Anatomic Relationship Between the Radial Nerve and the Musculo-Fascial Structures of the Arm and Forearm: A Cadaveric and Sonographic Study

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Research article

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Abstract

Background: Radial nerve (RN) compression most commonly occurs at the level of the supinator arch (SA), also called arcade of Fröhse, but other sites of entrapment along the course of the nerve are possible. This study aimed to perform an ultrasound and anatomical examination of these entrapment sites, to provide a solid anatomical base for the differential diagnosis of lateral arm pain, to allow a more precise manual therapy approach.

Methods: Nineteen fresh-frozen cadavers were examined, first on ultrasound then on anatomical dissection. Two points of possible RN entrapment were injected with dye under ultrasound guidance: where the RN crosses the lateral intermuscular septum (LIMS) and at the SA. Dissection confirmed the location of the dye at these points and allowed us to describe the relationship of the RN with the adjacent structures; the distances from each of these two points to the lateral epicondyle and the diameter of the RN were also measured.

Results: The dye was observed in the correct place in all specimens. We observed a close relationship of the RN with the lateral head of triceps brachialis (LHTB) muscle and the LIMS as it passed through these structures. In both structures, longitudinal aponeurotic extensions were observed. In the anterior compartment of the arm, where the RN glides between the brachialis (B) and brachioradialis (BR) muscles, we observed varying relationships between these three structures (5% had vascular unions, 79% had union of the epimysium, and 16% muscular unions). Finally, in the forearm, just before reaching the SA, we observed a septum that compartmentalize the forearm musculature and created an aponeurotic arch through which the motor branch of the RN passed.

Conclusions: Ultrasound study helps correctly identify the RN; the two points identified on US and dissection correlated well. The anatomical findings on the relationship of the RN with its surrounding structures may explain its entrapment.

1. Introduction

Nerve compression syndromes are a common cause of pain and have several possible causes. Due to the close anatomical relationship between arteries and nerves of the limbs, compression of a nerve may disrupt both the local blood flow and the axonal transport in the nerve. In addition, a drop in local blood pressure may reduce the blood supply to peripheral nerves and cause the recognizable dysesthesia, paresthesia, and occasional motor weakness that patients frequently report [1].

One of the most frequently injured nerves in the upper limb is the radial nerve (RN) in association with closed fractures [2]. The RN is the largest terminal branch of the posterior cord of the brachial plexus, innervating muscles in the posterior compartment of the arm and forearm as well as the skin. This nerve passes through the triangular interval and spirals obliquely across the posterior surface of the humerus to enter the anterior compartment after piercing the lateral intermuscular septum (LIMS) [3]. After passing between the brachialis (B) and brachioradialis (BR) muscles, the radial nerve divides into its superficial and deep branches at the antero-medial side of the lateral epicondyle [4].

The commonly known RN compression syndromes occur in the forearm [5, 6], and frequently at the supinator arch (SA), a musculo-aponeurotic furrow that extends from the lateral epicondyle of the humerus to the distal edge of the supinator muscle. At this point, the superficial head of the supinator muscle forms a fibrous arch [7], which is the most common site of compression of the RN motor branch [7, 8]. Many structures in the area surrounding the origin of the supinator are liable to have mechanical effects on the nerve [8]. Also, refractory lateral epicondylitis seems to cause the RN and common extensor tendons to swell, so some of the chronic symptoms of these patients might actually be due to RN entrapment [9].

Proximal anatomical compression sites have been also described. For example, a fibrous arch and accessory part of the lateral head of the triceps (LHTB) [10], the intermuscular septum region [11, 12], and the narrow space between the B and BR muscles [13] are areas where compression may occur. In some instances, symptoms are linked to muscular effort [14]. In addition, nerves must adapt to different positions by passive movement relative to the surrounding tissue: this is made possible by a gliding apparatus around the nerve trunk [15]. However, little attention has been paid to the biomechanical effects, such as nerve motion/gliding or stretching, that are associated with these movements and their possible contribution to the pathogenesis of peripheral radial neuropathies [16].

The main objective of this study was to study the RN on ultrasound and detailed anatomical examination, at points susceptible to compression due to its intimate relationship with myofascial or connective tissue. With these findings we aim to provide a solid anatomical basis for the differential diagnosis of lateral arm pain, allowing a more precise approach in manual therapy.

2. Materials And Methods

Specimens

This study included 19 cryopreserved upper limbs (9 right and 10 left) with no evident pathological findings (such as injury or previous surgery), from 19 cadavers (11 women and 8 men, aged 68–91 years old). Each specimen was identified with reference to laterality and age and sex of the donor. All participants voluntarily donated their bodies for teaching and research to the donor dissection room of the Faculty of Medicine and Health Sciences. The analysis involved two stages: an ultrasound (US) study followed by an anatomical study. Both were performed with the elbow in 90° flexion and in pronation.

2.1 Ultrasound study

US examination was performed by a professional with more than five years' experience in musculoskeletal US, using a General Electric Logiq P5, (medical systems, USA), with a high-frequency linear transducer (5–12 MHz).

In order to prove the accuracy of the ultrasound imaging and to correlate the findings with subsequent anatomical dissection, a series of high-resolution (HR) US-guided infiltrations were carried out. These infiltrations were performed using a 1-mL syringe and a 25-G needle to inject 0.01 to 0.05 mL of green or red dye adjacent to the nerves. The targeted points were where the RN pierces the LIMS and the SA (Table 1).

Table 1
Ultrasonographic (US) and anatomical (A) distances and the sites where RN diameter was measured

Distance label	Start point	End point	A	US
A	LE	Where RN pierces the LIMS	Yes	Yes
B	LE	SA	Yes	Yes
C	LIMS thickness at RN crossing point		Yes	No
D	RN Diameter at the entry of the LIMS		Yes	No
D´	RN Diameter at the exit of the LIMS		Yes	No
E	RN Diameter at 9 cm from LE (in the space between B and BR)		Yes	No
F	RN Diameter just before SA		Yes	No

Abbreviations: LE, lateral epicondyle; RN, radial nerve; LIMS, lateral intermuscular septum; SA, supinator arch; B, brachialis muscle; BR, brachioradialis muscle

The following US technique was used to locate the regions of interest: first, on a posterior approach of the arm, the probe was oriented on a short-axis view. The RN was located in the radial tunnel and then followed over its course. Marker dye was injected at the point where it crossed the LIMS of the arm. Subsequently, with the probe oriented on a short-axis view, the RN was followed distally to BR until it passed the elbow. The RN then divided into its two branches: motor and sensory. The motor branch was followed until it crossed the supinator muscle. At this point, we injected the second dye.

2.2. Anatomical study

Following ultrasound study, anatomical dissection of each specimen was performed. The skin of the upper limb was cut with a classical vertical line along the posterior side of the arm and extended distally and anteriorly toward the elbow. The skin and subcutaneous adipose tissue of the superficial fascia were removed in layers, exposing the deep brachial fascia and the LIMS. The RN was identified within the spiral groove at the elbow, and the surrounding tissues were studied in detail.

The dissection continued to the elbow. The tendons of the BR muscles, extensor carpi radialis longus and extensor carpi radialis brevis were located and identified from distal to proximal, exposing the lateral septum of the forearm and the SA. At this point the RN was visible on the anterior side of the elbow. The passage of the nerve through these two structures (lateral septum of the forearm and SA) was studied. The dissection also allowed us to check the agreement of the points where dye injection was located on ultrasound with the actual anatomical sites where the LIMS and SA are pierced by the RN. On both the ultrasound and anatomical studies, three consecutive measurements were taken at each of the sites studied and the arithmetic mean was calculated. During dissection, the distances were measured with a digital caliper, maintaining the elbow flexed at 90º and the forearm in pronation. RN length distances were measured from the lateral epicondyle (as the reference landmark) to the point where the RN pierces the LIMS and to the point where the motor branch of the RN pierces the SA. In addition, the diameter of the RN was measured at the different levels as indicated in (Table 1).

2.3. Statistics

The mean values of three consecutive measurements for each parameter were considered as the individual data for each specimen. Data in tables 2 and 3 are presented as mean values ± 95% confidence interval. We analyzed the agreement between US and anatomical measurements by applying the Bland-Altman graphical method of difference plot. Pearson's correlation analysis was used to evaluate the potential correlation between the different parameters studied.

3. Results

The US study of the upper limb showed that it was possible to correctly locate the points at which the RN pierces the LIMS and the SA, as confirmed on subsequent dissection. In addition, the measurements obtained on US showed good agreement with those obtained on dissection (Table 2), showing non-significant differences between both methods and a high degree of agreement as reflected in the Bland-Altman graphical analysis (Fig. 1)

Table 2
Ultrasonographic (US) and anatomic (A) distances from the different landmarks and RN diameter at different levels

Distances or thickness (mm)	A	US
A	113.1 ± 5.8 (38.2)	105.0 ± 5.0 (38.8)
B	43.4 ± 4.1 (29.4)	42.1 ± 4.4 (29.8)
C	1.1 ± 0.1 (0.8)	
D	2.9 ± 0.2 (2.0)	
D´	2.8 ± 0.2 (1.4)	
E	2.8 ± 0.3 (2.7)	
F	2.0 ± 0.2 (1.7)	

Mean values ± 95% confidence interval. Range of measurements is indicated in parenthesis

3.1. Ultrasound study

The image of the RN, as an ovoid shape with a typical fascicular echotexture, was identified in the radial tunnel. It was easily identified on the short-axis view, when it crossed this tunnel, in contact with the humerus (Fig. 2). It was correctly identified in all cases, as confirmed on dissection by finding the dye at this point. The RN continued for 10.5 ± 0.8 cm until it pierced the LIMS and entered the anterior compartment of the arm. At this point, it was possible to see the origin of BR covering the RN. The nerve continued down between B and BR until arriving at the elbow. At the anterolateral side of the elbow, and deeply, the nerve divided in two branches. The superficial branch continued anteriorly under the BR. The deep or motor branch continued 4.2 ± 0.8 cm to the origin of the supinator muscle (Fig. 3). This point was also correctly identified on US exploration, as confirmed by the dye location after specimen dissection.

3.2. Anatomical study

We confirmed the correct identification of the RN in all cases (in 100% of cases the dye was located at the correct points).

Dissection showed that the RN crossed from the posterior compartment to the anterior compartment, maintaining a close relationship with the LHTB muscle. We observed that this muscle gave off a longitudinal aponeurosis parallel to the intermuscular septum, in 10 of the 19 specimens, in the form of a fibrous arch through which the RN passed before crossing the LIMS (Fig. 4). This aponeurosis of the LHTB muscle originated in the area of distal insertion of the posterior deltoid muscle and showed loss of continuity. This aponeurotic extension continued to where the RN passed through the LIMS.

Regarding the LIMS, it was anchored superiorly at the deltoid V and inferiorly at the lateral epicondyle (Fig. 5). In most of the specimens the LIMS split into two layers, containing the RN between them as it passed from the posterior to the anterior compartment. In all specimens, we observed that the LIMS gave off a longitudinal aponeurotic extension (more marked posteriorly and similar to the split of the longitudinal aponeurosis of the LHTB muscle) that gave rise to the origin of a large part of the arm musculature (Fig. 4).

The mean length of RN from its passage through the LIMS to the lateral epicondyle was 11.3 ± 1.1 cm. When the RN passed through the LIMS, the nerve was in contact with the bone (Table 2) and the mean thickness of the LIMS at this point was 1.1 ± 0.5 mm.

The diameter of the RN, before and after crossing the LIMS, was 2.9 mm at both points. The diameter of the RN just before it crossed the space between the B and BR muscles was 2.8 mm and just after passing through the SA shrunk to 2 mm.

In the anterior compartment of the arm, the RN glided through a space between the B and BR muscles. We observed different relationships between these three elements, until arriving at the lateral cubital fossa. In one specimen (5%), the two muscles had a vascular union coming from the deep brachial artery in the posterior part of the arm, that severely limited the passage of the RN. In most cases (79%) the epimysium of the B and BR muscles created points of union above the RN as if wrapping around it (creating a tunnel) (Fig. 6A). In some cases (16%) we even observed muscular insertions at these bridges, corresponding to the B and BR muscles (Fig. 6B). In this same space, we observed morphological changes in the RN cross-section, from circular to flat (37%) (Fig. 7). The same also happened at the SA (10%).

After the division of the RN into its sensory and motor branches at the lateral cubital fossa, we followed the motor branch. To do so, we accessed the arcade between the fascicles of the origin of the supinator muscle where we observed the lateral (aponeurotic) septum of the forearm. The septum compartmentalized the anterior and lateral musculature of the forearm and served also as a large part of the insertion of the extensor carpi radialis brevis muscle. At the proximal end of this septum, it formed an aponeurotic arch through which the motor branch of the RN passed before arriving at the SA and becoming posterior (Fig. 8). The mean distance from the SA to the lateral epicondyle was 4.4 ± 0.2 cm. We also observed differences between the arcades from the supinator muscle: in 1 of the 19 specimens there was a tendinous or fibrous arcade crossing from the muscle and in the other 18 there was a muscular or membranous arcade.

4. Discussion

Our findings support our hypothesis that the RN's sinuous pathway predisposes it to potential compression. This could be further exacerbated by the presence of other associated pathology or dysfunction of myofascial or connective tissue surrounding the nerve: densification, fibrosis, shortening, contracture, adhesions or scars. A deeper knowledge of the course of the peripheral nerves and their relationships with intermuscular septa, fibrous bands, muscle margins, and interneural planes is therefore crucial to understand how and where nerve compression can occur [1]. This study shows the causes and possible sites where RN compression can occur. We will discuss, working from proximal to distal, the following critical sites.

Lateral head of the triceps brachii muscle & lateral intermuscular septum

Different anatomical variants, mainly in the LHTB muscle and LIMS, have been observed to interfere with the normal course of the nerve and cause entrapment neuropathy [12]. Building on these observations, our study found, in 53% of the specimens, a fibrous arch coming off the LHTB muscle, similar to other studies that found this in 40% of specimens [17]. The RN glides below this arch to enter the longitudinal aponeurosis of the LHTB. This aponeurosis may be generated as we described previously, either from the LHTB muscle itself or from the LIMS, or both (Fig. 4). Division of the LIMS in the posterior compartment of the arm was found in 100% of the specimens. These divisions reinforce the fascia, and may have a protective role for the nerve, as well as being points of insertion of the surrounding muscles. We observed that with greater densification of the fascia there was greater muscular insertion. Several studies support this theory and observe that the RN can be trapped either by the muscular fibres of the LHTB muscle [18–20]) or by a fibrous arch [10, 12]. These arches are of variable tightness, making them capable of creating local compression [10].

The mean thickness of the LIMS where the radial nerve pierced it was 1.1 mm, similar to the 1.0 mm thickness reported by Tubbs et al [21]. The present study also aimed to determine the relationship between LIMS thickness and RN diameter as a possible indicator of nerve damage. We observed that with an LIMS thickness > 1.1 mm there was an increase of 0.4 mm in RN diameter, both at the space between the B/BR muscles and at the SA, compared with those with an LIMS < 1.1 mm (Table 3). It could therefore be suggested that the RN diameter may be due to epineurial damage when it passes through a thicker LIMS. Likewise, it was observed that, when the LIMS was > 1.1 mm, the difference between the RN diameter at the level of the LIMS and that at the space between B and BR was 0.2 mm larger distally, when it would have been expected to get smaller (Table 3). Unfortunately, possibly as a consequence of the small sample size, non-significant differences were found between the two categories of LIMS thickness. Nonetheless, reinforcing the concept of entrapment by the LIMS, other authors have described that the RN is anatomically tethered in the brachium by the LIMS and has limited excursion compared with the median and ulnar nerves [22]. It seems possible then that the adjacent muscles could create traction in the fibrous canal leading to a smaller lumen [12]; in our opinion, this would be mainly be due to contraction of the muscles of the posterior compartment of the arm.

Table 3
RN Diameter (mm) regarding LIMS thickness

	LIMS > 1.1 mm	**LIMS < 1.1 mm**
Before LIMS	2.9 ± 0.3	2.8 ± 0.3
After LIMS	2.8 ± 0.3	2.9 ± 0.2
BR-B	3.0 ± 0.5	2.7 ± 0.4
SA	2.3 ± 0.5	1.9 ± 0.2

Abbreviations: LIMS, lateral intermuscular septum; B, brachialis muscle; BR, brachioradialis muscle; SA, supinator arch. Values are presented as mean (standard deviation)

Space between brachialis and brachioradialis muscles

In this space, some authors describe a different entrapment at the origin of the BR muscle, a tight angle of the BR muscle fibers compressing the nerve against the humerus [6]. Our findings suggest predisposition to entrapment may be affected by the type of tissue surrounding the RN as it glides through this space. We observed that in 79% of the specimens, there was a close relationship between the RN and the epimysium of BR. However, this could also be interpreted as a form of stabilizing the nerve, to avoid nerve displacement with the flexion-extension movements of the elbow. In the remaining 21%, where the relationship between the B and BR muscles was vascular or muscular, this could also predispose to nerve compression. RN compression between the B and BR muscles can also induce a sensory-motor radial deficit [13]

Supinator arch (Arcade of Fröhse)

The SA is the most common compression site of the RN motor branch (6). In some cases, however, compression may occur due to the medial edge of the extensor carpi radialis brevis muscle or adhesions binding the nerve to the capsule of the radio-humeral joint [23]. As Roles also found, we saw that the extensor carpi radialis brevis muscle may be involved in compression, but more attention must be paid to the direct relationship of the nerve with the aponeurotic arch generated by the lateral septum of the forearm (Fig. 8). Moreover, in this region, posterior interosseous nerve compression may coexist with lateral epicondylitis [1].

With movement of the upper limb, the RN glides and varies its tension in the areas of interest that we studied. As the elbow is flexed from 0º to 90º, the excursion of the RN is approximately doubled [22]and strain increases by approximately 15% or more [16]. Based on these features, it may be concluded that people with a lot of muscle exertion and/or professions that involve a repetitive movement at the elbow are predisposed to peripheral RN neuropathy [6, 10, 12, 20].

Therefore, any factor that limits excursion at these points could cause repetitive traction of the nerve that may manifest as pain [16]. This study demonstrates that the possible mechanical limiting factors to bear in mind would be connective tissue, or fascial elements that surround the nerve, and that the fascia (as generalized connective tissue including epimysium and perimysium, capable of proprioception and nociception) [24] is a plausible source of pain.

This study provides a description with ultrasound guidance to help identify the RN at different points. Further clinical studies are necessary to demonstrate that the manual treatment of the fascia and connective tissue, at these points, could improve RN neuropathy.

5. Conclusions

All the above-mentioned peripheral compression points of the RN are surrounded by soft tissues that can be treated with manual therapy. Therefore, the manual therapist's ability to identify potential compression sites is crucial. Although root pain from cervical compression is one of the most common causes of pain in the upper limb, peripheral compression of the RN should be also considered in the differential diagnosis. In our opinion, manual therapy could be a treatment option for neuropraxia (pressure on the nerve with resultant dysesthesias but no loss of continuity) [25]. When compression is severe, the application of more invasive solutions (surgery) could be required in most cases. However, during post-surgical recovery, manual therapy should be a valuable tool to contribute to a faster and more effective functional recovery.

Abbreviations

B
brachialis muscle
BR

brachioradialis muscle
LE
lateral epicondyle
LHTB
lateral head of triceps brachialis
LIMS
lateral intermuscular septum
RN
radial nerve
SA
supinator arch
US
ultrasound

Declarations

Ethical approval: This study was approved by local committee Institutional Ethical

Committee (Institutional Review Board number IRB00003099), in accordance with current

Spanish legislation. All studied limbs pertained to persons that voluntarily donated their bodies for teaching and research to the donor dissection room of the Faculty of Medicine and Health Sciences.

Consent for publication: Not applicable

Availability of data and materials: The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

Competing interest: The authors declare that they have no competing interests.

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Authors' contributions: JGM did the anatomical dissections and measurements and wrote manuscript draft. MIMP designed the study and performed ultrasound explorations, GV contributed to experimental design and data treatment, GA and APB critically reviewed the draft and contributed to writing the article. All the authors approved the final version of the manuscript.

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Figures

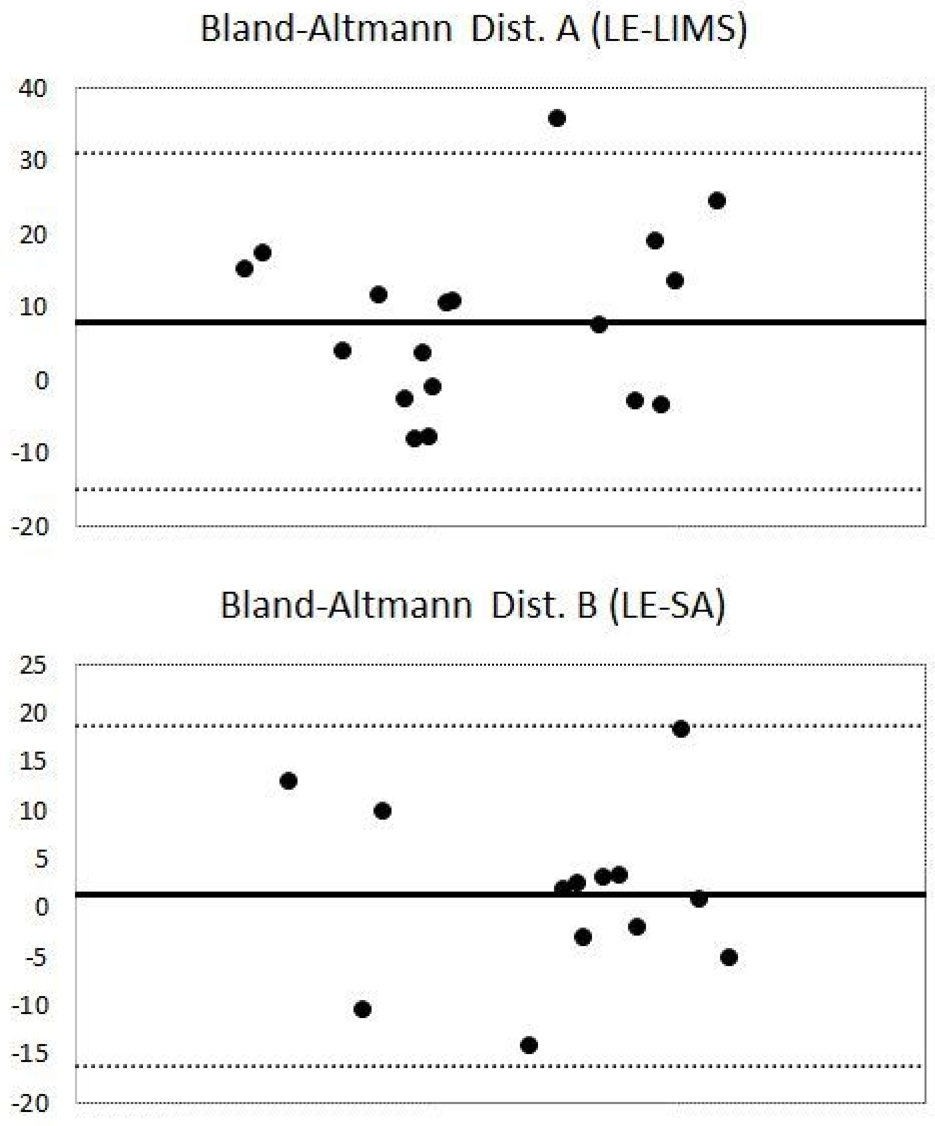

Figure 1

Bland-Altman graphs for the distances A: from the lateral epicondyle to the point the RN pierced the LIMS (upper panel) and B: from the lateral epicondyle to the supinator arch (lower panel). The Y axis represents the difference in the measurements taken at anatomical dissection and on US imaging. The X axis represents the mean measurement values for the two methods. The mean difference between the two methods of measurement is represented by the solid line whereas upper and lower limits of agreement (LOA), calculated as 1.96 times SD (standard deviation) are represented as dashed lines.

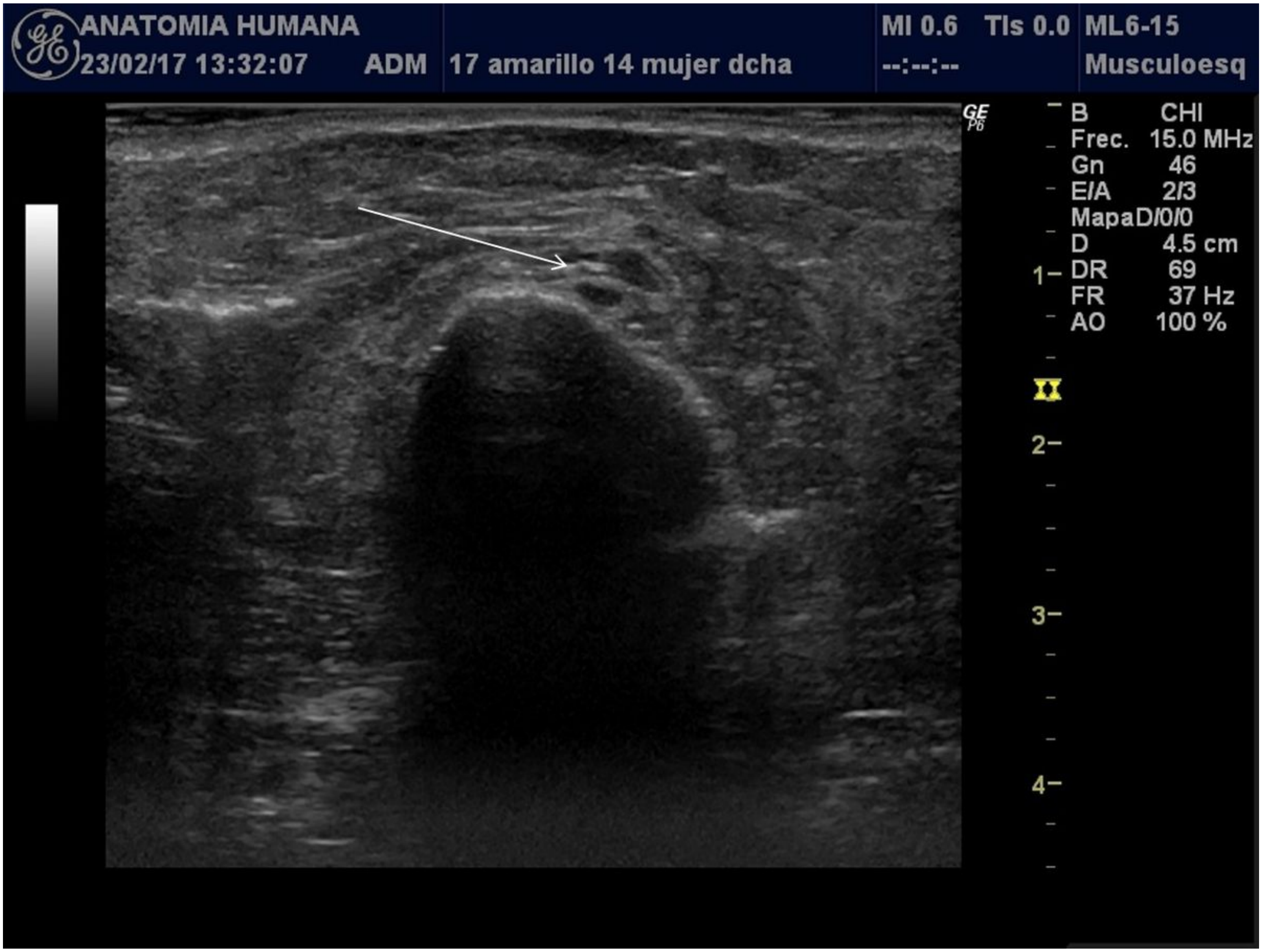

Figure 2

An ultrasound image of the radial nerve (white arrow) in contact with humerus.

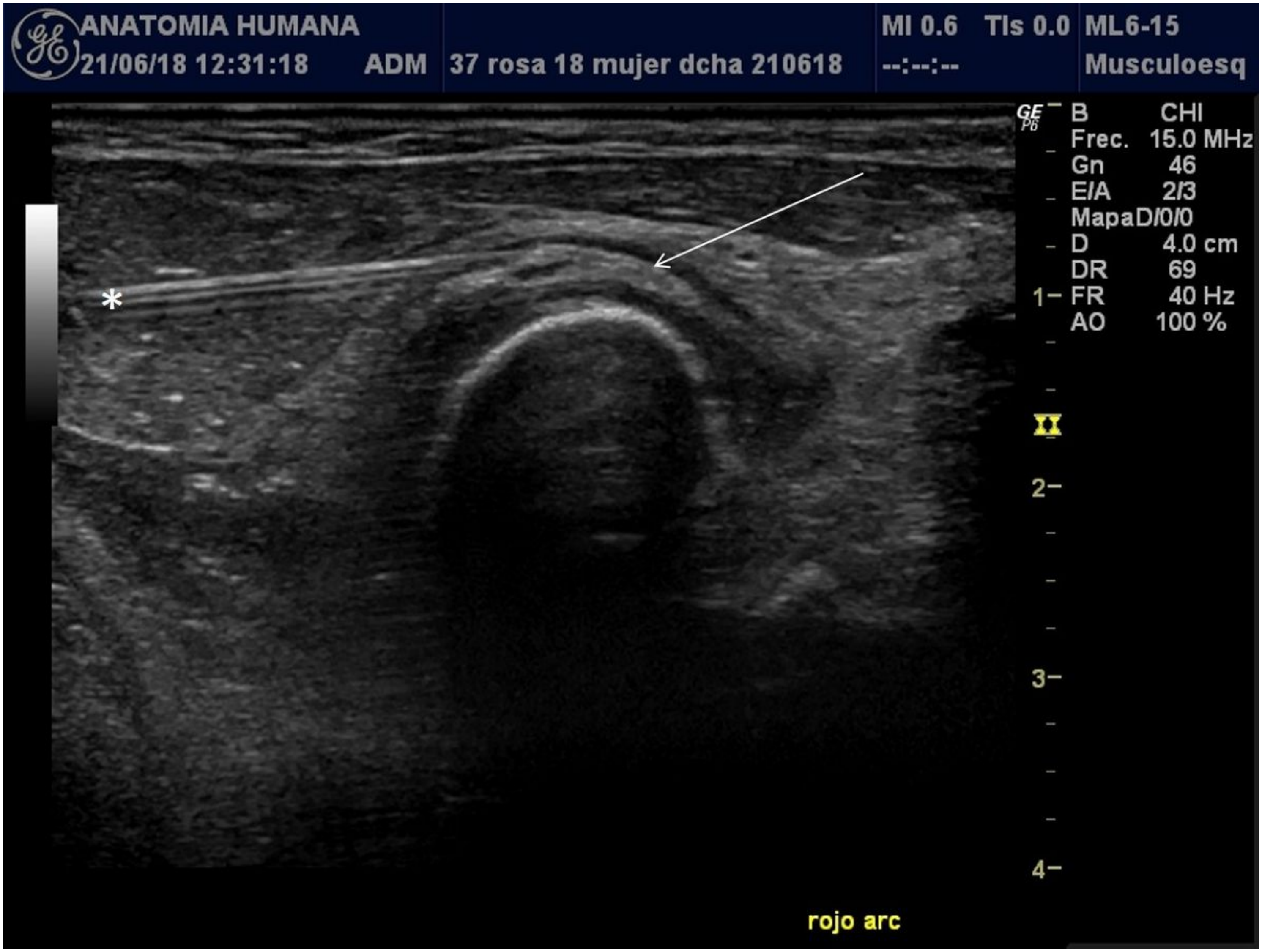

Figure 3

This US image illustrates the deep or motor branch in the origin of the supinator muscle. The needle (*) used to inject the dye in this point is clearly visible.

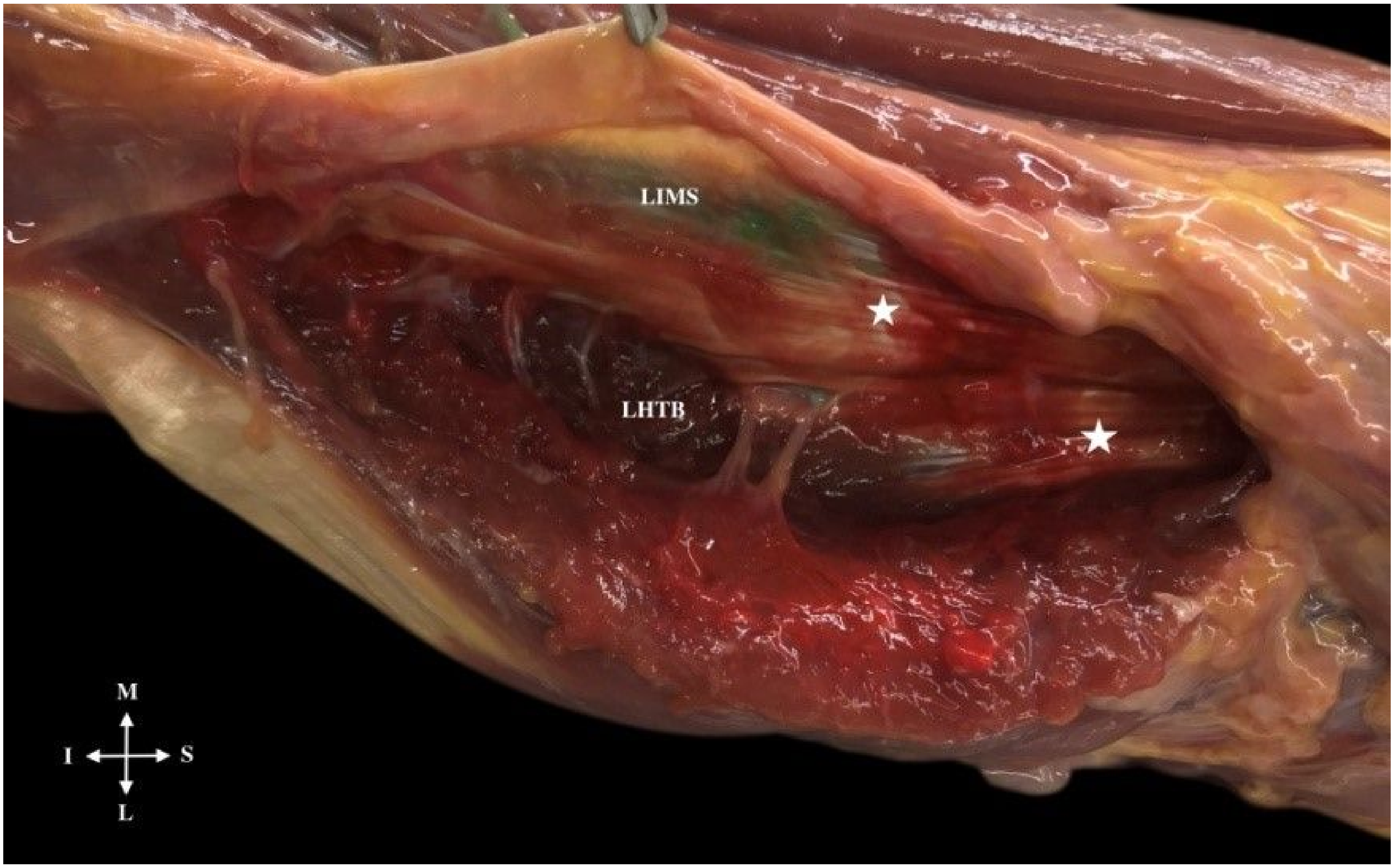

Figure 4

Longitudinal aponeurosis of the lateral head of triceps brachii muscle (LHTB) and longitudinal aponeurosis of the lateral intermuscular septum (LIMS).

Figure 5

Relationship of the lateral intermuscular septum (LIMS) inferiorly with the lateral epicondyle (LE) and superiorly with the deltoid V. Deltoid muscle (D), radial nerve (RN), brachioradialis muscle (BR), lateral head of triceps brachii (LHTB).

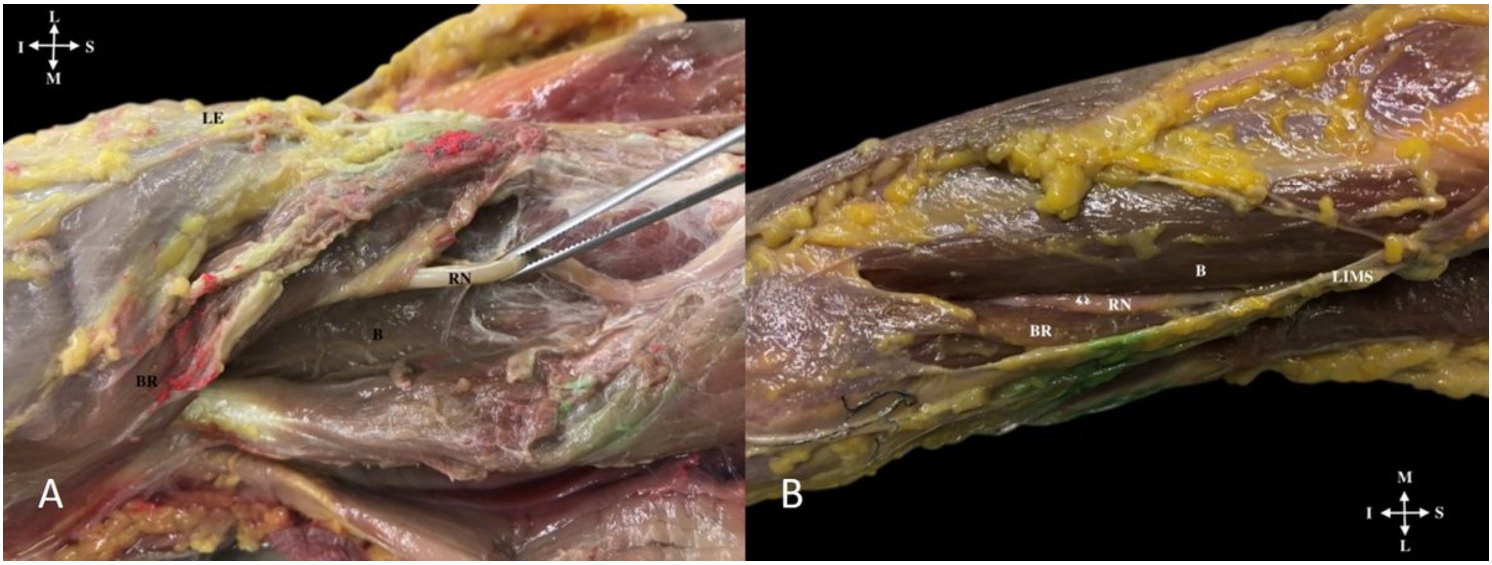

Figure 6

Different relationships in the course of the radial nerve (RN) in the space between brachialis muscle (B) [Panel A] and brachioradialis muscle (BR) [Panel B]. Lateral intermuscular septum (LIMS), lateral epicondyle (LE).

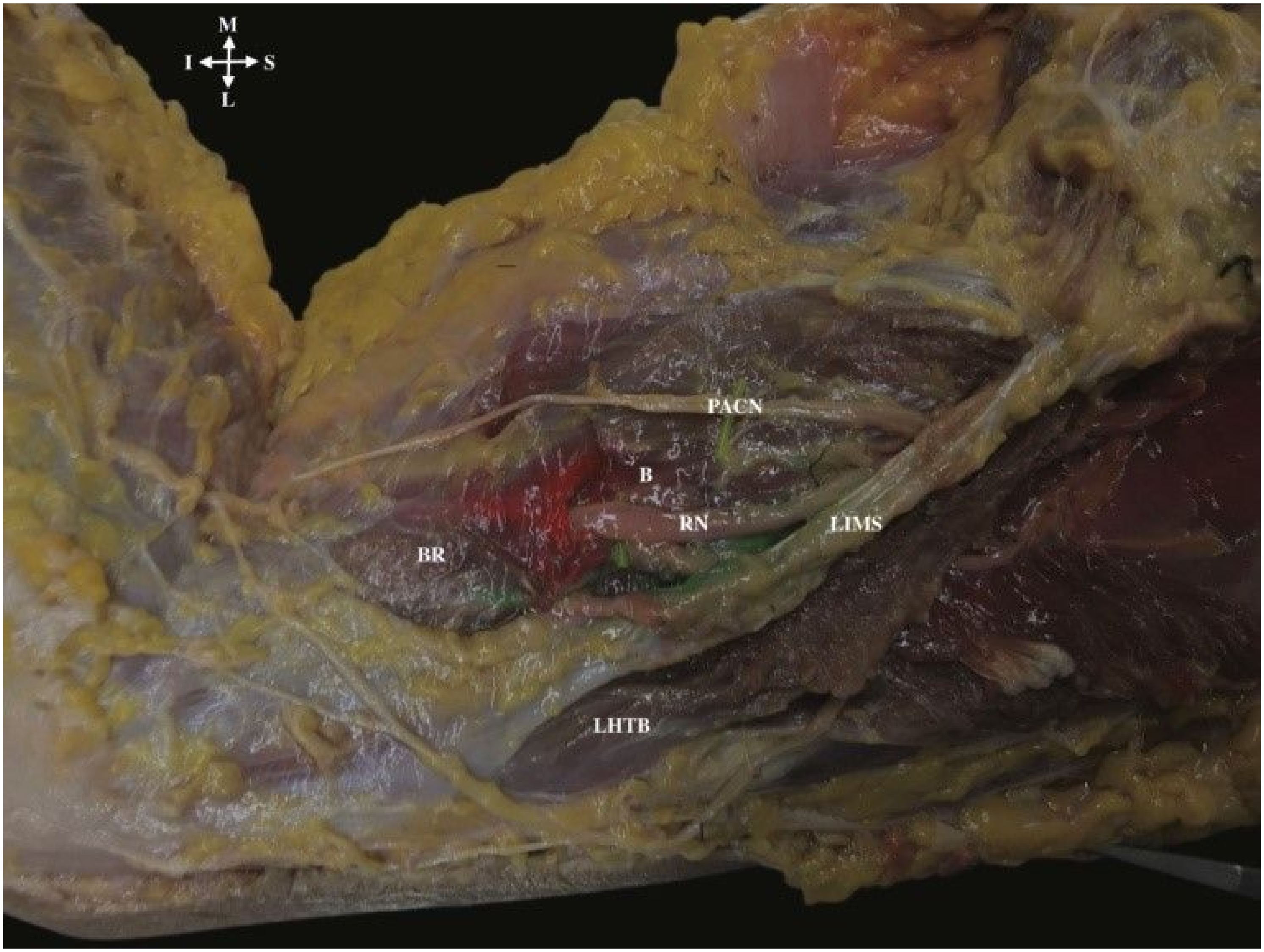

Figure 7

The radial nerve (RN) passes through the space between brachialis muscle (B) and brachioradialis muscle (BR) covered by the dense epimysium of these muscles. Gross flat appearance of the RN dyed in red. Lateral head of triceps (LHTB), lateral intermuscular septum (LIMS), posterior antebrachial cutaneous nerve (PACN).

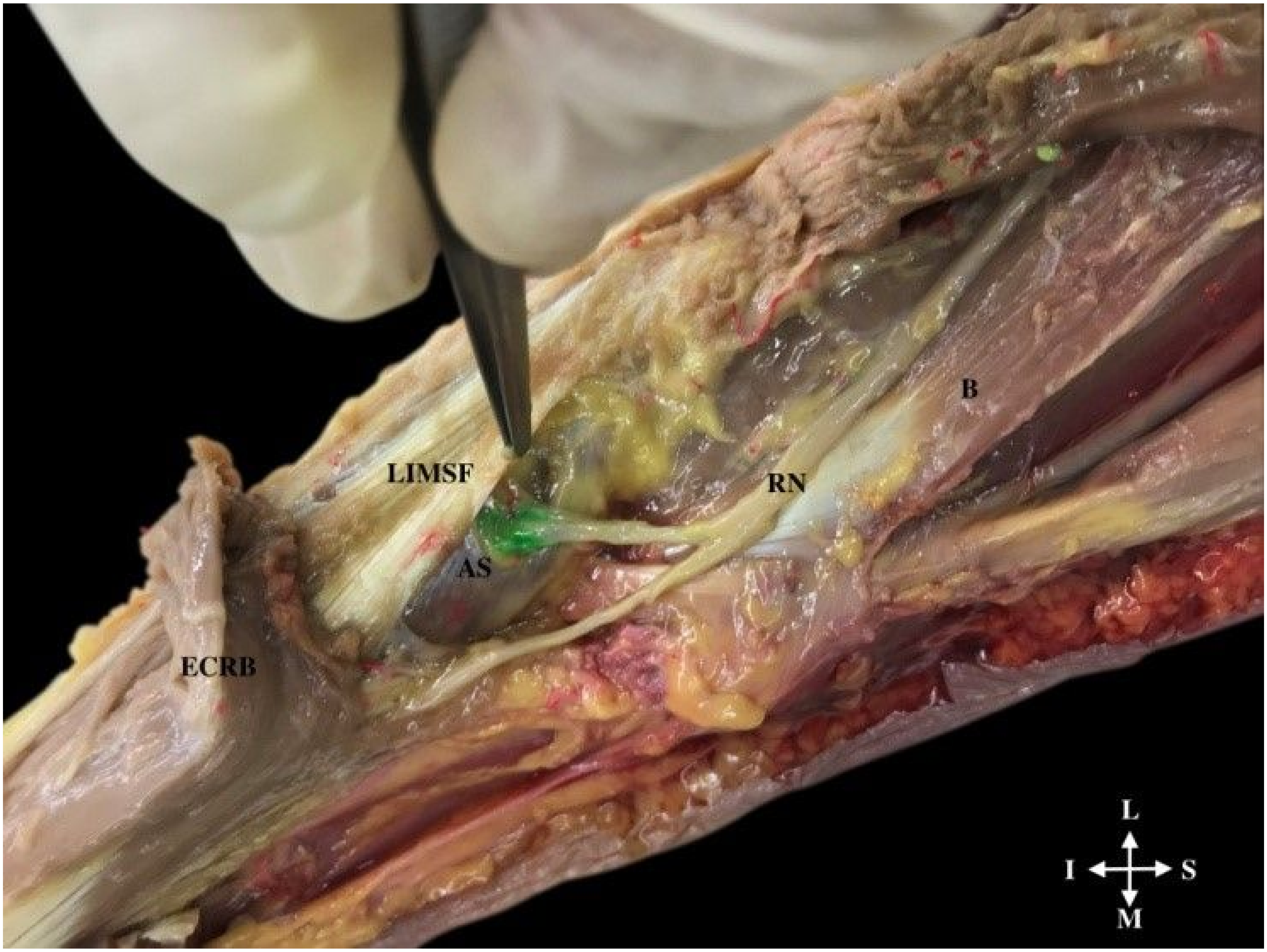

Figure 8

Relationship of lateral intermuscular septum of the forearm (LIMSF) and of supinator arch (arcade of Fröhse) (AS) with the motor branch of the radial nerve (RN) dyed green after injection with ultrasound guidance. Insertion of the extensor carpi radialis brevis (ECRB) at LIMSF. Brachialis muscle (B).