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SIGNIFICANT VARIATIONS IN THE ORIGIN AND TRAJECTORY OF THE RADIAL ARTERY IMPLICATIONS FOR CLINICAL PRACTICE.

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ABSTRACT:

Introduction: The radial artery serves as a crucial supplier of blood to the structures within the forearm. Variations in its origin, course, branching pattern, and termination mode have been frequently documented. Notably, studies have often identified the high origin of the radial artery from either the brachial or axillary artery. Given its clinical utility in procedures such as cardiac catheterization and bypass grafting, awareness of these variations holds paramount importance for surgeons.

Aims and Objectives

The primary aim of this study is to investigate variations in the origin and course of the radial artery (RA) in cadavers.

Methods: In this study, dissections were performed on 51 upper limb specimens obtained from the Government Medical College, Ongole. Variations in the origin and course of the radial artery were meticulously noted and documented through photography.

Results: Among the 50 upper limb specimens examined, variation in the radial artery's origin was detected in one specimen originating from the axillary artery and in three limbs from the brachial artery. Furthermore, the course of these variant arteries predominantly traversed superficially within the forearm.

Conclusion: Understanding the variations in the origin and course of the radial artery is essential for averting potential complications during procedures involving its utilization. This knowledge serves as a safeguard against untoward side effects, thereby enhancing the safety and efficacy of medical interventions.

Keywords: Radial artery, Variations, Anomalies.

INTRODUCTION

The radial artery (RA), an extension of the brachial artery, is essential for supplying blood to the forearm. It begins in the cubital fossa around the neck of the radius, then travels along the outer side of the forearm before dividing at the wrist to provide blood to the hand. The radial artery (RA) emerges as the smaller of the two terminal branches of the brachial artery (BA) within the cubital fossa, located medially to the biceps tendon. Originating from the BA approximately 1.0 cm below the elbow bend, directly opposite the neck of the radius, it serves as a more direct continuation of the BA. Progressing along the lateral aspect of the forearm, it travels towards its lower end, where it enters the palm to contribute to the formation of the deep palmar arch by connecting with the deep branch of the ulnar artery. Initially, the proximal segment of the RA passes beneath the muscle belly of the brachioradialis, while its middle section is closely associated with the superficial branch of the radial nerve. As it transitions towards its distal third, the RA assumes a superficial position, anterior to the radius and the pronator quadratus muscle, positioned between the tendons of the brachioradialis and flexor carpi radialis. Variation in the arterial pattern of the upper limb occurs at an incidence ranging from 18.53% to 20%. [1,2,3]

The trunk of the radial artery (RA) is segmented into three parts. The initial part stretches from its origin to the apex of the styloid process. The second part curves along the lateral side of the wrist, reaching the proximal part of the first interosseous space. The third part passes through the interosseous space into the palm. Understanding the various configurations of the arterial pattern in the upper limb is of crucial clinical significance. The radial artery (RA) displays significant anatomical variability, especially in terms of its origin, the arrangement of radial recurrent arteries, and the vascular territory within the hand. From a clinical perspective, the RA is notable for its palpable pulse at the wrist, which aids in determining heart rate. Additionally, it is the preferred artery for various medical procedures, including coronary artery angiography, percutaneous coronary artery intervention, and cannulation.

The increasing use of the RA in coronary interventions has renewed interest in its anatomy. Its popularity is attributed to factors such as easy access, high success rates, minimal nursing care requirements, abundant collateral circulation in the hand, and low thrombosis risk. These anatomical characteristics play a crucial role in determining the feasibility of using the RA for coronary intervention. It's vital to emphasize that the radial artery's adjacency to the cephalic vein introduces the possibility of perilous complications when administering intravenous medications. This close anatomical relationship increases the risk of inadvertently puncturing the radial artery while intending to access the cephalic vein for medication administration. Such inadvertent arterial puncture can lead to severe consequences, including hematoma formation, arterial thrombosis, embolism, and impaired blood flow to the hand, potentially resulting in ischemic complications. Therefore, healthcare practitioners must exercise extreme caution and employ appropriate techniques to minimize the risk of such complications when accessing veins in the vicinity of the radial artery for intravenous procedures. [4] Manners-Smith introduced a classification system for variations in the course of the radial artery, dividing them into two classes based on the relationship between the radial artery and the tendons forming the anatomical snuff box. [5] In the first class, the radial artery remains singular and entirely superficial to the tendons comprising the anatomical snuff box, often referred to as the superficial dorsal artery of the forearm. Meanwhile, the second class entails the radial artery dividing into superficial and deep branches, a phenomenon sometimes described as either partial duplication of the radial artery or duplication of the radial artery. [6,7]

Different terms have been utilized to denote the high origin of the brachial artery, such as a radial artery originating from the brachial (or axillary) artery, a high bifurcation of the brachial artery, the continuation of the superficial brachial artery as the radial artery, or a double brachial artery. Rodríguez-Niedenführ et al. advocate for a concise and standardized nomenclature for these variations, proposing the term "brachioradial artery" specifically for the "high origin of the radial artery." [8] In cases involving the brachioradial artery, an accessory artery is identified within the medial bicipital sulcus, running superficially to the median nerve. It then proceeds along the forearm, assuming the course typically followed by the radial artery. Concurrently, in this variant, the brachial artery maintains its conventional position, coursing deep to the median nerve. The brachioradial artery frequently establishes an anastomosis with the "normal" brachial artery within the cubital fossa, known as the "cubital crossover" or "cubital connection."

Understanding the variations of the radial artery is crucial in vascular, plastic, and reconstructive surgeries, as well as for procedures involving arterial puncture and cannulation (such as transradial access). In this regard, knowledge of the potential anatomical variations of the brachioradial artery holds significant clinical importance. These variations may encompass differences in its origin, the presence of an anastomosis with the brachial artery in the cubital fossa (referred to as "cubital crossover"), the arrangement of recurrent radial arteries, and the vascular territory within the hand. Being aware of these variations can aid healthcare professionals in planning and executing procedures accurately and effectively while minimizing the risk of complications. [9-11] Numerous anatomical variations of the radial artery (RA) have been identified, adding complexity to the upper limb arterial system. One notable variation is the high origin of the RA, occurring from either the brachial or axillary artery proximal to the antecubital fossa, with prevalence rates ranging from 2.4% to 14.3% in upper extremities. These variations are commonly encountered and have been extensively studied by researchers. Among the spectrum of variations, deviations from the typical anatomical course or origin of the RA represent a significant subset of vascular anomalies in the upper limbs. Such deviations have the potential to pose challenges in various diagnostic, therapeutic, and surgical interventions.[12-16]

An uncommon anatomical variation involves the opposite origin of the radial and ulnar arteries, where the radial artery (RA) arises from the medial side and the ulnar artery from the lateral side of the brachial artery. [17] Furthermore, although rare, the absence of the radial artery (RA) has been documented, with an estimated incidence of 0.03%. [18] The smaller size of the radial artery (RA) compared to the brachial and femoral arteries presents certain challenges, particularly in cases involving arterial interventions. Studies indicate that the mean radial inner diameters of patients may limit the size of arterial sheaths that can be safely used. For example, approximately 40.5% of female and 68.3% of male patients may accommodate a 6 Fr arterial sheath based on radial inner diameters. Understanding the anatomical distribution and variations of the RA is of paramount importance to ensure optimal outcomes and mitigate potential complications in diagnostic, therapeutic, and operative interventions. Therefore, the present study aims to provide a detailed description of the anatomical topography of the RA and determine the variant incidence of its origin, course, relation, branching pattern, and mode of termination in human cadavers. Variations in the anatomical pattern of the upper limb arterial system are indeed common and have been extensively reported by numerous investigators in previous studies. [19-21]

The deviations of the radial artery (RA) from its typical anatomical pattern, whether concerning its origin or course, represent the largest group of vascular variations observed in the upper limbs. The variations in radial artery (RA) anatomy can potentially disrupt various diagnostic, therapeutic, and surgical procedures . Renewed interest in RA anatomy has emerged due to its increased utilization in various coronary interventions. Factors such as easy access, high success rates, minimal nursing care requirements, abundant collateral circulation in the human hand, and low thrombosis risk contribute to the popularity of the RA . These anatomical characteristics of the RA play a pivotal role in determining its feasibility as a route for coronary intervention. Additionally, the close proximity of the RA to the cephalic vein can pose risks of dangerous complications during intravenous medication injections .[4] The variant high origin of the radial artery (RA), characterized by its emergence from either the brachial or axillary artery (AA) proximal to the antecubital fossa, has been identified in 2.4% to 14.3% of upper extremities. [15,16] The opposite origin of the radial and ulnar arteries, deviating from the typical arrangement, is defined by the radial artery (RA) arising from the medial side and the ulnar artery from the lateral side of the brachial artery. This rare anatomical variation has been scarcely reported. [22] The absence of the radial artery (RA), with an estimated incidence of 0.03%, is indeed considered rare. In terms of size, the RA is smaller compared to the brachial and femoral arteries. Subsequently, it may course superficially to the brachioradialis muscle in the forearm. [23,24] Understanding the variations in the radial artery is clinically crucial, particularly considering its frequent use in interventional cardiology procedures. A study focusing on retrograde radial arteriography involved 650 patients undergoing their initial transradial coronary procedure. The findings from this study revealed a high origin of the radial artery in 40 (6.2%) of the patients included in the study. [21] In a retrospective study analyzing 602 images of routine angiographies of the radial artery conducted during cardiac catheterization, the most prevalent anatomical variation observed was the high origin of the radial artery, occurring in 5.1% of the cases. [25] The main objective of this study is to investigate variations in the origin and course of the RA in cadavers.

AIMS AND OBJECTIVES

The primary objective of this study is to explore variations in the origin and course of the radial artery (RA) through cadaver dissection and examination.

MATERIALS AND METHODS

This study utilized 50 embalmed cadaveric upper limb specimens obtained from the formalinpreserved specimen collection at the Department of Anatomy, Government Medical College, Ongole. Among these specimens, 27 were sourced from formalin-preserved upper limb collections, while 12 upper limbs were obtained from cadavers used for routine dissection by undergraduate students over a two-year period. The upper limb arteries were meticulously cleaned, and their course, relations, and branches were thoroughly examined to identify variations. All procedures were conducted in accordance with ethical standards governing the management of cadavers for teaching and learning purposes. Photographs were taken under optimal lighting conditions using a Canon EOS 750D Digital SLR camera and were subsequently labeled for documentation purposes.

RESULTS

Variations were noted in four out of the 50 upper limb specimens examined, primarily pertaining to the origin and course of the radial artery.

In one left-sided upper limb specimen, a variation was observed in the origin and course of the radial artery. The radial artery originated from the third part of the axillary artery. Initially, it traversed the axilla, passing between the medial and lateral roots of the median nerve. Subsequently, it crossed the lateral root of the median nerve, continuing laterally alongside the brachial artery in the arm. Within the cubital fossa, it maintained a lateral course parallel to the brachial artery. Upon entering the forearm, it descended superficially to the pronator teres muscle, running along the medial side of the brachioradialis muscle. Throughout the forearm, it followed a superficial course just beneath the deep fascia. However, its course in the hand remained normal. Notably, in this specimen, the brachial artery persisted as the ulnar artery in the forearm, following a typical course.

In another left-sided upper limb specimen, a branch originated from the brachial artery at the midarm level. This branch proceeded laterally alongside the brachial artery in the arm before transitioning into the radial artery in the forearm. Similarly, this variation was observed in two additional specimens from the right side, where a branch emerged from the brachial artery in the proximal part of the arm and extended as the radial artery into the forearm. In all four limbs displaying this variation, the radial artery maintained a superficial course throughout the forearm, positioned just beneath the deep fascia.

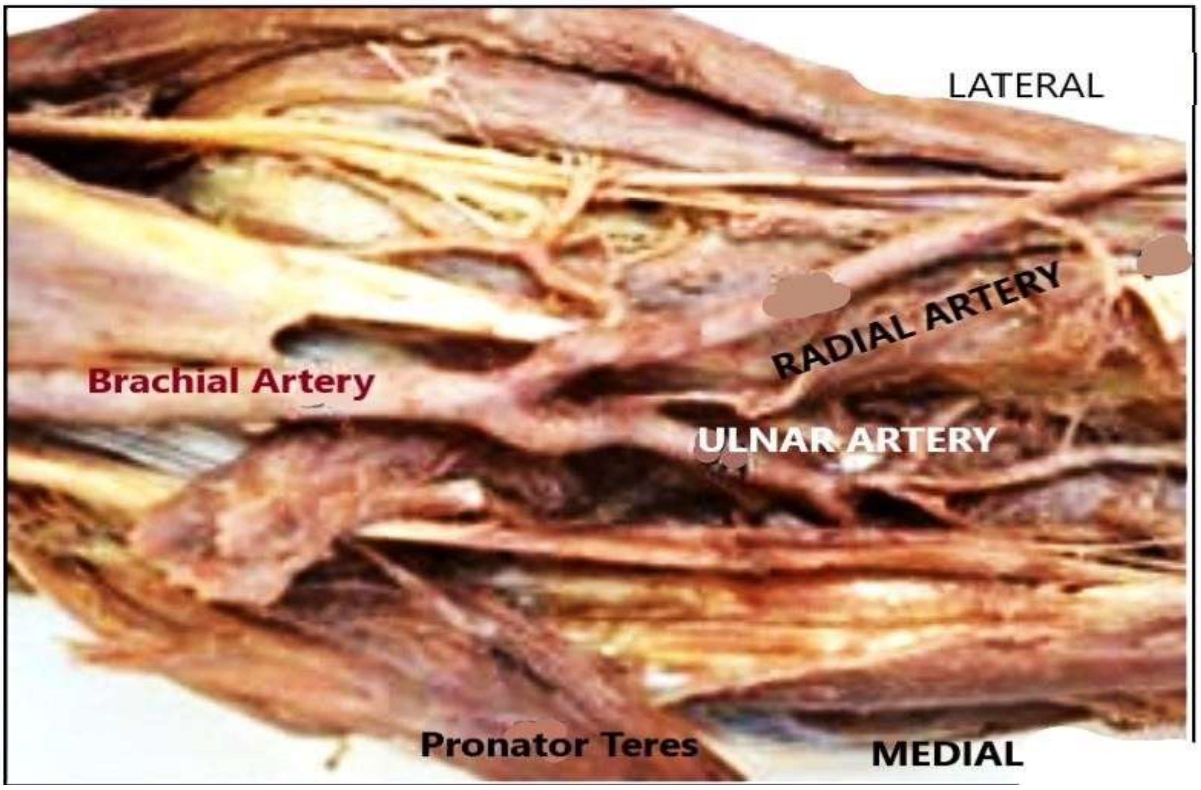

Figure2 : Origin of RA from brachial artery (BA) in cubital fossa.

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DISCUSSION

According to the classic 'sprouting' theory proposed by Singer in 1933 and corroborated by Standring in 2008, arteries in the developing upper limb emerge successively from a single trunk of the axial artery. In the early stages of upper limb formation, the dominant vessel is the subclavian artery, which continues into the axillary, brachial, and interosseous arteries in later developmental stages. Only at a further stage of development do the ulnar and radial arteries begin to appear. This developmental sequence suggests a hierarchical organization in the arterial system of the upper limb, with arteries sprouting successively from an initial trunk as the limb matures. [26,27] Rodríguez-Baeza et al. (1995) [28] proposed a model suggesting that upper limb arteries are formed through the convergence of superficial and deep pathways. In this model, the superficial brachial artery is considered a 'consistent embryonic vessel' crucial for the normal development of upper limb arteries. It was hypothesized that during the early stages of upper limb formation, the superficial brachial artery forms an anastomosis with a trunk responsible for the deep origin of the radial artery (RA) within the primitive axial artery. Recent theories proposed by Rodríguez-Niedenführ et al. [8] suggest that the definitive arterial pattern of the upper limb emerges from the primitive capillary plexus, often referred to as the 'vascular labyrinth.' According to this model, the dominant vascular channels gradually differentiate through capillary remodeling. It is hypothesized that this process of arterial development may lead to variations in the definitive arterial pattern. Some vessels that are typically retained may disappear or be incompletely developed, while certain collateral pathways may persist. Rearrangements are feasible until developing vessels are enveloped by vascular smooth muscle cells. Based on these concepts, a low origin of the radial artery (RA) may be considered a remnant of capillary anastomotic channels between the differentiating RA and the distal part of the primitive axial artery (or its branches) during the early stages of upper limb growth. Variations in the major arteries of the upper limbs are extensively documented in the literature, with reported frequencies ranging between 11% and 24% . Among these variations, a high origin of the radial artery from either the brachial or axillary artery stands out as the most common arterial anomaly. Its incidence ranges from 4.17% to 15.6% in cadaveric and embryonic studies, and from 8% to 24.4% in angiographic investigations. In the present study, a high origin of the radial artery was observed in four limb specimens. Specifically, in three (5.26%) specimens, the radial artery originated from the brachial artery at the midarm level, while in one (1.75%) specimen, it arose from the axillary artery. These findings are consistent with previous research and emphasize the significance of comprehending variations in the arterial anatomy of the upper limbs. Such understanding is essential for clinicians and surgeons to anticipate and effectively manage potential anatomical anomalies encountered during diagnostic and surgical procedures.

Haladaj et al. [29]conducted a study on 120 randomly selected upper limbs and found a high origin of the radial artery in 9.2% of the total limbs examined. Among these cases, two originated from the axillary artery, while nine arose from the brachial artery. They also noted an anastomosis between the brachioradial and normal brachial arteries in the cubital fossa. Icten and colleagues [30] reported a case where the radial artery originated from the axillary artery in both limbs of a cadaver. Similarly, Patnaik et al. [20]described a case of the radial artery's high origin from the third part of the axillary artery.Rodriguez-Niedenfuhr et al.

[8]conducted a comprehensive study involving 384 upper limbs, where they identified the high origin of the radial artery from the brachial artery, defining it as the brachioradial artery. They further classified it as a superficial brachioradial artery if the radial artery displayed a superficial course in the forearm. Among their specimens, the brachioradial artery was observed in 53 (13.8%) cases. In another study involving 100 upper limbs, researchers observed a high origin of the radial artery in 8 limbs. Among these cases, 7 originated from the brachial artery, while 1 arose from the axillary artery. These findings further highlight the variability in the origin of the radial artery and underscore the importance of understanding such anatomical variations for clinical practice. [31] In the present study, along with the high origin of the radial artery, all four limbs exhibited a superficial course of the radial artery in the forearm. Specifically, the variant radial artery passed superficially to the pronator teres muscle and laterally to the brachioradialis muscle, diverging from its typical course where it is overlapped by the brachioradialis muscle in its proximal third. These reports further support the variability in arterial anatomy and emphasize the importance of comprehensive anatomical knowledge for healthcare professionals. Understanding such variations is crucial for accurate diagnosis, effective treatment planning, and successful surgical interventions.

Table 1 gives a summary of the elevated origin of the radial artery in comparison to other research.

AUTHOR (YEAR)	SAMPLE SIZE	Variations %	Origin of RA from Axillary artery %	Origin of RA from Brachial artery %
Haladaj et al. 2018 [29]	120	9.2%	1.67%	7.5%
Nasr AY , 2012 [31]	100	8%	1%	7%
Yang et al. 2008 [32]	304	12.17%	12.17%	-
Kadel et al. 2019 [33]	53	13.2%	1.8%	11.3%
Agarwal et al. 2016 [34]	32	3.12%	3.12%	-
Zhan et al. 2010 [35]	1200	0.25%	-	0.25%
Present study	50	7 %	2 %	6 %

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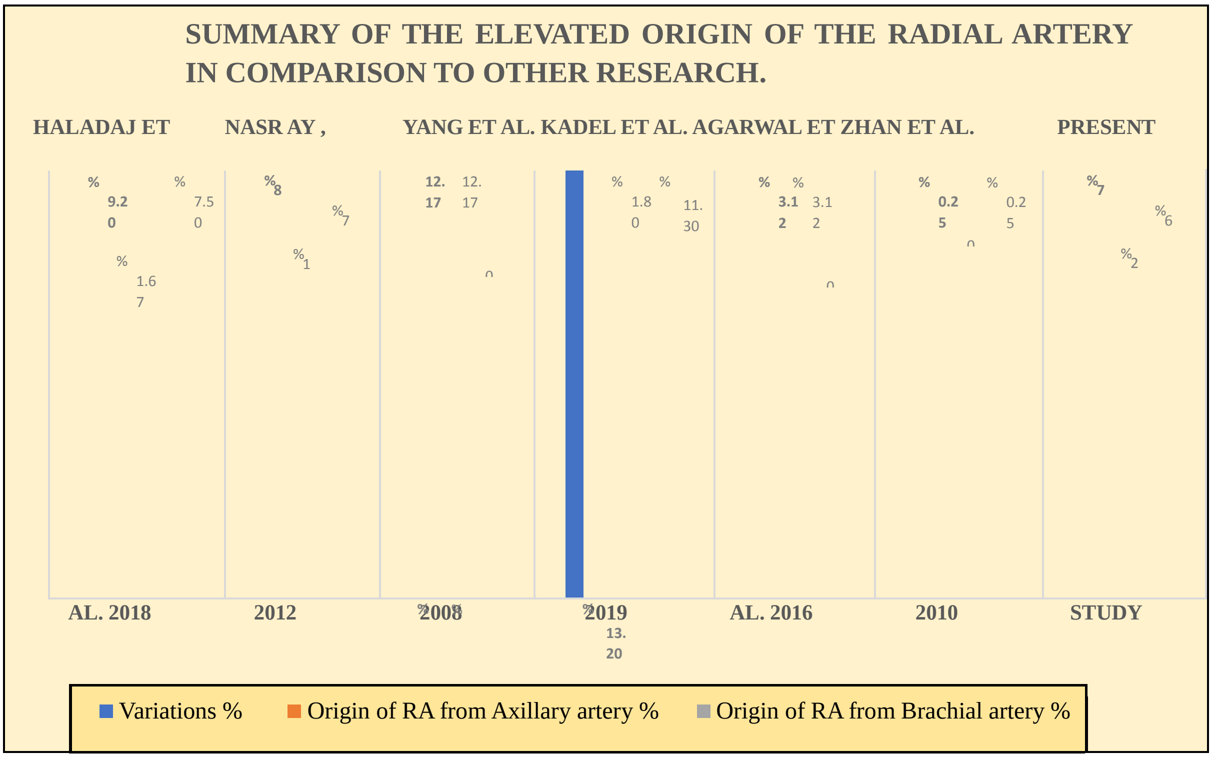

FIGURE 1: S**ummary of the elevated origin of the radial artery in comparison to other research.**

The table presents a comparison of variations in the origin of the radial artery (RA) across different studies. Sample sizes vary among the studies, ranging from 32 to 1200 specimens. The percentage of variations in the origin of the RA fluctuates between 0.25% and 13.2%, indicating variability in anatomical configurations. Some studies specifically delineate the percentage of cases where the RA originates from either the axillary or brachial artery, while others report an overall variation percentage. The present study contributes a variation percentage of 7 %, with 2 % originating from the axillary artery and 6 % from the brachial artery. Despite slight discrepancies, variations in the origin of the RA demonstrate consistent trends across studies, underscoring the importance of understanding anatomical diversity in clinical and anatomical contexts.

The table compares variations in the origin of the radial artery (RA) from several studies, including those conducted by Haladaj et al. (2018), Nasr AY (2012), Yang et al. (2008), Kadel et al. (2019), Agarwal et al. (2016), and Zhan et al. (2010), in addition to the present study. Sample sizes across these studies range from 32 to 1200 specimens. The reported percentages of variations in the origin of the RA vary between 0.25% and 13.2%, reflecting anatomical diversity. The development of limb arteries is a complex process involving vasculogenesis and angiogenesis. By the end of stage 12, approximately the 28th day of embryonic development, a capillary plexus forms within the limb, connected to the dorsal aorta. As development progresses, around stage 13, the subclavian artery begins differentiation. This artery persists as the axial artery of the upper limb, giving rise to the axillary and brachial arteries. In adults, the axial artery continues its course, becoming the anterior interosseous artery and contributing to the formation of the deep palmar arch. These arterial structures are crucial for supplying blood to the upper limb, ensuring proper circulation and function. This developmental process is essential for establishing the arterial network necessary for the proper growth and function of the upper limb.Understanding the embryonic development of limb arteries provides valuable insights into their anatomy and function in adulthood. [8] The anomalies of the radial artery (RA) may indeed be attributed to the persistence of its proximal segment, leading to the production of a high origin. During embryonic development, variations or disruptions in the differentiation and migration of arterial components can result in anomalous configurations. In some cases, the proximal segment of the RA may fail to regress as expected, leading to its continuation from a higher point than usual along the arterial pathway. This persistence of embryonic arterial segments can contribute to the development of anatomical variations observed in adulthood, such as a high origin of the RA. Understanding the embryological basis of these anomalies provides insights into their etiology and helps clinicians comprehend the underlying mechanisms driving variations in arterial anatomy. [36]

Indeed, pinpointing the precise factors responsible for each arterial variation is challenging. Numerous factors may contribute to these changes, including alterations in hemodynamic forces, fetal positioning within the uterus, genetic predisposition, chemical influences, and developmental arrest at any stage of embryonic development. Hemodynamic forces exerted on developing arteries play a crucial role in shaping their morphology and course. Additionally, the positioning of the fetus within the uterus can influence the mechanical stresses experienced by developing arterial structures. Genetic factors may also predispose individuals to certain arterial variations, influencing the expression of genes involved in vascular development. Furthermore, chemical cues within the intrauterine environment can impact arterial differentiation and remodeling processes. Lastly, developmental arrest at any stage of embryogenesis can lead to persistent embryonic structures or aberrant vascular patterns. The interplay of these multifaceted factors contributes to the wide spectrum of arterial variations observed in human anatomy. Pelin et al. documented an unusual course of the radial artery (RA), detailing its origin from the medial aspect of the upper part of the brachial artery (BA). In this unique configuration, the RA crossed the median nerve twice: once at its original level and again within the cubital fossa. Despite these deviations, the RA then descended in its typical anatomical pathway within the front of the forearm. This case highlights the remarkable variability that can exist in the arterial anatomy of the upper limb, emphasizing the importance of thorough anatomical knowledge for accurate clinical assessment and intervention. [37] Similarly, an instance of a high origin of the radial artery (RA) with double crossing of the median nerve within the arm was observed. In this case, the RA originated from a higher point than usual, and during its course, it crossed the median nerve twice within the arm. [38]Abnormal courses of the radial artery (RA) have also been documented within the anatomical snuffbox. Previous reports have described instances where the RA takes a superficial passage to reach the tendon of the extensor pollicis longus muscle within the anatomical snuffbox. These observations highlight the variability in the anatomical arrangements of the RA in this region, underscoring the importance of thorough anatomical understanding for accurate clinical assessment and management. [39] Additionally, Patnaik et al. reported an anomaly of the radial artery (RA) where it was located at the base of the 2nd metacarpal. From this point, the RA turned distally, passing through the 2nd intermetacarpal space situated between the two heads of the 2nd dorsal interosseous muscle. However, it's worth noting that such anomalies were not observed in the present study. [20]

The presence of a superficial radial artery highlights the need to recognize and understand variations in its course to prevent potential complications during medical procedures. Its proximity to the cephalic vein increases the risk of complications during intravenous injections and can interfere with palpating the normal radial pulse, leading to cannulation failure. Despite its late origin and connections with the main trunk, the radial artery exhibits significant anatomical variability. This poses challenges in medical procedures like cardiac catheterization and coronary artery bypass grafting, making it the second most frequent cause of failure in cardiac catheterization. Comprehensive anatomical knowledge and consideration of variations are crucial for optimal patient outcomes. Therefore, it is crucial to be aware of abnormalities in the radial artery in order to avoid difficulties, especially during coronary artery bypass treatments. By lowering the risk of intraoperative problems and improving patient outcomes, surgical planning and execution can be aided by an understanding of potential aberrations in the radial artery's path, branching patterns, and linkages. Surgeons can more adeptly negotiate the anatomical intricacies and ensure the safety and effectiveness of coronary artery bypass treatments by proactively identifying and managing these variances. Specifically, the superficially coursing version of a highoriginating radial artery might provide clinical difficulties since it can mimic a vein and be vulnerable to damage during orthopedic or venipuncture treatments. These possible side effects highlight how crucial it is to identify anatomical abnormalities when using the radial artery for medical treatments. The radial artery (RA) has become more important in clinical practice due to improvements in diagnostic and surgical methods. In several surgical and radiological treatments, such as the radial forearm flap in arm reconstructive operations and as a graft for cardiac bypass procedures, it plays a crucial role as a conduit. The transradial approach's acceptance in coronary procedures has brought even more attention to the RA's therapeutic relevance. Because the RA has strong collateral circulation and is not flanked by major veins or nerves, it has a superficially safe route that reduces the chance of problems like bleeding. This has led to an increase in the use of this method. Furthermore, there is rising evidence that the RA has better long-term patency than the great saphenous vein when used in coronary bypass grafting. As a result, it is being used more often in this capacity.

Furthermore, differences in the RA branching pattern have important consequences for cardiac catheterization, angioplasty, pedicle flaps, and arterial grafting, needing extensive pre-procedural examination. Future study should compare the clinical importance of RA parameters to those of the femoral artery in various cardiovascular surgeries in order to improve procedural results and patient safety.

Accidental cannulation or injection of the superficial radial artery requires rapid surgical intervention to avoid vascular damage caused by recurrent overuse. Given the radial artery's widespread usage in coronary artery bypass grafting, cardiovascular surgeons must carefully analyze its path to avoid difficulties during harvesting.

Additional study on the prevalence and clinical significance of these variants is needed to better our understanding and patient management.

CONCLUSION

As a popular location for evaluating peripheral arterial pulse, palpating the radial artery pulse against the lower end of the radius is still clinically meaningful. Furthermore, radial artery harvesting is a common procedure for coronary bypass graft surgery. Variations in the clinical importance and scholarly interest of anomalies in arterial routes are frequent. Due to its superficial path under the roof of the anatomical snuff box, the superficial radial artery might be mistaken for the cephalic vein. Drug injections into the artery by unintentionally may result in secondary problems. The radial artery's abnormal courses might be the cause of the lack of a pulse at the wrist on the radial side.

Understanding these atypical paths is essential for performing diagnostic, interventional, and surgical treatments. Although diagnostic arterial investigations such as arteriograms or MRAs can evaluate vascular abnormalities prior to surgery, healthcare workers should regularly palpate the patient's radial pulse as an easy and affordable way to find it before cannulating. More in-depth research on the radial artery's path across the anatomical snuff box and close to the distal forearm may provide light on this subject.

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