median nerve. In the carpal tunnel, atypical split of the median nerve (marked by the black arrowheads) is visible. MA (marked red) is located between the 2 parts of the median nerve and gives first 2 common palmar digital arteries. The incomplete superficial palmar arch is shown. MN – median nerve; RA – radial artery; UA – ulnar artery.

absent (Table 1). In the wrist region, the position of PMA in relation to the median nerve was variable (Figures 2–4). In 2 cases (40% of limbs with PMA; 1.6% of all examined limbs), the PMA was located anterior to the median nerve (Figure 2). In the next 2 cases (40% of limbs with PMA; 1.6% of all examined limbs), the PMA occupied an anterolateral position in relation to the median nerve (Figure 3). In 1 remaining case (20% of limbs with PMA; 0.8% of all limbs), the PMA occupied an anteromedial position in relation to the median nerve (Figure 4). In 3 out of the 5 specimens in which the PMA was present (60% of specimens with PMA), the occurrence of anatomical variations of the median nerve was also observed. In 2 cases, an atypical split of the median nerve was observed within the carpal tunnel. In those cases, the PMA, changed its position and was located between both parts of the divided nerve (Figure 3). Another variation of the median nerve, observed

on 1 limb with the PMA, was an atypical origin of the median nerve. In this case both roots (lateral and medial) of the median nerve merged more distally than usual (52 mm below the inferior border of the pectoralis major muscle).

The mean ratio of the diameter of the PMA to the diameter of the ulnar artery at the level of the wrist was 0.59 (min.=0.38, max=0.83, SD=0.19; For details see Table 1). The same coefficient assessed for the radial artery (i.e., the mean ratio of the diameter of the PMA to the diameter of radial artery at the level of the wrist) was 0.56 (min.=0.24, max=0.86, SD=0.22; Table 1). Two types of formations of the superficial palmar arches with significant contributions from the PMA were observed in the

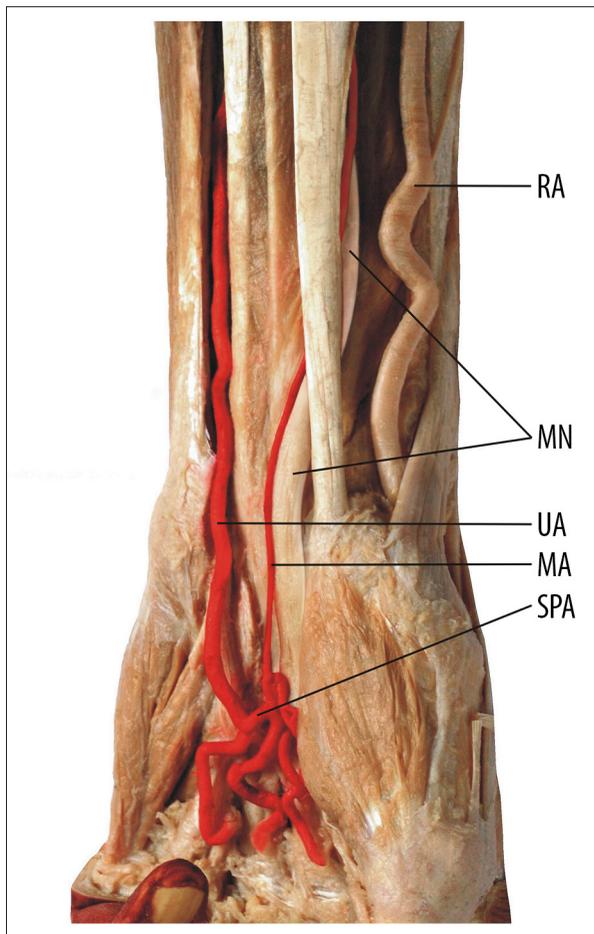


Figure 4. Specimen of the hand with a persistent median artery. Anterolateral aspect of the left hand. The wrist region, carpal tunnel, and the metacarpal regions were exposed. The flexor retinaculum was removed. In the wrist and carpal tunnel, the median artery (MA) occupies anteromedial position to the median nerve. The median artery (MA) and the ulnar artery (UA) contribute to formation of the complete superficial palmar arch (SPA). MN – median nerve; RA – radial artery.

studied material. The first variant included the cases with a complete superficial palmar arch. In this type, the superficial palmar arch was formed predominantly by the ulnar artery, with a significant contribution from the median artery, a so-called arch of “medio-ulnar type” (Figures 2, 4). This type was observed in 3 out of 5 specimens with the PMA (2.4% of all limbs and 60% of limbs with the PMA): in 2 male upper limbs and 1 female upper limb (Table 1). In 1 among these cases, the princeps pollicis artery originated from the superficial palmar arch. In the other 2 cases the incomplete superficial palmar arch was present (Figure 3). In this type, the common palmar digital arteries arose directly from the ulnar or median arteries. This variation was observed in 1 male upper limb and 1 female upper limb (Table 1).

Discussion

Median artery during ontogeny

Numerous factors might affect the definitive arterial pattern; specified cell adhesion molecules, transcription factors, as well as mechanical forces, vascular regression, and remodeling are all involved in the subsequent events of vasculogenesis at the earliest stages of ontogeny [3,9,24,25]. Gradually, the capillary labyrinth is formed, and dominant vascular channels differentiate themselves from the primitive vascular plexus [3,9,25]. In the developing embryo, the primary axial artery (precursor to the continuous subclavian, axillary, brachial, and interosseous arteries) are established this way. The median and anterior interosseous arteries are the main sources of blood supply to the hand during the first trimester of embryonic development. After the eighth week of gestation, radial and ulnar arteries develop, and the median artery begins to regress [12,13]. Thus, the persistence of the median artery in a human adult might be considered a remnant of primitive arterial architecture.

Incidence and anatomical variations of the PMA

The incidence of the PMA in adults reported by selected authors varies from 0.6% (the lowest incidence of PMA found by Ahn et al. [26]) to 21.1% (reported by Henneberg and George [27] based on the study performed on southern African cadavers). The incidence of palmar type of the PMA given by selected authors is shown in Table 2. The median artery seems to have a higher rate of persistence in human fetuses, considering its both palmar and forearm types [13,28,29]. In the study of Aragão et al. [13] the median artery, taking into consideration both its types, was present in 81.25% of the cases, and it was found more frequently in females than males. The lower frequency of PMA in adults might be due to the fact that the median artery progressively regresses to become a satellite artery for the median nerve [13]. This assumption is in line with Carry et al. research [30], which stated that for every 1-year increase in age, the odds of a persistent median artery decreased by 4.4%. Data regarding sexual dimorphism of PMA are ambiguous. Rodríguez-Niedenführ et al. [12] found PMA to be more frequent among females. However, Singer [31], as well as Henneberg and George [27,32], did not observe differences in the prevalence of PMA between the sexes. The PMA can be both bilateral and unilateral [12].

The most typical place of origin of the PMA reported in the literature are the ulnar artery [12,27,29] or the common interosseous artery [13,33]. However, the PMA might also be a continuation of the anterior interosseous artery [10,12,13,27,29,33]. In rare cases, the median artery might originate over the intercondylar line of the humerus, in the arm or even in the axillary

Table 2. The incidence of the palmar type of PMA as given by selected authors.

Author, year of study	Specimens	Sample (No. of limbs)	Incidence of palmar type of PMA
Henneberg and George, 1992 [27]	Adult cadavers	96	27.1%
Olave et al., 1997 [39]	Adult cadavers	102	22.5%
Rodríguez-Niedenführ et al., 1999 [12]	Adult cadavers	240	20.0%
Ahn et al., 2000 [26]	Adult patients	354 consecutive operations	0.6%
Rodríguez-Niedenführ et al., 2001 [9]	Embryons	150	18.7%
D'Costa et al., 2006 [10]	Adult cadavers	38	15.8%
Nayak et al., 2010 [33]	Adult cadavers	84	11.9%
Aragão et al., 2017 [13]	Fetuses	32	27.0%
This study	Adult cadavers	125	4.0%

fossa. According to the terminology introduced by Rodríguez-Niedenführ et al. [2,3,9,12] the high division of the median artery could be called “brachiomedian artery”. A case of the superficial brachiomedian artery was reported by Kachlik et al. [34].

Numerous neurovascular variations in the upper limb might accompany the PMA. In the most typical of cases the PMA simply accompanies the median nerve to the palm, contained within the epineurium of the nerve. Typically, it courses on the ulnar aspect of the normal median nerve. However, according to Chen et al. [35] who described sonographic findings within the carpal tunnel, positional relationship between the median nerve and persistent median artery in the carpal tunnel is uncertain, and thus, a preoperative ultrasound is necessary. This statement is consistent with our study results which revealed that the PMA in the carpal tunnel could occupy an anterior, anterolateral, or even an anteromedial position. The PMA could also occur alongside one of the most common variations of the median nerve, a bifid median nerve [35,36]. If the median nerve is bifid, the PMA could be located between the 2 nerve bundles, as observed in 2 cases in our study. Coexistence of PMA and muscular variations has also been reported. Singla et al. [36] described a case in which the PMA penetrated and divided the median nerve into 2 halves which joined to form a neural loop around the artery. Kachlik et al. [34] found coincidence of superficial brachiomedian artery and bitendinous palmaris longus muscle. A case of accessory flexor carpi ulnaris muscle coexisting with a PMA which pierced the median nerve and accompanied it deep into flexor retinaculum, terminating as 2 common palmar digital arteries was reported by Sakthivel and Verma [37]. In turn, coexistence of the PMA and an accessory head of flexor pollicis longus was noted by Patnaik and Paul [38].

Clinical significance

When there is a PMA, it might present as a contributing factor to the pain related to carpal tunnel syndrome. According to Olave et al. [39], the walls of the carpal tunnel are inflexible and any thickening of its components that reduce its area might compress the median nerve. A high risk of this state might be related to anomalous course of PMA or even the superficial branch of radial artery through this osteofibrous space [39,40]. Furthermore, an aneurysm or thrombosis of the PMA might cause carpal tunnel syndrome resulting in compression of the median nerve [41]. However, according to Gassner et al. [16], the PMA is also a common condition in healthy individuals.

Stavros et al. [42] described the case of penetration of the median nerve by a persistent median artery and vein in the mid-forearm, with a positive sonographic Tinel sign over this spot. In a study by Stavros et al. [42], a patient presented with the classic symptoms and neurological examination for carpal tunnel syndrome but had a normal nerve conduction study and electromyogram. According to the authors, diagnostic neuromuscular ultrasound and consideration of an anatomical variation involving the median nerve might be crucial to the differential diagnosis of various clinical syndromes. According to Singla et al. [36], an anomalous PMA which penetrates the median nerve might compress it and produce symptoms of proximal median neuropathy, which might be similar to those caused by the Struthers ligament or a tight bicipital aponeurosis. Moreover, the compressive force of the pulsating artery which pierces the nerve might produce ischemia in the nerve [36]. Compressed nerves are usually weak at the site of the arterial penetration and more susceptible to influence of other pathological conditions such as diabetes mellitus [36,43].

If the PMA is not recognized during the planning of surgical procedures, subsequent damage might be a cause of intra- or post-operative bleeding. Feintisch et al. [19] described the case of bilateral PMA in a 47-year-old female patient with bilateral carpal tunnel syndrome. The aberrant arteries on both sides coursed between the palmar aponeurosis and the flexor retinaculum, and were positioned directly in line with the surgical carpal tunnel incisions on both hands. Another case of an incidental finding of a large-caliber PMA, which was superficial to the flexor sheath was described by Butt et al. [44]. As in the previous case, the PMA was found during carpal tunnel decompression surgery. The anomalous artery was carefully retracted, and the procedure was completed, without any complications. Thus, surgeons should be aware of the possibility of occurrence of the PMA and its variable relation to the median nerve within the carpal tunnel. This is especially important when planning new techniques for carpal tunnel release. Currently, new approaches are being developed for minimally invasive carpal tunnel decompression [45].

Knowledge of the anatomical variations of the arterial supply of the hand, including variability of the superficial palmar arch, is of crucial significance for safe and successful hand surgeries [46–49]. In the study of Rodríguez-Niedenführ et al. [12], the PMA supplied the hand by joining the superficial palmar arch (35% of cases with palmar type of the PMA) or by forming some of the common palmar digital arteries (65% of cases presenting palmar type of the PMA). When the PMA did not join

the superficial palmar arch, it terminated as the first and second common palmar digital arteries, as in our study, forming an incomplete type of the superficial palmar arch. According to Coleman and Anson [50], incomplete superficial palmar arches occur in 18% of cases, which suggests that collateral circulation seems to be completed in most of the cases. However, the influence of rare anatomical variations on the arterial supply of the hand can be easily tested clinically by Allen's test [51].

Conclusions

Orthopedic and hand surgeons should be aware of the probability of occurrence of the PMA in both planning and conducting surgeries within the wrist region and within the carpal tunnel, as this anomalous vessel might present significant contribution to the arterial blood supply of the hand and might potentially play an important role in the presence of notable clinical symptoms and presentations.

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Conflict of interest

None.

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