Experimental Studies

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Upper Limb Structural Anatomic Mechanisms of Protection (SAMPs)

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Abstract

Introduction Nature has provided living bodies with extraordinarily effective reparative mechanisms. Furthermore, the biological processes involved in anatomical structures are designed to protect life against external injuries. A series of these protective systems in the upper limb are herein described. *Material and Methods* From 2009 to 2017, 864 fresh frozen cadaveric upper limbs were dissected from the axilla to the fingers during the Italian Hand Society surgical anatomy dissection course. *Results* Arrangement of anatomical structures in the upper limb is able to protect major life supporting organs. *Conclusions* External injuries affecting the upper limb may cause damage to many important structures resulting in severe functional impairments. The layout of the structures and the relationship between them are organized to preserve life at any functional cost.

Keywords: protection mechanisms, upper limb, anatomy, injury

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Introduction

The human body is an efficient machine, capable of spontaneous repair and wear resistance more than any other existing system. Indeed, regenerative mechanisms are continuously active on our DNA and tissues (Talaoui *et al*. 2016). The preservation of our organism is pursued not only by regeneration but also by preservation of the most important anatomical structures. Collateral circles and the presence of different structures performing the same function are examples of this concept.

A trauma is defined "complex" when at least three main anatomical structures are involved (muscle, bone, nerve, vessel). The goal of surgery is to guarantee appropriate vascularization to preserve vitality of the upper limbs (De Francesco 2020). Upper limb trauma is a frequent injury especially for manual workers who are commonly prone to accidents involving specific working tools i.e. saws that produce deep wounds with a cut-laceration trauma mechanism. On arrival in the emergency room, the patient will present with damage to the musculocutaneous and neurovascular structure and occasional cases of intactness of the vascular bundle albeit laceration of the nerve.

In the last eight years, an accurate study of the upper limb anatomy has revealed the presence of structural anatomical protection mechanisms, intrinsic to the disposition of anatomical structures. We defined them Structural Anatomic Mechanisms of Protection (SAMPs). The existence of these mechanisms provides important cultural implications as well as crucial clinical and surgical perspectives.

1. Background

From 2009 to 2017, during the Anatomic Dissection Course of the Italian Society for Surgery of the Hand (SICM, Società Italiana Chirurgia della Mano), 864 upper limbs were dissected. During the courses, anatomy lessons were associated to clinical evaluations and surgical technical demonstrations. The accurate study of the upper limb showed peculiar disposition features, which may be described as intrinsic protection systems of the upper limb due to their specific exposure to trauma compared to other systems. Self-protection of the head and thorax using the upper limbs is an instinctive reaction to unexpected incidents, which renders specific limbs vulnerable and mostly exposed to trauma. The specific disposition of nerves, vessels, and tendons, thus plays an important role to ensure vitality of these limbs.

Upper limb anatomical structures were examined from the axilla to the hand and accurate dissection was performed in compliance with objectives of the anatomic dissection course and reciprocal relations.

1.1. The Hypothesis

We were able to expose several SAMPs, which we hereby describe as progressing from proximal to distal.

1) The Brachial Plexus – This is a network of nerves beginning in the upper limb, generally represented in textbooks as a flat "M" shaped structure but is substantially cylindrical (Zhong 2017). Primary trunks, which are the proximal components of the plexus, occupy the supraclavicular fossa between the anterior and middle scalene muscles, lying posteriorly to the subclavian artery. These muscles run between the inferior border of the clavicle and superior border of the first rib towards the axilla, sending forth the anterior and posterior divisions, which anastomose to form the Cords (or secondary trunks). These Cords are known as Posterior, Lateral and Medial, in relation to the axillary artery location and represent the distal components of the plexus. The posterior cord arises from the union of the three posterior divisions; the lateral cord emerges from the union of the anterior divisions of the superior and middle trunks; the medial cord is basically the continuation of the anterior divisions of the inferior trunk. Bulky muscles surround and envelop the cords: the Pectoralis Minor muscle and the corresponding clavipectoral fascia enclose the cords anteriorly, the Subscapularis muscle posteriorly, the Teres Major proximally, and Latissimus Dorsi tendons distally. This disposition allows for protection of the Axillary artery, which is surrounded by the plexus and a thick resistant fibrous structure or fibrous tissue called Brachialis Plexus Fascia (Franco 2008) and represents a supplementary protective barrier for the principal vascular structure of the upper limb (Figure 1). In case of direct trauma to the arm, the artery is protected by specific structures, first and foremost by the brachial bulky muscles and subsequently by the brachial plexus sheath which are both considered important but not essential for life. The expendability of nervous structures to protect vascular structures is found throughout the upper limb, on condition that an artery is more superficial and exposed to external events.

2) The Median Nerve – This nerve is found at the antecubital fossa, in juxtaposition and acts as a shield for the Brachial artery, in the most superficial area (Figure 2). Moreover, to guarantee the blood supply to the forearm in case of trauma or throughout the range of motion of the elbow, the Brachial artery gives off collateral branches, which constitute, together with the recurrent branches of the Ulnar and Radial artery, an anastomotic circle. Since the antecubital fossa is an exposed area, with only skin coverage containing major vascular bundles for forearm vascularization on the upper limb, we are able to understand the quantity of anatomical variations involved in this area (Shyamala 2013; Kusztal 2014; Cherukupalli 2007; Klimek-Piotrowska 2013)

3) At the wrist level, the ulnar artery is medial to the ulnar nerve and both represent an alternative anatomical protective mechanism, running under the flexor carpi ulnaris muscle. To reinforce the

importance of the ulnar artery and nerve, flexor carpi ulnaris possesses a long muscle ending in the hand that covers and protects both structures (Figure 3).

4) Deep Palmar Arch – The presence of a complete Superficial Palmar Arch was reported by different authors, with a percentage varying from 78,5% to 84,4% (Gellman 2001). The existence of a Deep Palmar Arch, less exposed to traumatic events, represents a SAMP. The superficial palmar arch is based mainly on the contribution of the ulnar artery in 66% of cases (Joshi 2014). These data justify the presence of multiple protection mechanisms for this artery (Figure 4).

5) Digital Collateral Nerves – A similar disposition previously described is also encountered distally in the fingers. Indeed, the digital collateral nerves run more externally and superficially than the digital collateral arteries. On examination of the radial digital bundle, we observed that the digital nerve is more radially positioned compared to the artery. Conversely, the ulnar digital pedicle nerve has a greater ulnar deviation compared to the artery (Figure 5).

6) Collateral Digital Arteries – A common observation during surgery is the difference in calibre of the ulnar and radial collateral digital arteries of the finger. As demonstrated by Leslie (1987) in both arteriograms and cadaver specimens, the dominant vessel in the index and long finger is the ulnar digital artery, differing mainly in the long finger, while in the ring and small finger, it is the radial digital artery. A SAMP is thereby indicated by the main blood supplying vessel of the finger which is protected by the other fingers from traumatic events. The external side of the fingers is, undoubtedly exposed to injury.

7) Flexor Tendons – The hand is the most traumatised part of the upper limb. The two flexor tendons in each long finger represent functionality but also play a role in protecting and preserving flexion in case of tendon injury. The two tendons run into a complex structure of pulleys that not only favour the flexion, but also contribute to envelop and protect the tendons. Moreover, the specific relationship between the superficialis and profundus flexor tendons represents a SAMP in itself. The deep flexor tendon passes through the fibers of the superficialis in the Camper's Chiasm, which is located in the area where the forces are stronger due to the strength grip, between the metacarpal head and the PIP. Accordingly, the deep flexor tendon, an integral part of finger flexion, is enveloped and protected by the superficialis where the risk of injury is higher. Camper's Chiasm may be considered not only as a mechanism pumping synovial fluid through the flexor tendons sheath but also as a protective system.

8) Extensor Digiti Indicis (EDI) and Digiti Minimi (EDM) – In the dorsal part of the fingers, the extensor tendons are extremely superficial. The presence of an appropriate extensor tendon for the second and fifth finger, along with the Extensor Digitorum Comunis (EDC) tendons for all the long fingers, represents a SAMP preventing the loss of the pincer grip, even in cases of EDC lesions.

9) Extensor Pollicis Brevis (EPB) – A SAMP in the thumb was observed by the concomitance of the Extensor Pollicis Longus (EPL) tendon running into its own third compartment in the extensor retinaculum, separately from the more expendable EPB, running in the first canal together with the Abductor Pollicis Longus (APL). In this canal, an inconstant septum may be in a seen in a variable percentage. (Lee, 2017).

1.2. Evaluation of the Hypothesis

The anatomical structures in the upper limb follow a specific scheme with the purpose to protect the most important elements for viability and function of the limb. Herein, a teleological interpretation of anatomy is not intended but rather the findings of an evolutionary prerogative. As Monod (1998) clearly states in his essay *Chance and Necessity*, a fortuitous and useful evolutionary event may be attributed to a specific structural change in the body.

We can divide the SAMPs into two categories:

1) Protection of limb viability: the axillary artery is protected by the brachial plexus, the brachial artery is protected by the median nerve, the ulnar artery is protected by the ulnar nerve. Moreover the superficial and deep palmar arches are evident, and the collateral digital arteries are protected by the collateral nerve and with a larger calibre and a high frequency of trauma occurrences concerning the lateral aspect of the finger.

2) Protection of limb function: two flexor tendons are evident for each finger and two extensor tendons for the thumb, index, and small fingers.

In the axilla, consistent connective tissue was observed, forming the bundle sheath, providing protection to the nerves and artery. These findings are consistent with Franco's analysis (2008), which described the fibrous structure as an expansion of the prevertebral fascia. On the contrary, Cornish (2008) suggested that such fibrous structured sheath may be the result of connective tissue coalescence in cadavers. The protective role of muscle and tendon tissue from nervous damage has been recently studied by Lee and colleagues (2016) who evaluated the protective role of Flexor Radialis Carpi (FCR), Palmaris Longus (PL) and Flexor Carpi Ulnaris (FCU) in wrist lesions, where the neurovascular bundles are most superficial, and which present a higher exposure to injury. The authors showed how FCR is protective to the radial artery in radial side lesions, PL in the median nerve in median side lesions and FCU for the ulnar nerve in ulnar side lesions. From the anatomical dissections, it is clear that the neurovascular bundle is positioned externally to the corresponding vessel, suggesting a non-incidental arrangement which provides protection to the vascular bundle.

It is noteworthy that we do not yet fully understood how specific nerves are guided to supply specific muscles (Al Qattan *et al*. 2009). In particular, blood vessels and nerve fibers are often closely arranged in parallel throughout the body. Therefore, neurovascular interactions may be important for the development of vascular networks. In view of these considerations, investigations have demonstrated that JunB is induced in endothelial cells by neuro-vascular interactions and regulates neurovascular juxta-positional alignments during embryonic vascular development (Yoshitomi *et al*. 2017). It is also worth mentioning that mesenchymal signals and mesenchymal extracellular matrix deposition represent fundamental cues that drive nerve and blood vessel elongation. Concomitantly, the mesenchyme provides differentiating information for myoblasts and connective cells. In the light of these observations, reciprocal induction of upper limb cellular players may occur during embryonic development, and that this molecular dialogue is accountable for the acquisition of their anatomical localization (Deries & Thorsteinsdottir 2016). Moreover, the protective roles of tendons or nerves in vascular injuries is an important aspect of upper limb traumatology with the brachial plexus exerting a significant protective barrier effect for the axillary artery in the axilla (Figures 6 and 7) while at the middle third of upper limb, the brachioradialis muscle and the flexor carpi ulnaris muscles provided a significant protective barrier respectively for the radial artery and ulnar artery (Figure 8). Finally, the digital collateral nerves offered a protective barrier for digital collateral arteries in the finger (Figure 9).

1.3. Consequences and Discussion

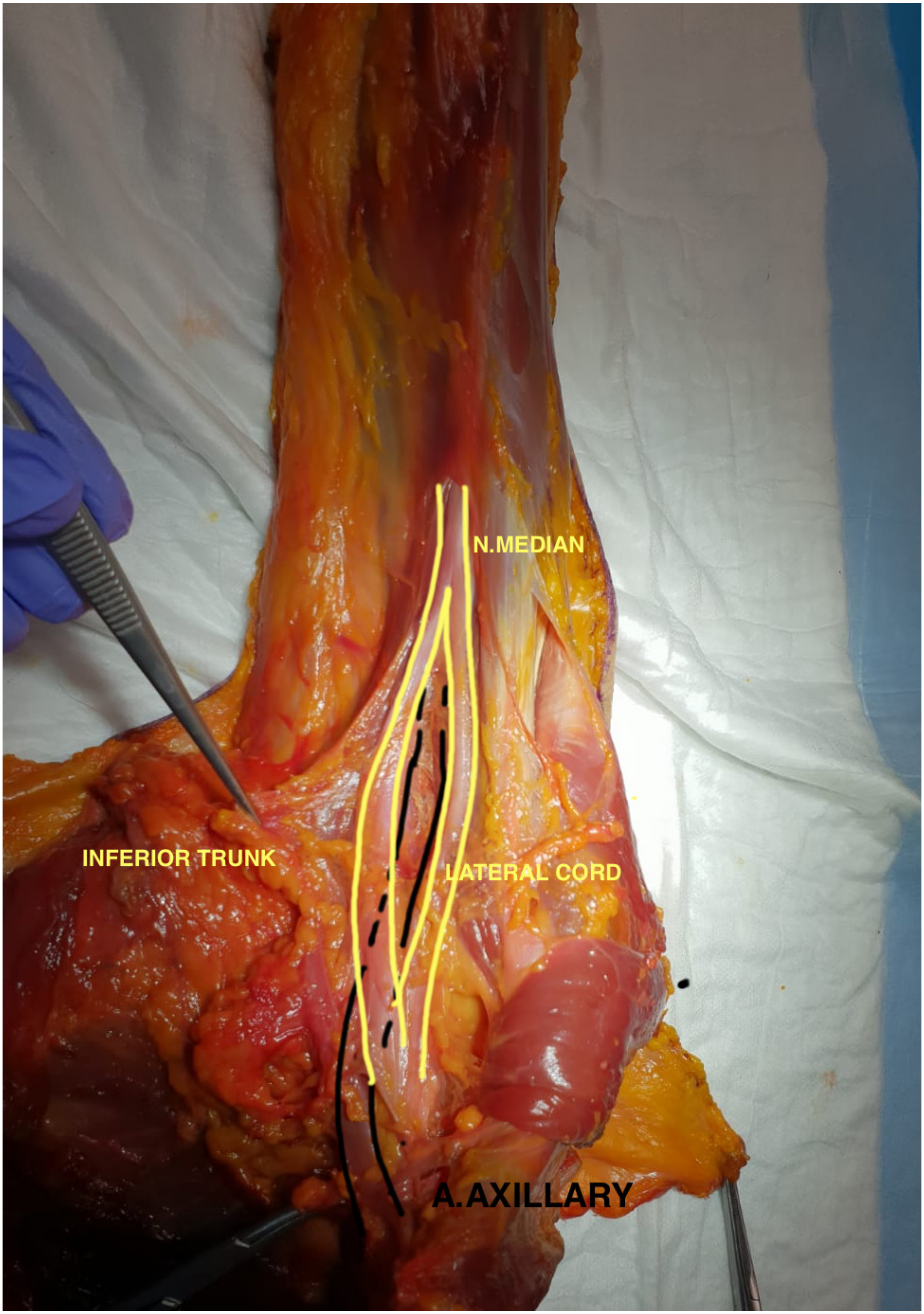
Adequate knowledge of anatomy is crucial to diagnosis and treatment. It is imperative for a surgeon to be well- trained in the dissection of normal anatomical structures to avoid the most common complications and to prevent errors, in consideration of the potential anatomical variations.

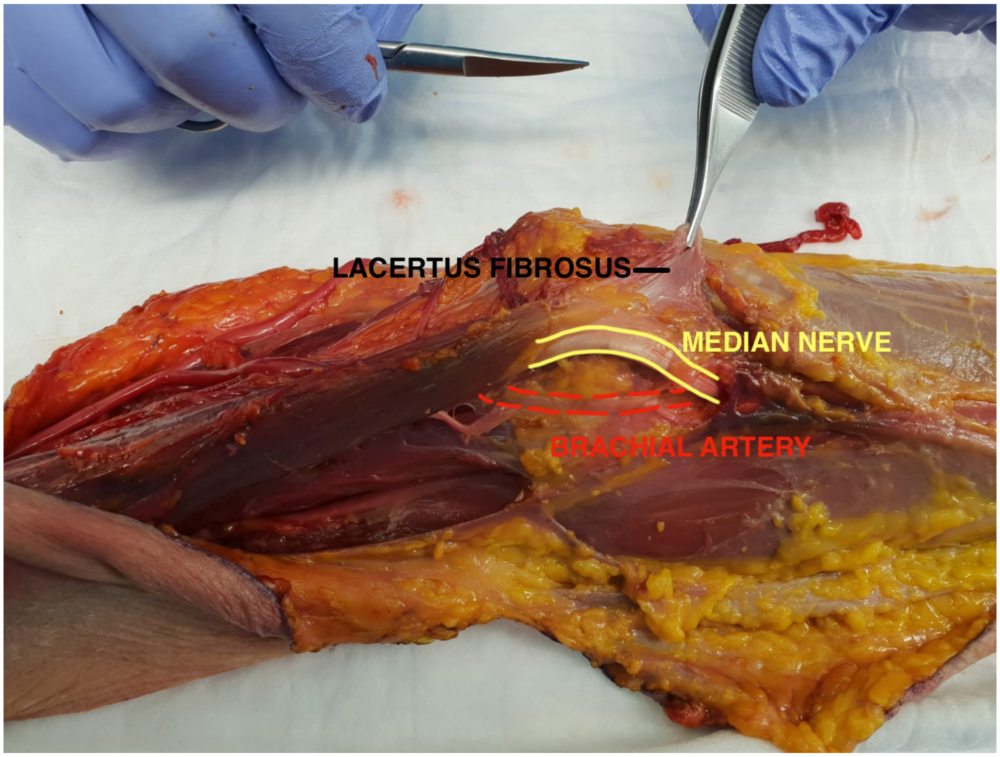
SAMPs are to be acknowledged for their importance in the diagnosis and surgical management of upper limb conditions. Every structure plays a role in the function of the entire limb and should be preserved or restored after surgery. The knowledge of the molecular dialogue among blood vessel, nerves, and muscles during limb patterning is still poor, but represents a theoretical foundation in the identification of mechanisms that assess the embryological origin of SAMPs.

"The only sure foundations of medicine are an intimate knowledge of the human body, and observation on the effects of medicinal substances on that." (Thomas Jefferson 1829).

3. Figures

Figure 1 (next page): The anatomical specimen showed that the Axillary artery was protected by the plexus (lateral cord and inferior trunk, which join to form the median nerve) and a thick resistant fibrous structure.


N.MEDIAN
INFERIOR TRUNK
LATERAL CORD
A.AXILLARY



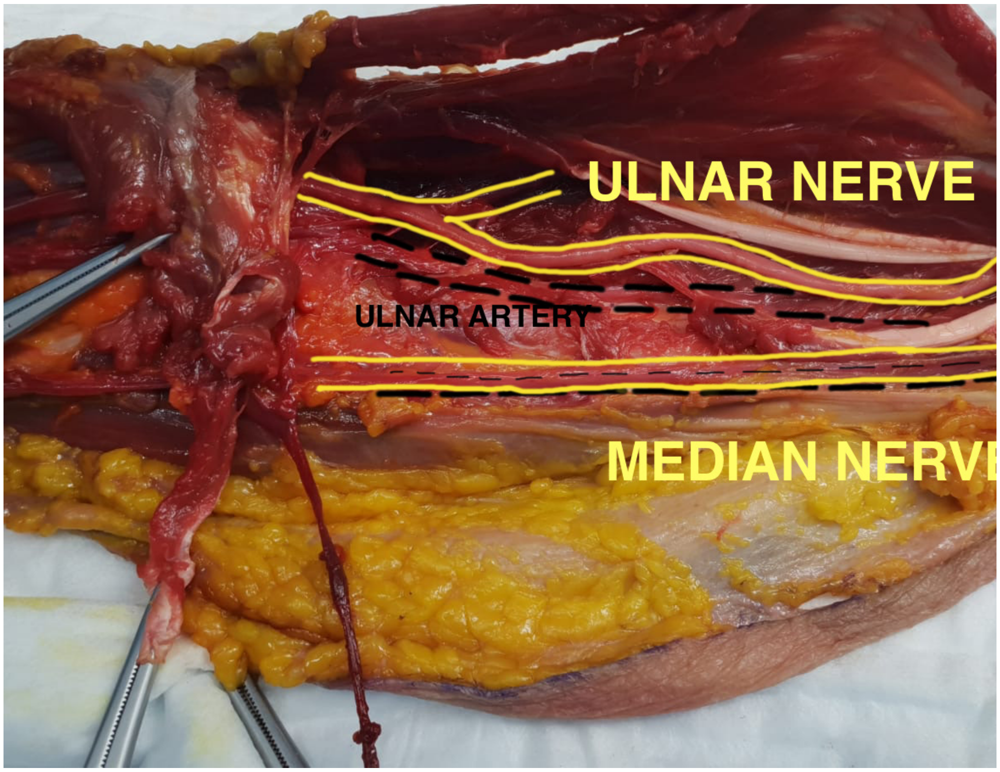


Figure 2 (above): The anatomical specimen showed that the brachial artery, in the forearm, was protected by the median nerve, which is located superiorly to it, the entire nervous vascular bundle is then covered by the fibrous lacer.

Figure 3 (below): The anatomical specimen showed that the ulnar artery, in the wrist, was protected by the ulnar nerve which is located superiorly to it, the entire nervous vascular bundle is then covered by the flexor carpi ulnaris.

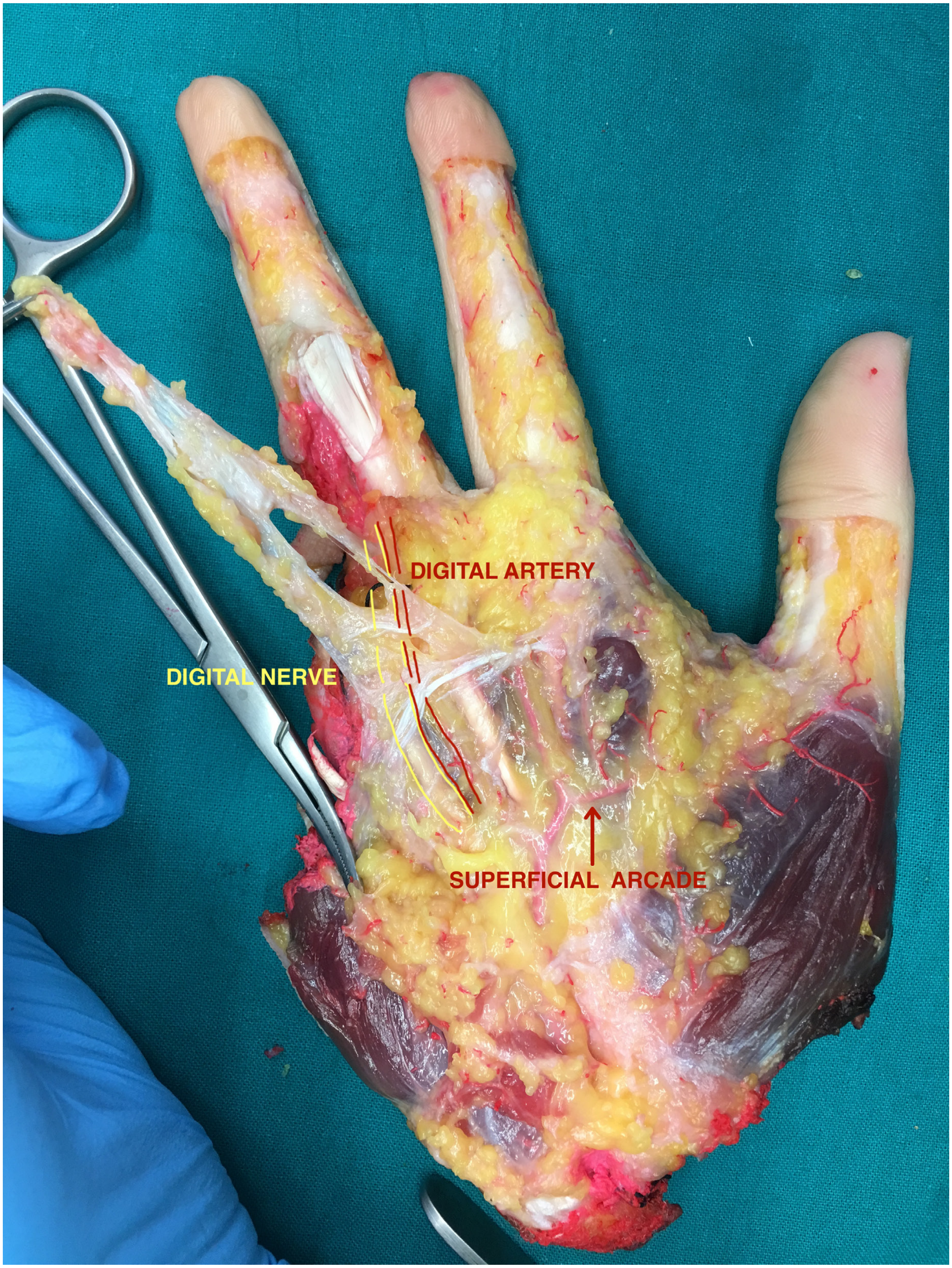


Figure 4: The anatomical specimen showed the superficial arch, in the palm, which protected the deep arch, and the digital collateral artery was protected by the digital collateral nerve.

Figure 5 (right): The anatomical specimen showed the system of connections between the two digital collateral arteries through the interphalangeal arches and the digital collateral nerve, which is located above the corresponding digital collateral artery.

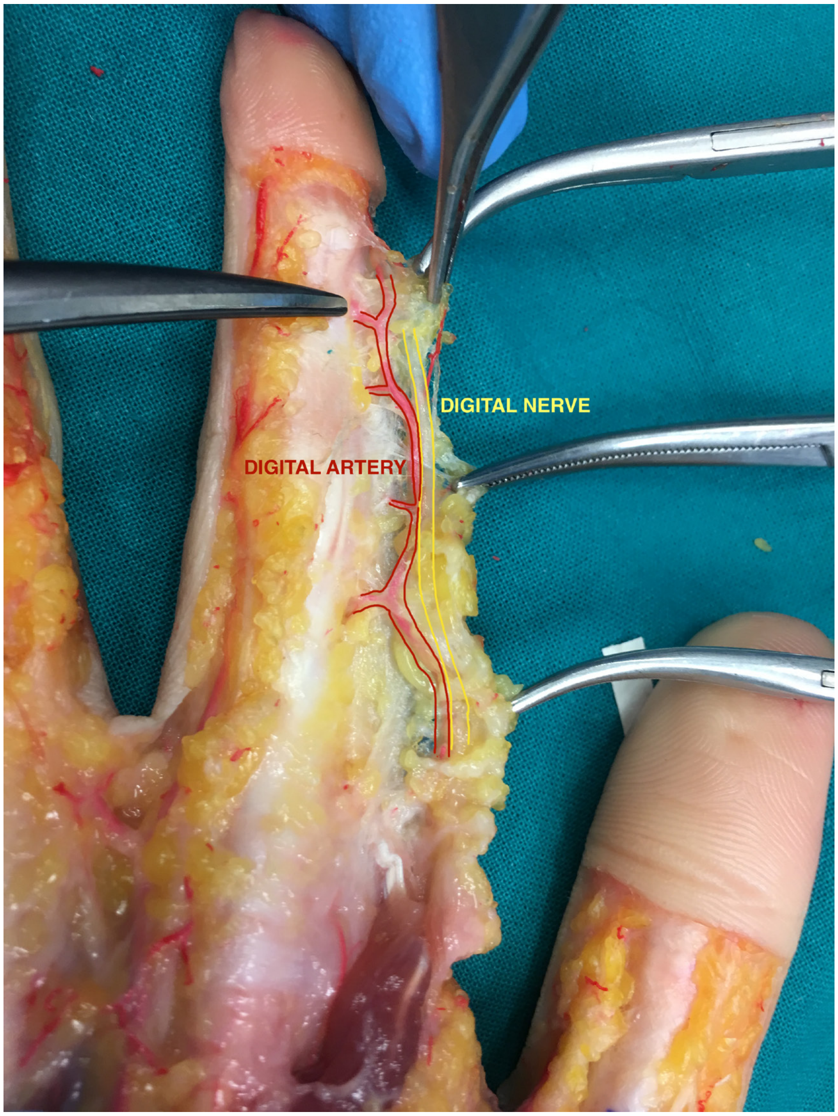
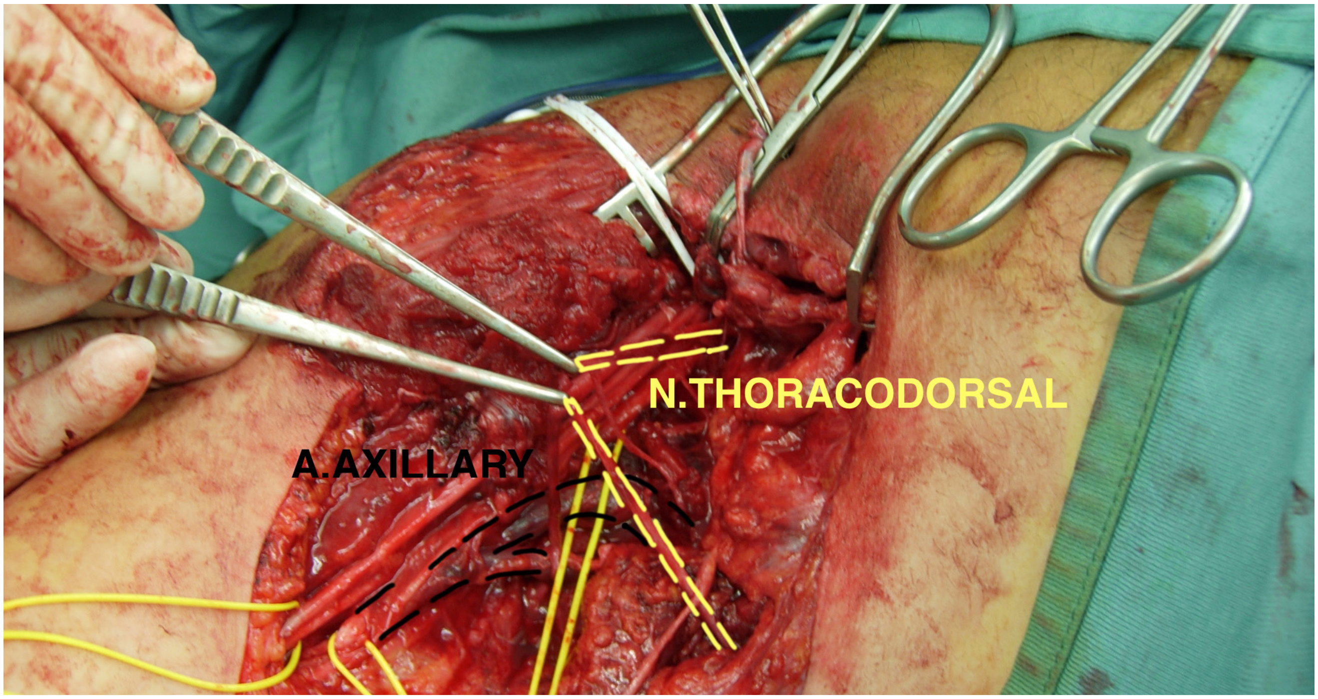


Figure 6 (below): Intraoperative image showing the position of the plexus above the axillary artery with injury to a branch of the brachial plexus (thoracodorsal nerve) and fibrous fascia.



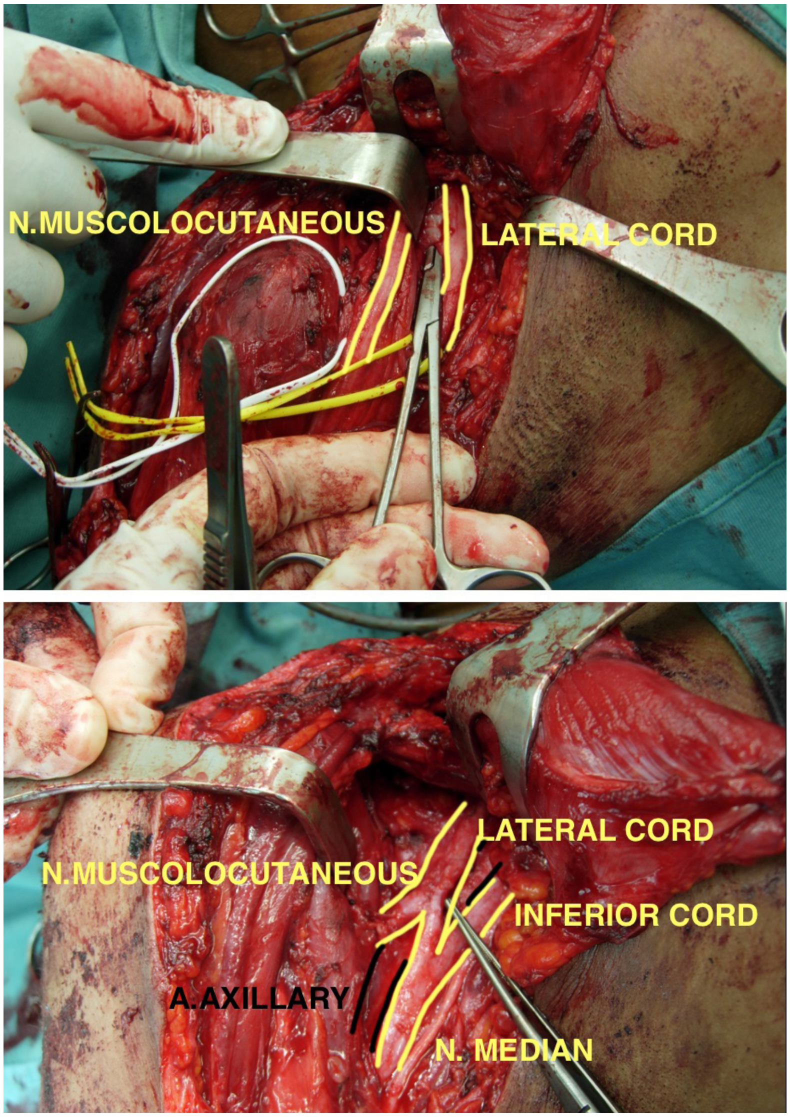
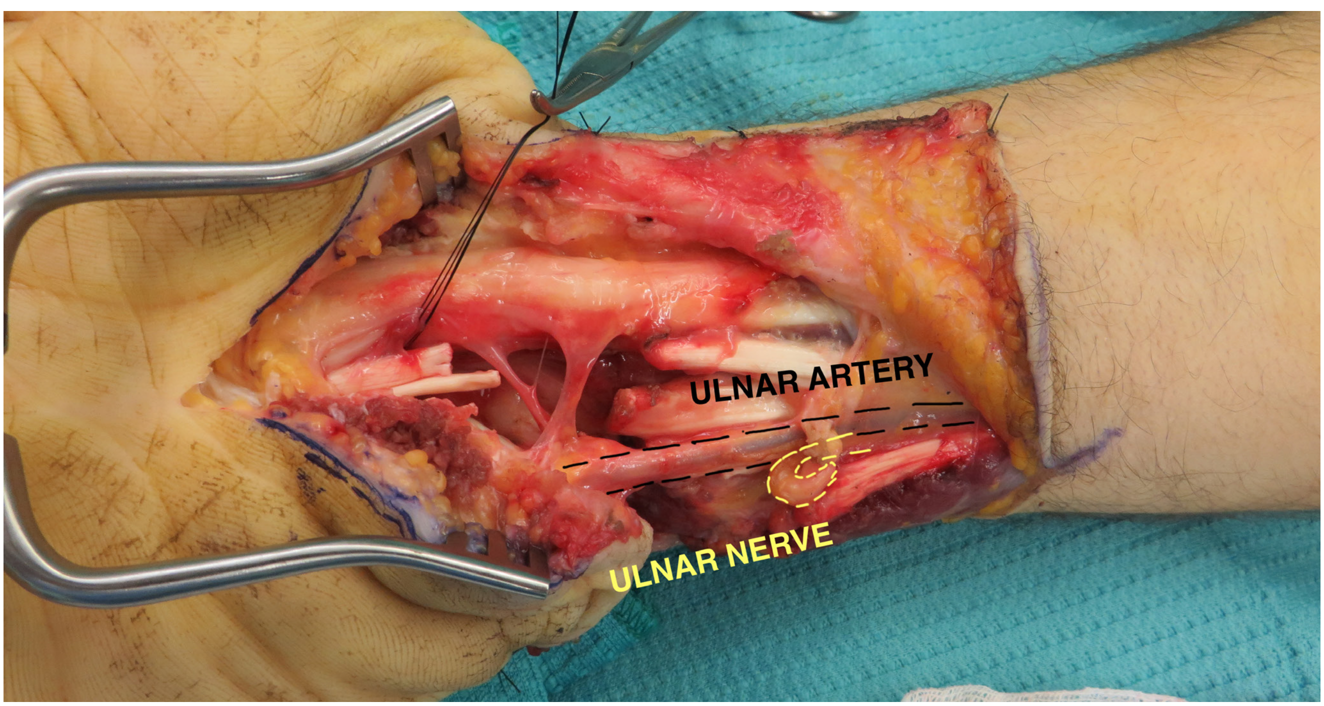


Figure 7 (left): Two intraoperative images showing the position of the plexus above the axillary artery with injury of a branch of the brachial plexus (lateral cord) and fibrous fascia.

Figure 8 (below): Intraoperative image of the wrist showing retrieval of the ulnar artery deeper than the injured ulnar nerve and the injured flexor carpi ulnaris and injured flexors digitorum profundus of the fourth and fifth finger.



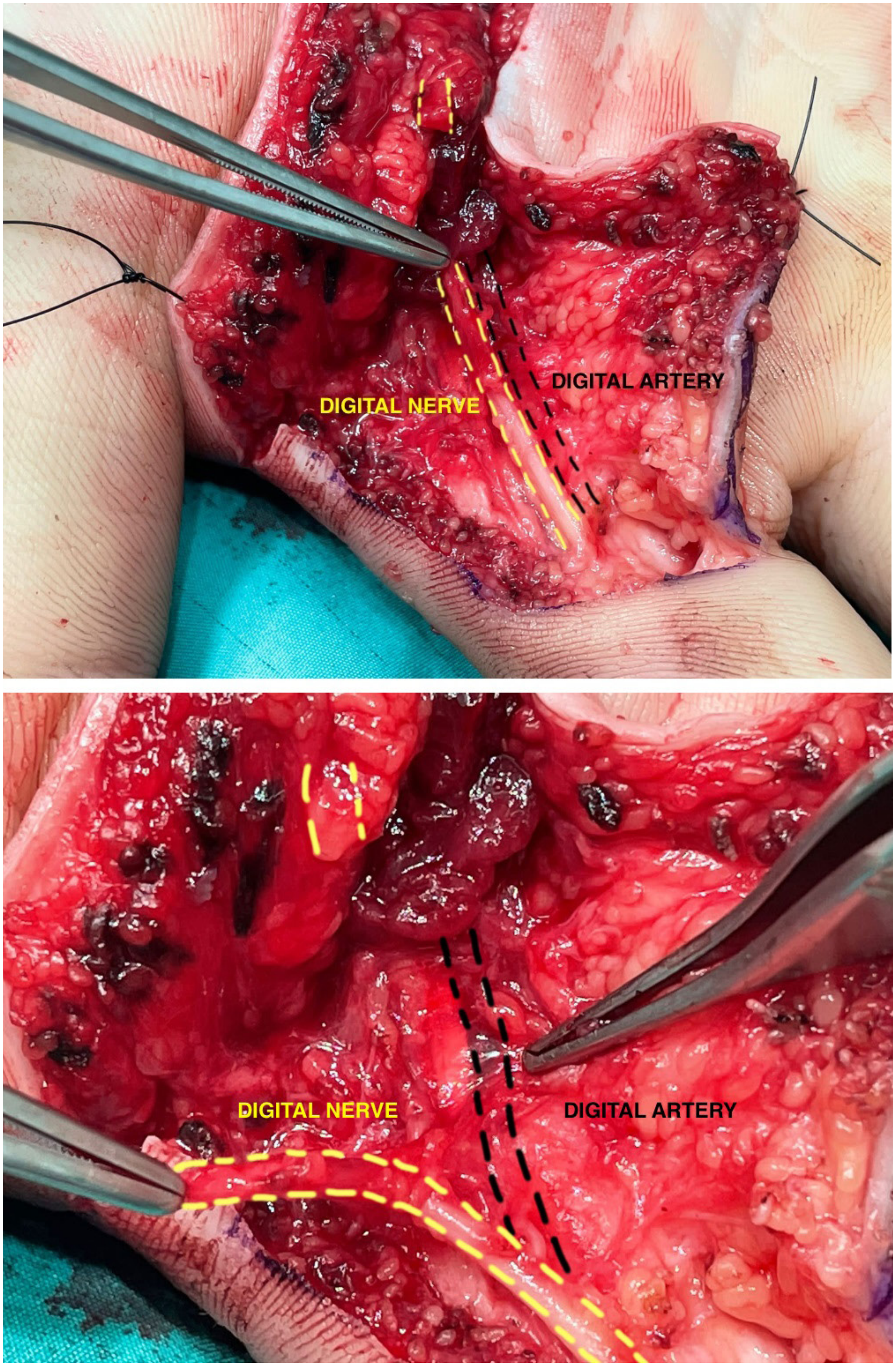


Figure 9: Intraoperative images of the finger showing the retrieval of the collateral digital artery deeper than the injured collateral digital nerve.

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Conflict of Interest

The authors declare no conflict of interest.

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