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Case Study

Anatomical Variations of the Superficial Palmar Arch in Human Cadavers: A Case Study

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ABSTRACT

Background: The superficial palmar arch (SPA) is a key structure in hand vascularization, yet its morphology is highly variable. These anatomical variations can have important implications for procedures such as revascularization, graft harvesting, and reconstructive hand surgery. The purpose of this study was to document variations of the SPA in human cadavers and consider their potential relevance for surgical planning and risk reduction.

Methods: Hands from ten cadavers were dissected to expose the SPA and surrounding neurovascular structures. Variations were documented and compared with the Coleman and Anson classification system.

Results: Superficial palmar arch morphology varied between hands from the same cadaver on bilateral comparison, with no consistent pattern observed across specimens. Only one hand demonstrated a classical radial–ulnar anastomosis. Other configurations included ulnar-dominant arches, complete and incomplete patterns, and a unique incomplete configuration in which perfusion to the first three digits was not observed. These findings highlight the substantial variability of the SPA and the limitations of existing classification schemes in capturing all observed patterns.

Conclusion: Recognition of SPA variability is important for surgical planning involving the hand. Preoperative vascular assessment may reduce the risk of iatrogenic injury, particularly in procedures involving arterial harvesting or reconstruction. Even within a small sample size, configurations were observed that extend beyond traditional descriptions, underscoring the importance of individualized anatomical evaluation.

KEYWORDS: Median Artery, Median Nerve, Radial Artery, Radial Nerve, Superficial Palmar Arch, Ulnar Artery, Ulnar Nerve.

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INTRODUCTION

Embryogenesis of the upper limb vascular tree involves a series of dynamic events, including the formation of the superficial palmar arch (SPA). The arterial supply of the hand begins as the seventh intersegmental artery, which eventually becomes the subclavian artery and capillary plexus in the distal portion of the hand, forming arches and digital arteries. The median artery (MA), a branch of the anterior interosseous, typically regresses at the level of the elbow. The palmar capillary plexus differentiates into superficial and deep arches, with the radial artery (RA) and ulnar artery (UA) located deep and superficial, respectively. The RA and UA display a range of anastomosing vascular calibers depending on their vascular arborization, thereby affecting blood perfusion to the digits. Incorrect grafting within these structures or trauma to the area poses a risk of accelerating vascular pathologies [1,2]. The SPA is one of the important arterial structures necessary for proper vascularization of the hand. Procedures such as hand replantation or transplantation, post-traumatic revascularization, and composite tissue transfer may involve the SPA, making familiarity with its morphological variations clinically relevant in select surgical contexts [3]. Variation in arterial structures arises from aberrations in angiogenic signaling during vascular development in utero and often develops proportionally within the individual [4-6].

Arising from the mesodermal angioblast precursor cells, vasculogenesis of the vessels is driven by basic fibroblast growth factor, which initiates cellular migration in the embryo to form loose cords [7,8]. It has been hypothesized that morphological variation of vessels can also result from postnatal vasculogenesis, in which vascular endothelial growth factor stimulates proliferation of bone-marrow-derived endothelial precursor cells [9,10]. While most variations are unremarkable, some result in hand and digital ischemia requiring surgical intervention [11,12]. In this study, we examined the anatomical variation of the SPA, documenting patterns that may inform reconstructive microsurgical procedures of the hand, such as posterior interosseous artery flap reconstruction [12,13]. Moreover, a robust knowledge of variant arterial arch patterns, arterial diameter capacity, and subsequent comprehensive surgical-anatomical implications is instrumental [14,15].

In the most common pattern, the SPA represents the principal continuation of the UA, which courses laterally deep to the palmar aponeurosis to anastomose with the superficial palmar branch of the RA on the lateral aspect of the hand. This configuration gives rise to the ulnar metacarpal arteries supplying the second, third, and fourth lumbrical muscles, as well as a single proper palmar digital artery along the medial aspect of the little finger. Previously described variations include formation of the SPA solely by the UA or through anastomoses between the UA and the princeps pollicis artery, arteria radialis indicis, or MA [11,13,16–18]. The classification system proposed by Coleman and Anson [19] remains one of the most commonly used frameworks for describing morphological variation of the SPA.

While these variations are known, their relative prevalence, anatomical presentation, and correspondence to a standardized classification framework remain inconsistently characterized. Using cadaveric palms and applying the Coleman and Anson classification, this study systematically documents SPA variants, quantifies their distribution, and evaluates their relevance to surgical anatomy. By correlating observed configurations with established classifications, this work provides a more comprehensive and standardized understanding of SPA diversity, offering practical insights for surgical planning and anatomical education.

METHODS

Study Design

This study was conducted as a descriptive cadaveric case study examining anatomical variation of the SPA. Ten human cadavers donated by the West Virginia University School of Medicine were included in this study, consisting of five males (M1–M5) and five females (F1–F5), with donor ages ranging from 70–88 years. All cadavers were formaldehyde-embalmed, and no vascular injection techniques were used to enhance arterial visualization.

Procedures

Cadavers were positioned on the dissection table with the hand fixed in the supine position. Initially, a midline incision was made along the palmar surface starting from the distal palmar crease, extending to the transverse carpal ligament. A second incision was made on the palmar surface of each digit.

Subsequently, a transverse incision was made along the base of the digits. The skin was carefully reflected and removed using a number 20 and 22 blade, straight iris scissors, and forceps to expose the palmar aponeurosis. The palmar aponeurosis was lifted and separated from the underlying neurovascular structures. After the palmar aponeurosis was removed, the SPA was exposed. Before continuing dissection, the branches of the common palmar artery associated with the MN were identified. Dissection then proceeded toward the phalanges to properly separate these branches. Fasciae covering the abductor and flexor digiti minimi muscles were removed. Residual palmar aponeurosis and adipose tissue were dissected and removed to improve visibility of the underlying structures.

To accurately classify the SPA and determine its origin, continuity, and completeness, it was necessary to trace the contributing arteries proximally into the forearm. An incision was made along the forearm starting from the wrist, extending to the cubital fossa. Skin was reflected and removed to expose the neurovascular structures and anterior forearm muscles. Once the adipose tissue was removed from the forearm and wrist, the UA and ulnar nerve (UN) were exposed, including the flexor retinaculum. The flexor retinaculum was retracted to expose the MN deep to the flexor digitorum superficialis and within the carpel tunnel. Connective tissue sheaths were removed from the MN and the flexor digitorum superficialis. Muscles of the thenar group and recurrent branch of MN were identified. The abductor pollicis brevis muscle was retracted from the flexor pollicis brevis to identify the opponens pollicis muscle. Once all structures in the hand were exposed, the SPA, UA, UN, and MN were cleared of any loose connective tissue.

Following dissection, the SPA of each cadaver was evaluated according to the Coleman and Anson classification system, which categorizes arches as complete or incomplete based on anastomotic patterns between the UA and RA. Each arch was assessed for continuity, arterial contributions, and branching pattern to determine its classification, and observed variations were recorded to ensure standardized identification. This approach allowed consistent categorization across cadavers and facilitated comparison with previously reported anatomical patterns.

RESULTS

Morphological variation of the SPA was observed during dissection of ten cadavers. Variation was also noted between the right and left hands of individual cadavers, and differences in SPA patterns were apparent across different cadavers. A wide spectrum of complete and incomplete configurations was observed, underscoring the heterogeneity of superficial palmar arterial anatomy. Among our findings, only one hand demonstrated the classic radial–ulnar anastomotic configuration. On the right hand of M1, the classical radial–ulnar arch was present, formed by the superficial palmar branch of the well-developed RA and UA. This configuration represents the typical Type 1 complete arch in which both arteries contribute to the superficial palmar circulation. From this arch, branches arose and bifurcated to supply the digits, serving as a reference pattern for comparison with less common configurations (Figure 1).

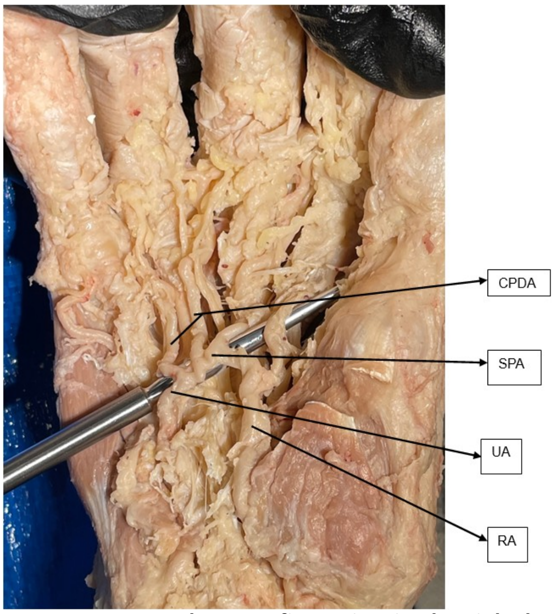

Fig. 1: Type 1 complete configuration in the right hand of M1. The superficial palmar branch of the RA anastomoses with the UA forming a well-defined arch across the palm. Abbreviations: UA, ulnar artery; RA, radial artery; CPDA, common palmar digital artery; SPA, superficial palmar arch.

A more complex and uncommon arrangement was observed in the left hand of M1. In this corpse, the superficial palmar circulation arose predominantly from a dominant ulnar-derived vessel that supplied multiple digital branches, including branches to the medial and lateral aspects of the fourth digit and the lateral aspect of the third digit. Distally, the vessel terminated as a small bifurcation coursing deep toward the second digit, where communication with a deeper arterial branch was suspected. Although the course and depth of this terminal branch raise the possibility of contribution from the MA, definitive identification could not be established without further exploration of the deep palmar plane. Consequently, this configuration did not conform precisely to a defined Coleman and Anson classification, but most closely resembled a mirror-image variant of the rare Type 2 complete arch. Unlike a true Type 2 pattern, however, the RA was observed to traverse the anatomical snuffbox without contributing to the formation of the SPA, which was supplied predominantly by the UA (Figure 2).

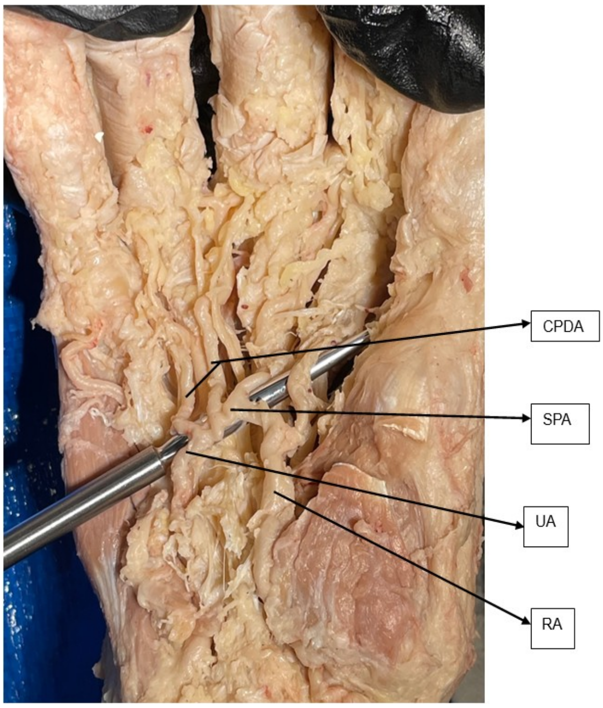

Fig. 2: Atypical SPA resembling Type 2 configuration in left hand of M1. The UA supplies multiple digital branches, while the RA courses through the anatomical snuffbox without contributing to the SPA. Abbreviations: UA, ulnar artery; RA, radial artery; CPDA, common palmar digital artery; SU, superficial palmar branch of ulnar artery.

In the right hand of F2, the SPA demonstrated a complete configuration in which the UA formed the primary transverse arch, with completion provided by a radial-derived contribution entering the palm between the heads of the first dorsal interosseous muscle and anastomosing with the terminal portion of the UA. This anastomosis resulted in a continuous arterial loop across the palm, consistent with a Type 1 complete arch (Figure 3).

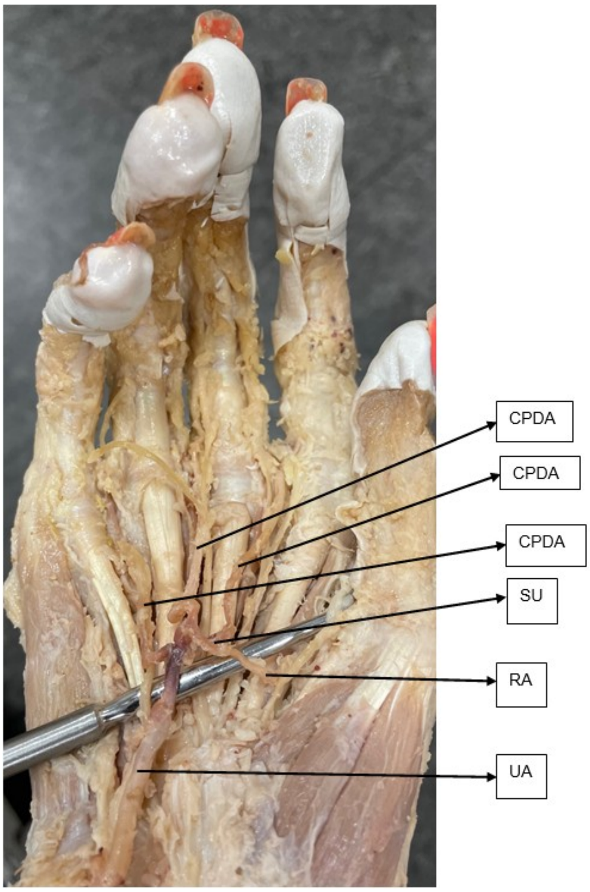

Fig. 3. Type 1 complete configuration in the right hand of F2. A radial-derived vessel enters the palm and anastomoses with the terminal portion of the UA, completing a continuous arterial loop.
Abbreviations: UA, ulnar artery; RA, radial artery; CPDA, common palmar digital artery; SU, superficial palmar branch of ulnar artery.

Several specimens demonstrated incomplete arches characterized by ulnar dominance and absence of a transverse anastomosis. In the right hand of F1, reflection of the palmar tissues revealed a SPA formed exclusively by the UA. The UA gave rise to three common palmar digital branches supplying the third and fourth digits and the medial aspect of the fifth digit, as well as a proper palmar digital artery to the medial side of the fifth digit. No anastomotic contribution from the radial or median arteries was identified, consistent with a Type 1 incomplete arch (Figure 4).

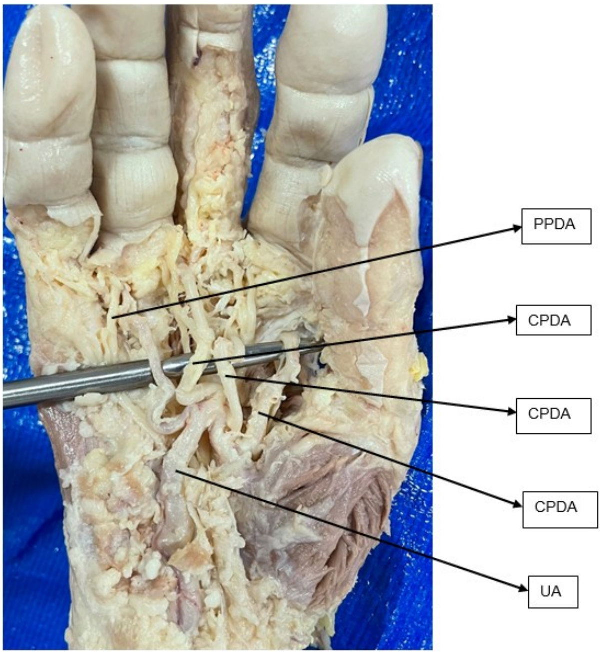

Fig. 4: Type 1 incomplete configuration in the right hand of F1. The UA forms the SPA and gives rise to three common palmar digital branches and a proper palmar digital artery to the medial side of the fifth digit, with no contribution from the RA.

Abbreviations: UA, ulnar artery; RA, radial artery; CPDA, common palmar digital artery; SPA, superficial palmar arch; PPDA, proper palmar digital artery.

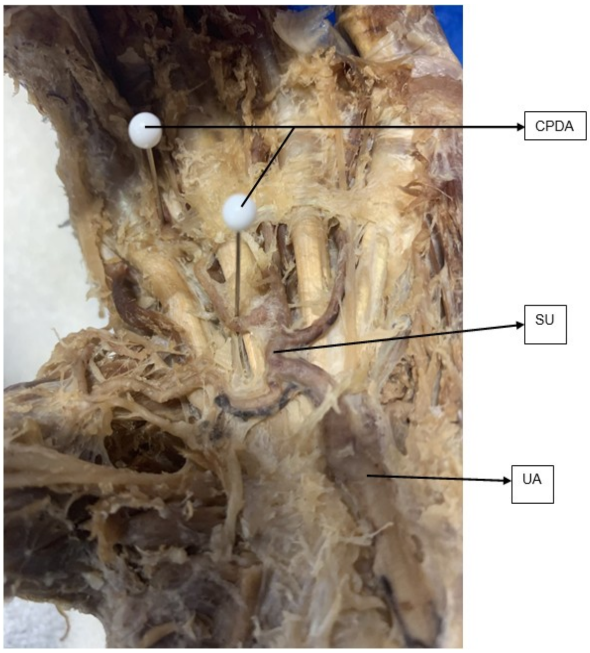

Fig. 5: Type 1 incomplete configuration in the left hand of F5. The SPA is formed exclusively by the UA without radial contribution or transverse anastomosis. White pins indicate common palmar digital arteries CPDA arising from the ulnar-derived trunk.

Abbreviations: UA, ulnar artery; SU, superficial palmar branch of ulnar artery; CPDA, common palmar digital artery.

In the left hand of F5, the SPA was formed exclusively by the UA, which coursed transversely across the palm and gave rise to the common palmar digital arteries without contribution from a superficial palmar branch of the RA. The absence of a transverse anastomosis resulted in a unilateral ulnar pattern of superficial palmar circulation, consistent with a Type 1 incomplete arch (Figure 5).

A similar incomplete configuration was observed in the left hand of M5. In this specimen, the UA formed the SPA and supplied three common palmar digital arteries, which subsequently bifurcated into proper digital branches. No radial or median arterial contribution was identified, and no anastomotic connection was present. The arch lay superficial to the flexor tendons and followed a typical transverse course across the distal palm, confirming a Type 1 incomplete ulnar-derived configuration (Figure 6).

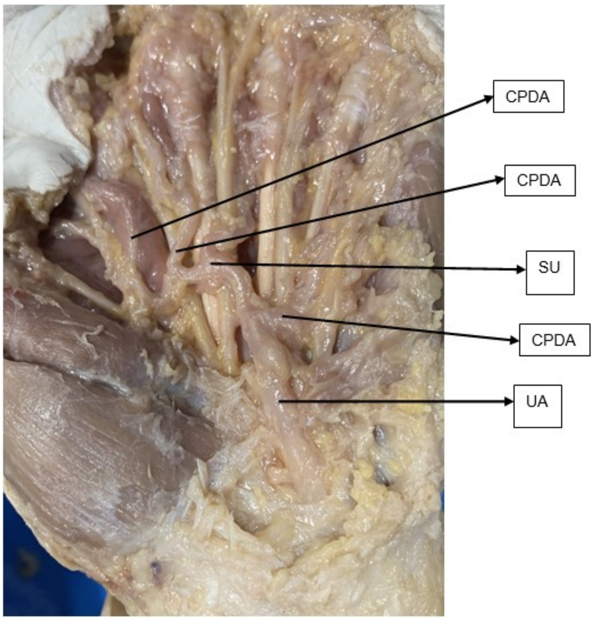

Fig. 6: Type 1 incomplete configuration in the left hand of M5. The UA forms the superficial palmar system and gives rise to the common palmar digital arteries without formation of a continuous arterial loop.

Abbreviations: UA, ulnar artery; SU, superficial palmar branch of ulnar artery; CPDA, common palmar digital artery.

DISCUSSION

Traditional hand performance is rated on the dexterity of thumb and finger movements. Movement is heavily dependent on the number of muscles intersecting a particular digit. The distal branch of the superficial arch should have a higher rate of perfusion or a larger arterial diameter due to dual vasculature and its increased mobility and muscle involvement in moving the index finger. The index finger is attached to an extra-extensor muscle, which requires additional vascular support from digital arteries such as those stemming from the superficial arch. Mobility of the index fingers results from the action of several muscles: extensor indicis, extensor digitorum communis, flexor digitorum profundus, flexor digitorum superficialis, the first lumbrical, and the interossei muscles. As a result of these muscle attachments, the index finger (second digit) requires greater oxygen perfusion and is richly supplied with vasculature.

One may ask how this is relevant to the perfusion of other digits in the hand or what best practice exist to ensure maximal perfusion following surgical intervention or when the SPA becomes the arterial graft site. Updated classification of the SPA depends on the continuity of the anastomosis circle within the deep arch, as it is considered more surgically reliable [19]. Notably, upwards of 59% of arches are ulnar type, with minimal or absent contribution from the RA [1,3]. Due to favorable anastomosis between the contributing vessels, the arches offer a high beneficial collateral supply to the hand. In the absence of vascular disease, the RA can therefore be safely harvested for graft surgeries. A common example is coronary bypass surgery, where the UA's collateral supply prevents ischemic changes in the hand post-harvesting [17,18,20].

Although these anastomoses are common, preoperative assessment of collateral circulation may be considered in selected hand procedures, as anatomical continuity does not always correspond to functional perfusion [17]. Current protocol is based on collateral perfusion from the MA, but this is not always reliable, as the MA typically regresses in the second month of intrauterine life. If the MA does not regress, there will be variation from early vasculogenesis when the anterior interosseous artery becomes the MA. The resulting MA will present in two different patterns: palmar type (reaches the palm) and the antebrachial type (ends in the forearm) [18]. The palmar type of the MA traverses the carpal tunnel alongside the MN and has been reported as a rare anatomical variant that may be encountered in association with carpal tunnel syndrome [21]. Surgical intervention for carpal tunnel syndrome is well established [22] and is not further discussed in this case study.

We focused our analysis on the superficial palmar site. The index branch of the SPA was consistently identifiable, potentially reflecting its anatomical relationship with muscle attachments and the functional dynamics of the digits. Future studies could examine our findings in a clinical setting, evaluating methods to improve preoperative visualization of vascular variation, potentially using adjuvant arteriography to identify hidden arterial connections. Such visualization may support more precise surgical handling of the SPA. Steve et al. [20] demonstrated that a novel reconstruction utilizing the subscapular arterial system to reconstruct arterial vasculature, such as the SPA, demonstrated a promising arterial interposition graft, offering an optimal branching pattern along with generous graph length and perfusion. The application of arterial grafts from the SPA are vast. Even with a small sample size, we observed dynamic variation between the SPAs in our cadavers. We believe this indicates that vascularity and perfusion differences among patients may be even greater than the current ratios reported in the literature.

Strengths of this study include the use of the Coleman and Anson classification system to categorize SPA variations, bilateral comparison of cadaveric hands, and documentation of both common and rare anatomical patterns. By linking these observations directly to clinical contexts such as grafting and reconstructive procedures, this work underscores the importance of individualized vascular assessment in surgical planning. Although this study has notable strengths, there were also several limitations. The small sample size of ten cadavers restricts the generalizability of our findings. All donors were elderly, which may have introduced age-related vascular changes not representative of younger populations. Functional perfusion assessments, such as dye injection or angiography, were not performed, and the deep palmar arch was not consistently examined in all cases, limiting our ability to fully map collateral circulation. Future research should include larger and more diverse samples, integrate functional imaging, and evaluate both superficial and deep palmar arches to provide a more comprehensive understanding of vascular variation in the hand.

CONCLUSION

This study demonstrates substantial variability in the morphology of the SPA. Differences were observed both between specimens and between the right and left hands of individual cadavers, indicating that SPA anatomy is highly variable and not reliably predictable. While many configurations could be described using the Coleman and Anson classification system, some patterns did not conform clearly to defined categories. These findings emphasize the importance of careful anatomical assessment of the superficial palmar system during surgical and interventional procedures involving the hand.

ABBREVIATIONS

MA: Median Artery
MN: Median Nerve
RA: Radial Artery
RN: Radial Nerve
SPA: Superficial Palmar Arch
UA: Ulnar Artery
UN: Ulnar Nerve

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Author Contributions

George N. Diamantis was involved in cadaveric dissection, identification of anatomical anomalies, image acquisition, data analysis, and manuscript writing and editing. Dr. Ali A. Abdulrahman served as the principal investigator, was involved in study conception and conduct, assisted with manuscript writing, supervised the study, and approved the final version of the manuscript.

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