Original Research

ANATOMICAL VARIANTS OF THE PERSISTENT MEDIAN ARTERY AND INCOMPLETE SUPERFICIAL PALMAR ARCH: A CADAVERIC CASE SERIES

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ABSTRACT
The vascular anatomy of the human upper extremity exhibits significant morphological diversity, often driven by complex remodelling variations during embryonic development. This case series documents four distinct, high-risk neurovascular variations of the superficial palmar circulation identified during gross anatomical dissections, highlighting a critical complete loss of the hand's classic collateral safety net. While traditional anatomy dictates a complete superficial palmar arch formed by the radial and ulnar arteries, these specimens demonstrate how embryonic remodelling failures can drastically alter hand haemodynamics. The variations range from a persistent median artery (PMA) acting as a dominant, non-communicating central conduit for digital perfusion, to an isolated, incomplete superficial palmar arch that leaves a definitive hemodynamic gap between independent medial and lateral digital zones. Clinically, a patent, large-calibre palmar-type PMA traverses the carpal tunnel alongside the median nerve, acting as a space-occupying lesion that heavily predisposes individuals to compression syndromes. Most critically, because these architectural variants replace the standard interconnected palmar arcade with independent territorial perfusion, specific digits are left relying entirely on a single, isolated vessel for survival. Under these conditions, the surgical harvesting, traumatic laceration, or inadvertent ligation of any of these un-anastomosed trunk arteries eliminates all collateral pathways, risking sudden and catastrophic digital ischemia or tissue necrosis. This series emphasizes that a thorough understanding of upper limb vascular anomalies, paired with routine preoperative objective imaging such as colour Doppler ultrasonography, is paramount for hand surgeons, plastic reconstructive surgeons, and interventional radiologists to preserve vital digital perfusion and ensure safe surgical margins during operative procedures.

INTRODUCTION
The vascular anatomy of the human upper extremity is highly variable, a characteristic widely attributed to complex remodelling and regression processes during embryonic development. [ ] Typically, the primary blood supply to the hand is dominated by the radial and ulnar arteries, which form interconnected vascular networks known as the superficial and deep palmar arches. The superficial palmar arch (SPA) is conventionally established by the terminal continuation of the ulnar artery anastomosing with the superficial palmar branch of the radial artery. This classic, complete configuration provides a robust, highly collateralized perfusion network to the digits, protecting the hand against focal vascular compromise. [ ] However, significant deviations from this textbook morphology are frequently Encountered during surgical procedures, radiological interventions, and anatomical dissections, carrying major diagnostic and clinical therapeutic implications. [ ] During the early stages of intrauterine morphogenesis, the developing upper limb is temporarily vascularized by a central embryonic axis artery derived from the brachial artery. This vessel, designated as the median artery, serves as the primary vascular conduit for the forearm and developing hand until approximately the eighth week of gestation. As the radial and ulnar arteries progressively develop and assume hemodynamic dominance, the embryonic median artery typically undergoes regression and apoptosis, tapering into a minor, regressed vestige known as the arteria comitans nervi mediani that closely accompanies the median nerve. When this evolutionary regression fails to occur, the vessel persists into adulthood as a persistent median artery (PMA). Anatomically, the PMA is categorized into two distinct morphological phenotypes based on its termination point: the antebrachial type, which is a short, slender vessel that terminates within the forearm without reaching the palm, and the palmar type, which is a large, fully patent vessel that

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traverses the carpal tunnel deep to the flexor retinaculum to actively participate in the vascular supply of the hand. [ ] The reported incidence of a persistent median artery varies considerably across historical and modern literature, a discrepancy often influenced by variations in sample sizes, dissection methodologies, and regional population cohorts. Broad epidemiological and cadaveric data indicate that a PMA can be found in anywhere from 1.5% to 27.4% of individuals. [,] Notably, recent anatomical studies suggest a secular upward trend in prevalence, with some modern data reporting the presence of any form of PMA in more than 30% to 43% of sampled upper limbs. [ ] When isolating the clinically critical palmar-type PMA, the incidence is considerably lower, historically ranging between 4% and 15% of the general population. [1,2] Concurrently, variations in the SPA are also widespread. While a complete, collateralized arcade is considered standard, incomplete superficial palmar arches—where the ulnar artery fails to anastomose across the palm to form a closed loop—are documented in 16% to 50% of cases depending on the classification system utilized. [,] The co-occurrence of a unilateral palmar PMA terminating directly into an incomplete superficial palmar arch represents an exceptionally rare and critical subset of these neurovascular configurations. Understanding this specific combination of vascular variants is crucial for several medical specialties, including orthopaedic hand surgery, interventional radiology, and plastic reconstructive surgery. Clinically, the presence of a substantial palmar PMA expanding the volume of the carpal tunnel can act as a direct compressive, space-occupying factor in idiopathic carpal tunnel syndrome or pronator syndrome. Furthermore, because the superficial palmar arch is incomplete in these individuals, the digits rely heavily on isolated, non-collateralized arterial branches for survival. Unintentional ligation, traumatic laceration, or surgical harvesting of either the ulnar artery or the PMA can lead to sudden, catastrophic digital hypoperfusion or avascular ischemic necrosis. [ ] This case report documents the rare, incidental discovery of a unilateral, palmar-type persistent median artery failing to anastomose with an incomplete superficial palmar arch in an adult specimen during a routine educational cadaveric dissection—a highly unusual dual anomaly typically restricted to unexpected clinical encounters. CASE 1: During the routine anatomical dissection of the right upper limb of a 70-year-old male cadaver, a prominent palmar-type persistent median artery (PMA) was observed, accompanied by a complete absence of the classic superficial palmar arch (SPA). Deep dissection of the forearm and hand compartments was executed to meticulously trace the origin, exact course, spatial relationships, and terminal branching patterns of this arterial variant. On the right side, the PMA originated atypically as a direct branch from the anterior interosseous artery within the cubital fossa, rather than arising from the main ulnar or common interosseous trunks. Upon emerging, the PMA descended through the forearm by establishing a strict topographical relationship with the median nerve, running parallel along the nerve's lateral border. In the distal third of the forearm approaching the wrist, both the PMA and the median nerve became increasingly superficial. Within the tight osteofibrous boundaries of the carpal tunnel, deep to the flexor retinaculum, the PMA shifted its course to adopt a distinct anteromedial position relative to the median nerve trunk.

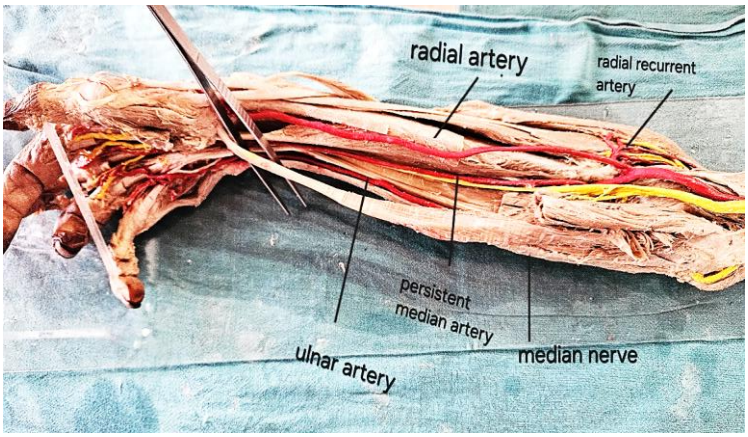
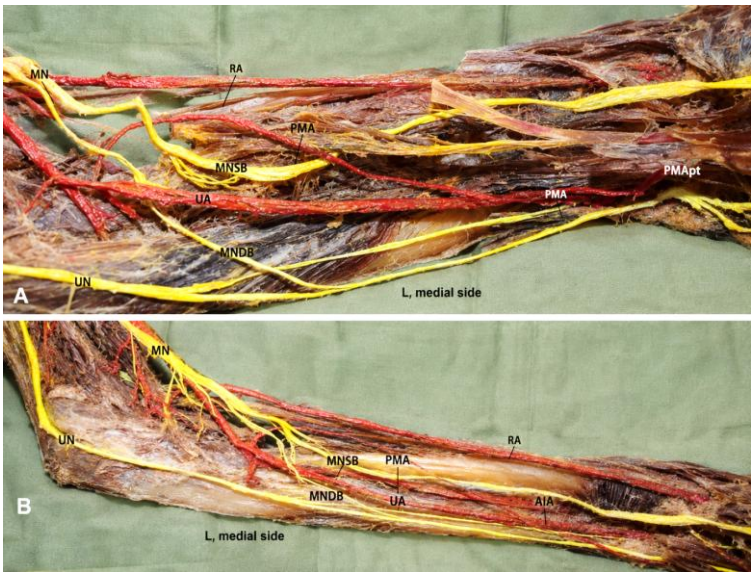


Fig 1. Gross Anatomical Dissection of the Right Upper Extremity Demonstrating a Palmar-Type Persistent Median Artery and an Incomplete Superficial Palmar Arch.

Upon entering the palmar region, deep to the reflected palmar aponeurosis, the PMA coursed medially to the tendon of the flexor pollicis longus muscle and laterally to the tendons and muscle bellies of the flexor digitorum superficialis. Instead of communicating with an ulnar-derived vascular arcade, the PMA functioned as a primary contributor to the palmar vasculature, giving rise directly to the

common digital artery to the second interdigital cleft, which supplied the adjacent sides of the index and middle fingers. The branch directed toward the lateral side of the index finger travelled across the palm to form a definitive macroscopic anastomosis with terminal branches of the radial artery. No superficial palmar arch was observed in the hand, leaving the ulnar artery to terminate independently on the medial side of the palm while the PMA and radial artery assumed territorial supply over the lateral digits. In contrast to these extensive right-sided variations, identical dissection of the left upper limb revealed entirely normal vascular anatomy, with a standard radial and ulnar distribution and a classic, complete superficial palmar arch. Case 2: During a routine gross anatomical dissection of the left upper extremity of an 58-year-old male cadaver, a rare vascular variation involving a highly functional, palmar-type persistent median artery (PMA) was identified and isolated. The origin, diameter, and course of this isolated left palmar-type PMA presented several unique morphological characteristics. The vessel originated directly from the ulnar artery, arising 3.5 cm distally to the brachial artery bifurcation, which is proximal to where the ulnar artery begins its standard downward course into the medial forearm. Immediately following its origin, the vascular trunk exhibited an unusual, highly tortuous path. It took an initial ascending course lateral and proximal to the primary division of the median nerve before looping and crossing over its superficial branch. Following this looping anomaly, the PMA straightened and descended through the anterior compartment of the forearm, running medially to the flexor digitorum superficialis muscle belly. As it approached the wrist, the artery assumed an anteromedial position and was situated medially to the ulnar nerve before entering the hand. Upon entering the palmar compartment of the hand, the PMA displayed a rare termination and territorial supply pattern. The superficial palmar arch of this specimen was identified as incomplete, as the PMA failed to form any classical vascular anastomosis with the superficial branches of either the ulnar or radial arterial systems. Instead of serving as a supplementary vessel, this patent embryonic artery functioned as the primary source of digital perfusion for the central compartment of the hand. It terminated directly within the palm by giving off the 3rd and 4th proper palmar digital arteries, which provided the sole arterial supply to the adjacent sides of the middle and ring fingers. The presence of a palmar-type persistent median artery of this calibre carries immense clinical and surgical significance. Because the vessel occupies space within the crowded carpal tunnel, it predisposes individuals to carpal tunnel syndrome through mechanical compression of the median nerve, a condition that can be acutely exacerbated by age-related atherosclerosis, thrombosis, or aneurysmal changes within the variant vessel. Furthermore, during surgical procedures such as an open or endoscopic carpal tunnel release, the anomalous looping course of this artery poses a severe risk of accidental laceration or haemorrhage. Most critically, because the superficial palmar arch in this hand was incomplete, the middle and ring fingers rely entirely on the PMA for survival; inadvertent ligation or injury to this vessel during surgery would cut off collateral circulation, leading to immediate digital ischemia and tissue necrosis.



Case 3: During routine dissection of the right upper limb of a 63-year-old male cadaver, a large-calibre persistent median artery (PMA) of the palmar type was identified in the distal forearm and hand. The vessel remained patent and maintained a wide calibre throughout its course. The PMA descended through the distal forearm and entered the carpal tunnel, running in close association with the median nerve within the confined osteofibrous canal. After

emerging from the distal margin of the tunnel, it continued deep to the palmar aponeurosis and became the dominant arterial channel within the central palmar compartment. Instead of contributing to, or completing, a superficial palmar arch, the PMA remained independent. It did not anastomose with superficial branches of either the radial or ulnar arteries. The vessel terminated directly by giving rise to common and/or proper palmar digital arteries, which supplied the central digits. Because the radial and ulnar arterial systems remained separate, the PMA provided an exclusive, non-collateral vascular supply to the central fingers, demonstrating a fully independent territorial perfusion pattern.

Case 4:

During a routine, systematic gross anatomical dissection of the palmar compartment of the hand in a 47-year-old female donated cadaver, a significant vascular anomaly involving the superficial palmar network was identified and isolated. In this specimen, no persistent median artery was present within the central hand, carpal tunnel, or antebrachial regions. Instead, the dissection illustrated a purely incomplete superficial palmar arch with distinct course characteristics and compartmental relationships.

The ulnar artery entered the hand normally by tracking superficial to the flexor retinaculum, passing through the fibro-osseous boundaries of Guyon's canal alongside the ulnar nerve. Upon emerging into the palm deep to the palmar aponeurosis, the ulnar artery gave off standard digital branches to supply the medial fingers. It crossed the palmar surface of the flexor digitorum superficialis and profundus tendons, tracking laterally toward the midline of the hand. However, as its main superficial trunk extended across the palm, it rapidly attenuated and terminated abruptly in the central palmar compartment. It failed to form any macroscopic connection, transverse loop, or terminal anastomosis with the superficial palmar branch of the radial artery.

The radial artery emerged into the lateral palm via its standard course, passing superficial to the muscles of the thenar eminence. From this position, it independently supplied the lateral structures of the hand, tracking distally to distribute branches to the thumb and the lateral aspect of the index finger. Because both primary forearm trunks terminated independently within their respective lateral and medial territories, a definitive gap was left in the central collateral circulation of the hand, leaving the central palmar space devoid of a protective vascular arch.

DISCUSSION

The ontogeny of the upper limb vasculature provides a vital framework for understanding the structural anomalies observed in this case. As described by Umarji JS et al., the primitive axis artery of the upper extremity arises directly from the seventh cervical intersegmental (subclavian) artery. [ ] This foundational vessel grows distally along the ventral axial line of the limb bud, ultimately terminating in a rich palmar capillary plexus within the developing hand plate. Under typical morphological conditions, the main trunk of this axis artery undergoes segment-specific remodelling to establish the definitive axillary, brachial, and anterior interosseous arteries, as well as the deep palmar arch. The median artery develops slightly later as a specialized branch of the anterior interosseous artery, growing distally to establish a temporary hemodynamic communication with this palmar capillary plexus to nourish the rapidly developing hand. Dhakshanamoorthy N et al. emphasize that this sequence relies heavily on precise spatial angiogenesis and synchronized regression. When variations occur in this delicate balance of differentiation, timing, or localized regression, the embryonic vessel fails to undergo apoptosis by the eighth week of intrauterine life and remains fully patent into adulthood as a persistent median artery (PMA). [ ] Morphologically, the categorization introduced by M. Rodriguez-Niedenfuhr et al. delineates two distinct patterns of anatomical persistence: the antebrachial type, which undergoes partial regression and terminates within the forearm median nerve sheath, and the palmar type, which remains fully patent to participate directly in the palmar blood supply. The findings in our current case demonstrate a classic palmar-type PMA. [ ] However, while the literature notes that a palmar-type PMA most frequently arises from the ulnar artery or the caudal angle between the ulnar and common interosseous arteries, our current case revealed a distinct origin arising as a direct branch of the common interosseous artery. Case 1 presents a distinct origin arising as a direct branch of the anterior interosseous artery, whereas Case 2 and Case 3 exhibit a direct origin from the ulnar trunk before embarking on a highly unique looping course. Conversely, Case 4 stands in distinct contrast to the other three, showcasing a complete normal embryonic regression of the PMA but demonstrating an independent failure of the traditional forearm trunks to establish an interconnected terminal arcade. The overall global incidence of an adult PMA ranges widely from 0.6% to 44.2% across different geographical populations, whereas the specific palmar-type pattern historically spans between 1.5% and 13.3%. [ ] While older data from Srivastava and Pande reported a low functional palmar PMA prevalence of 1.5%, recent temporal data compiled by Lucas et al. confirm a secular upward trend in human prevalence, indicating ongoing microevolutionary shifts within modern populations. [,] According to Carry et al., racial differences heavily influence these statistics, noting that African American cohorts demonstrate a statistically higher prevalence of a PMA than non-African American populations. [ ] This macro-temporal shift is strongly reflected in regional data from the Indian subcontinent, where the documented prevalence exhibits localized diversity. In a South Indian cadaveric study conducted in Bangalore, investigators reported an overall PMA incidence of 4%, highlighting a rare bilateral palmar variant that modified digital vascularity. [ ]Similarly, a North Indian baseline study by Rajan Kumar Singla et al. in Amritsar observed a persistent median artery in 6.6% of analyzed limbs, where the vessels originated from the anterior interosseous artery and tracked into the hand to terminate within an incomplete mediano-ulnar superficial palmar arch. [ ] Furthermore, data from Chandigarh, India, recorded a persistent median artery prevalence of 7.5%, with the vast majority presenting as an incomplete mediano-ulnar variant where the ulnar and median arteries collectively supplied the palm without establishing an anatomical anastomosis. [ ] These regional Indian cohorts showcase a distinct morphological alignment with the Type C incomplete superficial palmar arch under the Coleman and Anson classification. Case 1 directly mirrors this structural framework, where the PMA gave rise to the common digital artery of the second interdigital cleft to supply the index and middle fingers in the complete absence of a superficial palmar arch platform. This structural divergence is further enriched by Case 2 and Case 3, which present an incomplete superficial palmar arch due to the PMA functioning as an isolated, non-communicating central conduit for the 3rd and 4th digits, while Case 4 completely redraws the regional profile by presenting an isolated incomplete superficial palmar arch without any embryonic PMA assistance, resulting in a physical and hemodynamic gap directly in the center of the palmar circulation. The spatial relationship and course of a palmar PMA in relation to the median nerve through the forearm and hand compartments are highly variable. Literature reviews indicate that a PMA may descend anterior, posterior, ulnar, or radial to the median nerve in the forearm, and adopt anterior, anterolateral, or anteromedial positions in the hand. In Case 1, the PMA travelled along the lateral side of the median nerve within the forearm compartment, shifting its spatial alignment at the wrist to lie directly anteromedial to the median nerve trunk as it passed through the carpal tunnel under the flexor retinaculum. This pattern stands in stark architectural contrast to the localized neurovascular guidance modifications seen in Case 2 and Case 3, where the PMA exhibited an initial tortuous,

ascending course lateral and proximal to the division of the median nerve before executing a definitive loop over its superficial branch. In further contrast, Case 4 completely bypasses these neurovascular tracking anomalies, displaying standard muscular and neural relationships while demonstrating an abrupt lateral attenuation of the ulnar artery as it tracks across the palmar surfaces of the flexor digitorum superficialis and profundus tendons. While Gassner et al. observed that 63% of unilateral PMAs are associated with a corresponding structural variation of the median nerve—such as a high division or a bifid nerve configuration within the carpal tunnel—the findings in our PMA specimens (Cases 1, 2, and 3) were unique because the underlying median nerve remained fully unified and structurally normal despite the close arterial proximity. [ ]Additionally, certain rare presentations feature the palmar PMA piercing through the divisions of a split median nerve trunk in the upper forearm, a variation documented by Rodriguez-Niedenfuhr et al. that carries a significant risk of pronator or anterior interosseous nerve entrapment. [ ] The behaviour of the palmar PMA upon reaching the hand further accentuates the uniqueness of our current case. Literature notes that a palmar PMA typically terminates in one of two configurations: it either joins a complete or incomplete superficial palmar arch, or it directly terminates as the first, second, or combined common digital arteries supplying the digits. In Case 1, the PMA entered the palm passing medially to the tendon of the flexor pollicis longus muscle and laterally to the flexor digitorum superficialis, giving rise directly to the common digital artery to the index and middle fingers, where its branch to the index finger formed a definitive macroscopic anastomosis with the terminal branches of the radial artery. This arrangement stands in direct opposition to the independent terminal patterns of Case 2 and Case 3, where the large-caliber PMA failed to form any collateral loops or anastomoses with either the radial or ulnar systems, acting instead as the sole vascular supplier to the 3rd and 4th digits. These three settings contrast sharply with Case 4, where the total absence of a PMA isolates the medial and lateral components of the palm entirely, forcing the radial and ulnar systems to independently perfuse their respective digital territories with zero cross-over support. Most critically, this entire branch distribution took place in the complete absence of a superficial palmar arch. In usual morphology, the superficial palmar arch is formed by the anastomosis of the superficial palmar branch of the ulnar and radial arteries in the palm. In our current case, no superficial palmar arch was observed, leaving the ulnar artery to terminate independently on the medial side of the palm while the PMA and radial artery assumed territorial supply over the lateral digits. This functional contribution directly contrasts with other rare case variations where a bilateral PMA acts as the sole source of the princeps pollicis and radialis indicis arteries, or studies by Rajan Kumar Singla et al. where the palmar-type PMA simply accompanied the nerve up to the palm without contributing any blood supply to the hand. [19] The palmar-type persistent median artery (PMA) acts as a space-occupying lesion within the rigid carpal tunnel, predisposing patients to median nerve entrapment. This risk escalates if the vessel develops calcification, thrombosis, atherosclerosis, or aneurysmal dilatation. Vessel caliber is a key predictor of symptoms; Gassner et al. noted that a PMA diameter exceeding 3 mm frequently triggers carpal tunnel syndrome, whereas diameters under 1.7 mm usually remain asymptomatic. [21] While Haładaj et al. established a standard wrist-level PMA range of 1.04 mm to 2.21 mm, extreme variants can measure up to 2.3 mm and 3.77 mm inside the carpal tunnel. [2] Proximally, a PMA perforating the median nerve deep to the pronator teres can induce pronator or anterior interosseous nerve syndromes, while its distal pathway mirrors the palmaris longus tendon, posing an accidental injury risk during autologous tendon graft harvesting. The surgical challenges of these configurations are illustrated by Butt J et al. in a case of a 55-year-old female with severe thenar wasting and positive signs of median nerve compression, where open decompression revealed an unexpected palmar PMA superficial to the palmar aponeurosis, requiring precise retraction to safely incise the flexor retinaculum. [ ] Crucially, the varying structural patterns in our case series illustrate a shared, highly dangerous clinical feature: the loss of vascular redundancy. In Case 1, the ulnar artery terminates independently while the lateral digits rely on a radio-median network; in Cases 2 and 3, the middle and ring fingers depend solely on the independent PMA; and in Case 4, the hand is divided into completely segregated medial and lateral zones. Under these highly specialized anatomical conditions, the classic collateral safety net of the hand is entirely missing. Accidental ligation, laceration, or surgical harvesting of any of these un-anastomosed or terminal vessels—whether it be the looping PMA of Case 2/3 or the isolated ulnar trunk of Case 4—will eliminate collateral pathways and cause sudden, catastrophic digital ischemia or avascular necrosis. To prevent these ischemic complications, pre-operative mapping via ultrasonography, colour Doppler, or MRI is essential to locate such vascular anomalies. This clinical utility was demonstrated by Menichini et al., who successfully mapped and harvested a 2.1 mm radial-derived PMA for an intraoral free flap reconstruction after testing for vascular insufficiencies. Implementing these non-invasive diagnostic tools prior to carpal tunnel release, radial artery cannulation, or flap design ensures safe surgical margins and preserves vital

digital perfusion. [ ] CONCLUSION In conclusion, this case series highlights the extensive morphological diversity of the superficial palmar vasculature, demonstrating that classic textbook descriptions of a complete superficial palmar arch are frequently replaced by highly individualized arterial patterns. The variations documented across these four specimens—ranging from the preservation of embryonic pathways with anomalous origins and neurovascular tracking loops to the total absence of a persistent median artery coupled with an incomplete terminal arcade—redefine the architectural rules of hand haemodynamics. By eliminating the hand's natural collateral vascular network, these configurations create an environment of independent territorial perfusion where specific digits rely entirely on a single, isolated vessel for survival. Additionally, when a patent, large-caliber persistent median artery traverses the carpal tunnel, it acts as a structural, space-occupying lesion that significantly preorients the patient to median nerve compression syndromes. Ultimately, these findings emphasize that a thorough understanding of upper limb vascular variants, paired with routine preoperative objective imaging such as duplex ultrasound or colour Doppler, is paramount for hand surgeons, radiologists, and clinicians to avoid catastrophic ischemic complications and ensure safe surgical margins during microvascular and interventional procedures.

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