**Université de Poitiers**
**Faculté de Médecine et Pharmacie**

**ANNEE 2019**

**THESE**
POUR LE DIPLOME D'ETAT
DE DOCTEUR EN MEDECINE
(décret du 16 janvier 2004)

Présentée et soutenue publiquement
le 29/04/2019 à Poitiers
**par Anne-Charlotte SERGEANT**
**Interne en imagerie médicale et radiodiagnostic**

# Carpal tunnel: Is the "Safe Zone" really avascular?

**COMPOSITION DU JURY**

**Président** : Monsieur le Professeur Rémy GUILLEVIN (CHU de Poitiers)

**Membres** :
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Monsieur le Pr Jean-Pierre TASU (CHU de Poitiers)
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**Directeur de thèse** : Dr Thibaut JACQUES, CCA (CHU de Lille)

## ABSTRACT

*Introduction*
Numerous publications have studied the regional anatomy of the carpal tunnel to define a "Safe Zone" in order to reduce the risk of perioperative neurovascular complications. This zone is located between the ulnar neurovascular bundle and the median nerve. It is considered to be safe essentially because of the absence of vascular structures. This study aims at assessing the presence of arterioles within this area using Superb Microvascular Imaging ("SMI").

*Materials and Methods*
Twenty-seven patients underwent a bilateral routine wrist ultrasound, including SMI between January 28th and February 28th, 2019. The images from 54 wrists were retrospectively reviewed by two radiologists to evaluate presence and location of arterioles in the Safe Zone. In addition, 5 cadaveric wrists injected with intra-arterial red latex underwent a dissection of the carpal tunnel.

*Results*
In the Safe Zone, arterioles were seen above the flexor retinaculum in 36 wrists (36/54; 66.7%) and under the flexor retinaculum in 21 wrists (21/54; 38.9%). The arterioles located under the flexor retinaculum were more frequently located close to the median nerve (21/54; 38.9%) than to the ulnar artery (9/54; 16.7%). In cadaveric wrists, arterioles were seen above the flexor retinaculum in 3 wrists (3/5; 60%) and under the flexor retinaculum in 2 wrists (2/5; 40%).

*Conclusion*
Arterioles can be seen in the Safe Zone both above and under the flexor retinaculum. Under the retinaculum, these vessels are essentially observed in the proximal aspect of the carpal tunnel and more frequently close to the median nerve.

**Keywords**
Carpal tunnel release; ultrasonography; Superb Microvascular Imaging; Safe Zone; ulnar artery, median nerve.

**Key Points**

- Treatment of carpal tunnel syndrome is one of the most frequent wrist interventions, but is also a treatment in permanent improvement ;
- The Safe Zone located between the median nerve and the ulnar neurovascular bundle is targeted during these interventions, as it is considered to be avascular ;
- New imaging techniques such as SMI enables the visualization of arterioles within the Safe Zone (visible both above and under the flexor retinaculum) ;
- Arterioles were more frequently observed in the proximal aspect of the carpal tunnel ;
- Under the retinaculum, they were more frequently seen in proximity to the median nerve.

**Abbreviations and Acronyms**

- SMI: Superb Microvascular Imaging
  PRF: Pulse Repetition Frequency

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## INTRODUCTION

Carpal tunnel syndrome is a frequent condition that leads to 140 000 surgical procedures per year in France (1). Surgery is, as of today, the main curative intervention for this condition. However, ultrasound-guided carpal tunnel release, via a minimally invasive approach is a recently-developed ambulatory procedure and a new technique of percutaneous interventional radiology (1, 2). This technique could reduce the risk of iatrogenic injury by using continuous ultrasound in order to visualize the median nerve, the ulnar artery, the recurrent branch of the median nerve, the superficial palmar arch and the palmar cutaneous branch of the median nerve (1–5).

Thanks to a small cutaneous incision (0.1 – 0.3 cm against 3.0 – 4.0 cm in open surgery and 1.5 – 2.0 cm in endoscopic and mini-invasive surgical procedures), the patient's return to daily activities seems to be faster, grip strength quicker to recover, scar-related pain reduced and scar formation accelerated (1–3, 6). A punctiform percutaneous incision is performed on the palmar face at the proximal wrist crease to introduce a hook knife under ultrasound guidance. The device is first moved horizontally under the flexor retinaculum (staying away from the median nerve and the sensory branches), then vertically (in order to cut the deep fibers of the flexor retinaculum) (1, 2).

Prior to this intervention, an ultrasound examination is useful to analyze the anatomic structures of the carpal tunnel and to locate the Safe Zone. It has been described as a zone located between the ulnar neurovascular bundle and the median nerve, where a retinacular section can be safely performed (Figure 1) (1–3, 6, 7). It is admitted to consider that it is safe because of the absence of visible vascular or nervous structures, in ultrasound or in magnetic resonance imaging (8, 9). However, a few anatomic studies reported that small arterial branches originating in the ulnar artery cross the carpal tunnel transversely to irrigate the median nerve (10–12), the flexor tendons sheaths and the flexor retinaculum (12–14) or the skin (12).

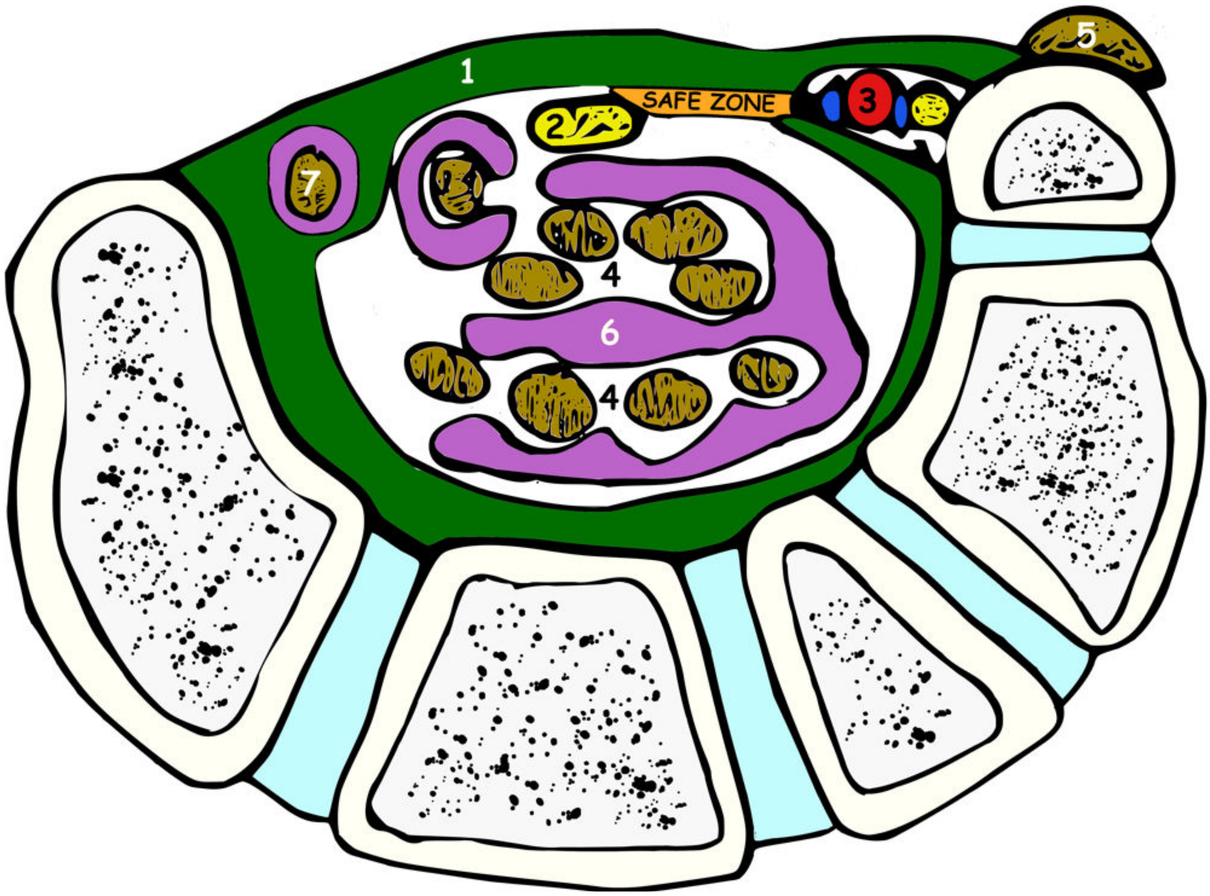


**Figure 1: Transversal cross-section of the carpal tunnel and representation of the Safe Zone.** 1: flexor retinaculum; 2: median nerve; 3: ulnar artery; 4: flexor superficialis and profundus tendons; 5: flexor carpi ulnaris tendon; 6: common synovial sheath of the flexor tendons; 7: flexor carpi radialis tendon

Superb Microvascular Imaging (or “SMI”) is a novel sonographic mode (developed by Toshiba/Canon - Tokyo, Japan) with a higher level of sensitivity and a high frame rate for microvasculature imaging. SMI visualizes finer details of micro vessels and blood flow signals in real time and can differentiate low-speed blood flow signal from tissue motion artifacts (15, 16). Traditional ultrasonography procedures such as Color Doppler and Power Doppler ultrasound seem to be less suitable to show small vessels and low-velocity blood flow because of a lower sensitivity to the blood flow signals (15, 16).

The purpose of this study was to assess the presence of arterioles within the Safe Zone using SMI and to confront the results with cadaveric dissections.

## MATERIALS AND METHODS

### Patients and ultrasound technique

Between January 28th and February 28th, 2019, 85 patients underwent a bilateral routine wrist ultrasound in the Musculoskeletal Imaging Department of the University Hospital of Lille (France). Patients who had a complete examination protocol of the carpal tunnel with SMI acquisitions were included in this retrospective analysis. Patients with chronic conditions that can affect local vascularization such as rheumatoid arthritis or carpal tunnel syndrome were not included. At the end, a total of 27 patients who underwent a bilateral routine wrist ultrasound with SMI were selected, leading to the analysis of images from 54 wrists. They were 11 men (11/27; 40.7%) and 16 women (16/27; 59.3%). The mean age was 40.4 years (range: 20 – 73).

All examinations were performed on an Applio i800 ultrasound device (Canon Medical Systems, Otawara-Shi, Japan).

This retrospective analysis was declared and approved by the institutional board under the number DEC19-057.

As part of the routine ultrasound examination of the wrist, five levels of assessment of the carpal tunnel are systematically performed in our department (Figure 2), in line with the literature (8).

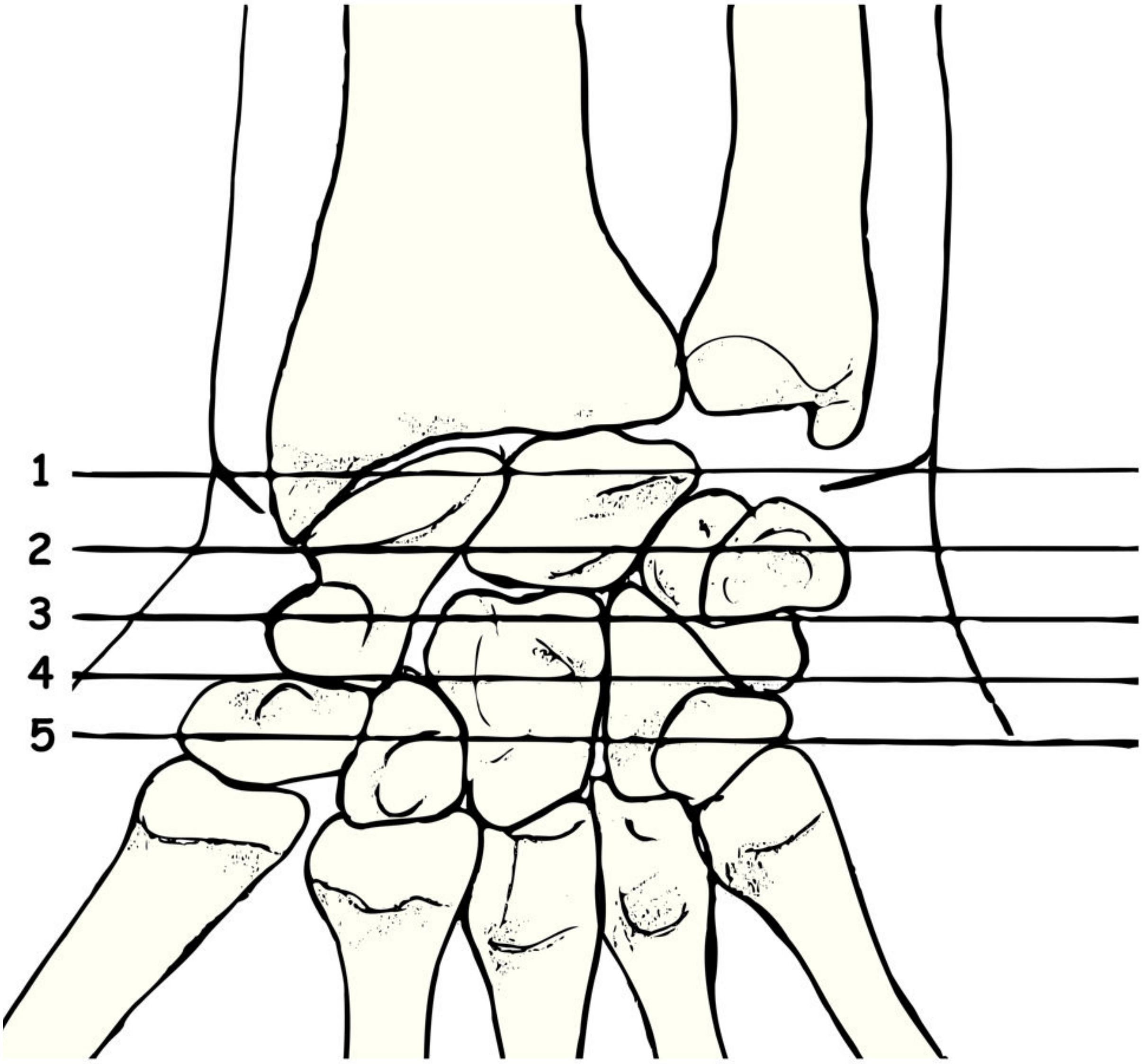


**Figure 2: Levels of assessment of the carpal tunnel.** Level 1: wrist crease; level 2: convex surface at the center of the pisiform; level 3: just below the pisiform bone; level 4: just above the hook of the hamate bone; level 5: high-echogenic surface at the center of the hamate hook.

**Data collection and analysis**
The images from the 54 wrists were analyzed retrospectively together by a junior radiologist (ACS) and a senior radiologist (TJ), between March 4$^{th}$ and March 8$^{th}$, 2019.

The primary criterion was the presence or the absence of an arteriole seen in the Safe Zone. The second criterion was the localization of this arteriole within the Safe Zone. For each image, the Safe Zone was divided in six equally-distant areas (Figure 3) for a reproducible mapping of the vascularization. Three equally-distant areas were located on the superficial side of the retinaculum (towards the ulnar artery: SA; towards the median nerve: SN; in the middle: SM) and three equally-distant areas on the deep side of the retinaculum (towards the ulnar artery: DA; towards the median nerve: DN; in the middle: DM).

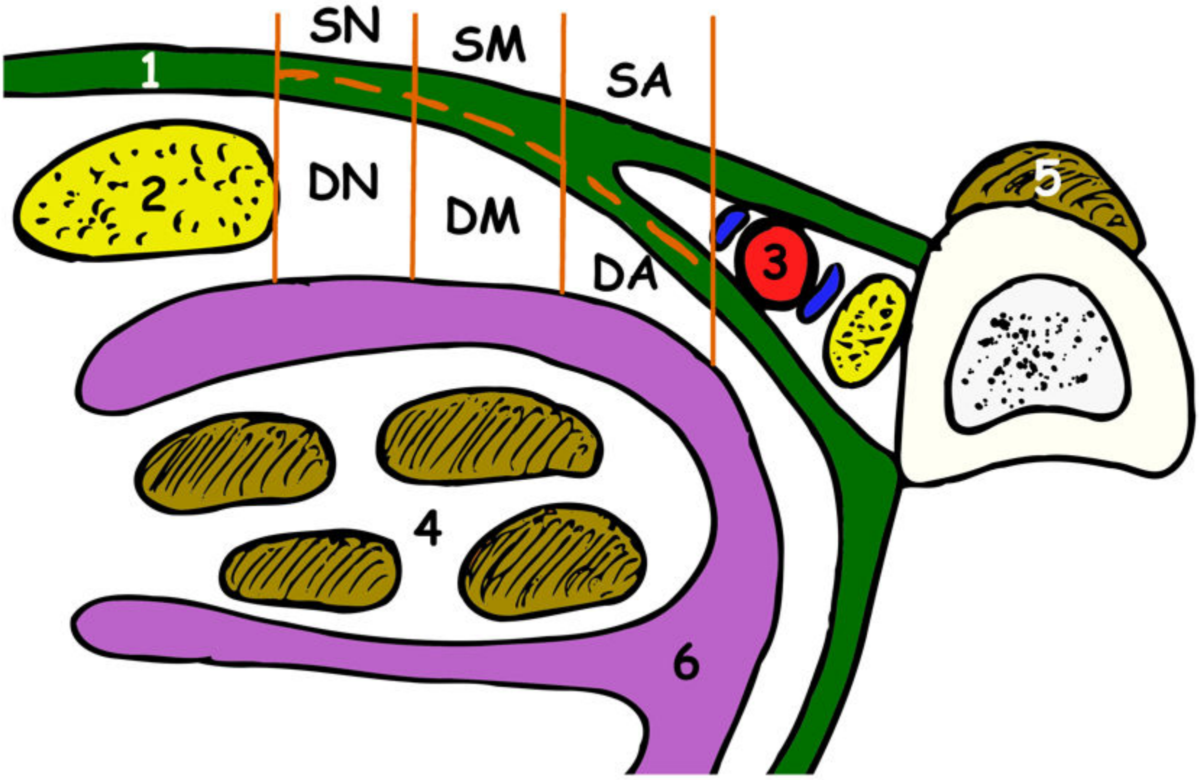


**Figure 3: Subdivision of the Safe Zone in 6 areas.** Three equally-distant areas on the superficial side of the retinaculum (towards the ulnar artery: SA; towards the median nerve: SN; in the middle: SM) and three equally-distant areas on the deep side of the retinaculum (towards the ulnar artery: DA; towards the median nerve: DN; in the middle: DM). Anatomical structure 1 to 6 refer to legend in Figure 1.

Each area in their respective image was rated in consensus by the readers, to assess the presence of arterioles in SMI mode, with a binary notification of 0 (if no blood flow) or 1 (if one or more vascular spots was present). To qualify as an arteriole, a SMI signal had to be associated with a compatible Pulsed Doppler (PD) spectrum (Figures 4 and 5).

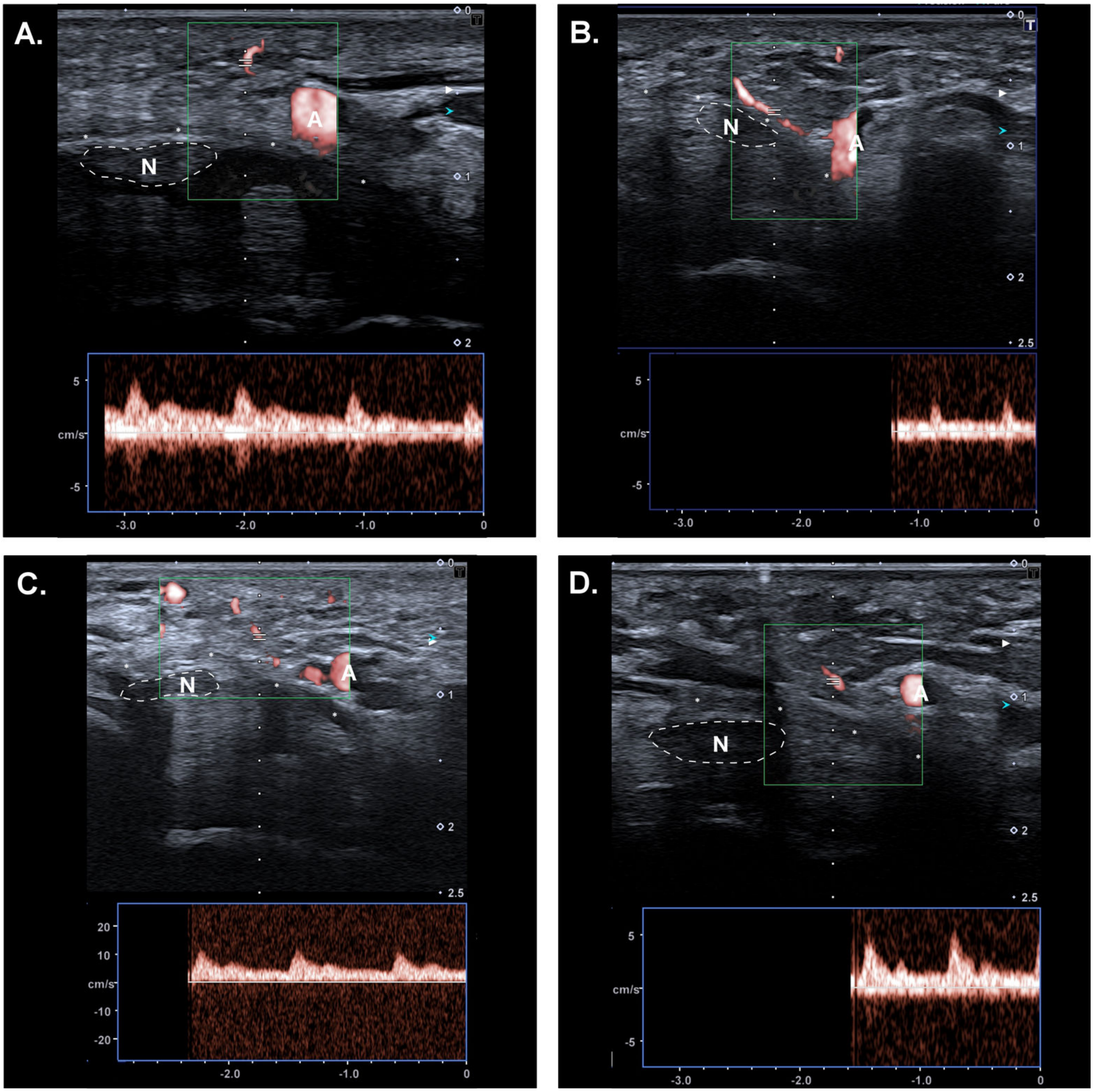


**Figure 4: Examples of micro-vessels detected in SMI and confirmed in Pulsed Doppler in the Safe Zone, on the superficial side of the retinaculum in 4 different patients.** N: median nerve; A: ulnar artery; asterisks: flexor retinaculum.

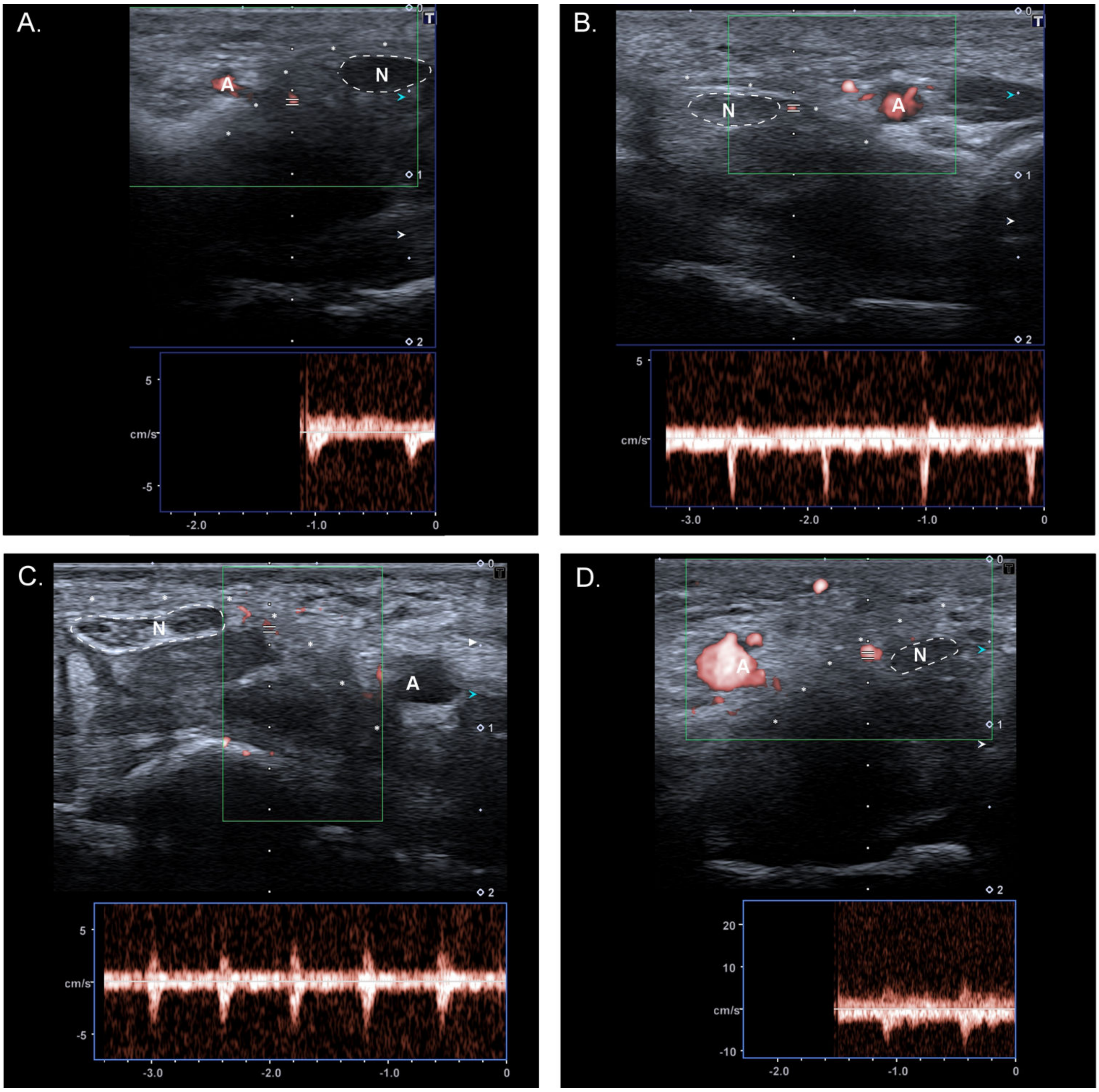


**Figure 5: Examples of micro-vessels detected in SMI and confirmed in Pulsed Doppler in the Safe Zone, on the deep side of the retinaculum in 4 different patients.** N: median nerve; A: ulnar artery; asterisks: flexor retinaculum.

**Anatomical study on cadavers**

Finally, five forearms of three embalmed cadavers (two males and one female) were injected by hand pump with red latex via the brachial artery to fill arterial vessels. Macro and micro-dissections of the carpal tunnel (especially, at the Safe Zone level) were undertaken to search for arterial vessels. These dissections were analyzed by two musculoskeletal radiologists and one anatomist.

## RESULTS

**Supra-retinacular region (superficial aspect of the Safe Zone)**
When analyzing the 3 equally-distant areas of the superficial aspect of the Safe Zone (supra-retinacular), numerous arterioles could be seen in SMI, as detailed in Table 1.
The highest number of arterioles was seen on the ulnar side (area SA), with up to 36/54 wrists (66.7%) displaying arterioles in this area.
The lowest number of arterioles was seen in the proximal aspect (level 1) of the median side (area SN), with 9/54 wrists (16.7%) displaying arterioles seen in SMI in this area.
The arterioles were more frequent in the distal levels of the Safe Zone, with 27 to 36 wrists (50.0% to 66.7%), out of 54 displaying arterioles in level 5, whereas 9 to 23 wrists (16.7% to 42,6%) had arterioles seen in SMI in the proximal level (level 1).

| Area SN | Area SM | Area SA | |
|---|---|---|---|
| 9/54 (16.7%) | 14/54 (25.9%) | 23/54 (42.6%) | **Level 1 (proximal)** |
| 22/54 (40.7%) | 24/54 (44.4%) | 33/54 (61.1%) | **Level 2** |
| 34/54 (63.0%) | 32/54 (59.3%) | 34/54 (63.0%) | **Level 3** |
| 36/54 (66.7%) | 36/54 (66.7%) | 36/54 (66.7%) | **Level 4** |
| 27/54 (50.0%) | 34/54 (63.0%) | 36/54 (66.7%) | **Level 5 (distal)** |

**Table 1: Proportions and percentages of wrists with arterioles seen on SMI in the supra-retinacular region of the Safe Zone, depending on the 3 equally-distant superficial areas (SN, SM, SA) and on the 5 levels of ultrasonographic assessment.** Light green: 1-20%; yellow: 21-40%; orange: 41-60%; red: > 60%.

**Anatomical correlation (supra-retinacular region)**
In anatomical pieces, arterioles were seen in the supra-retinacular region in 3 wrists (3/5; 60%). They all originated from the ulnar artery and had a medial course along the flexor retinaculum and in the adjacent soft tissues (figure 6).

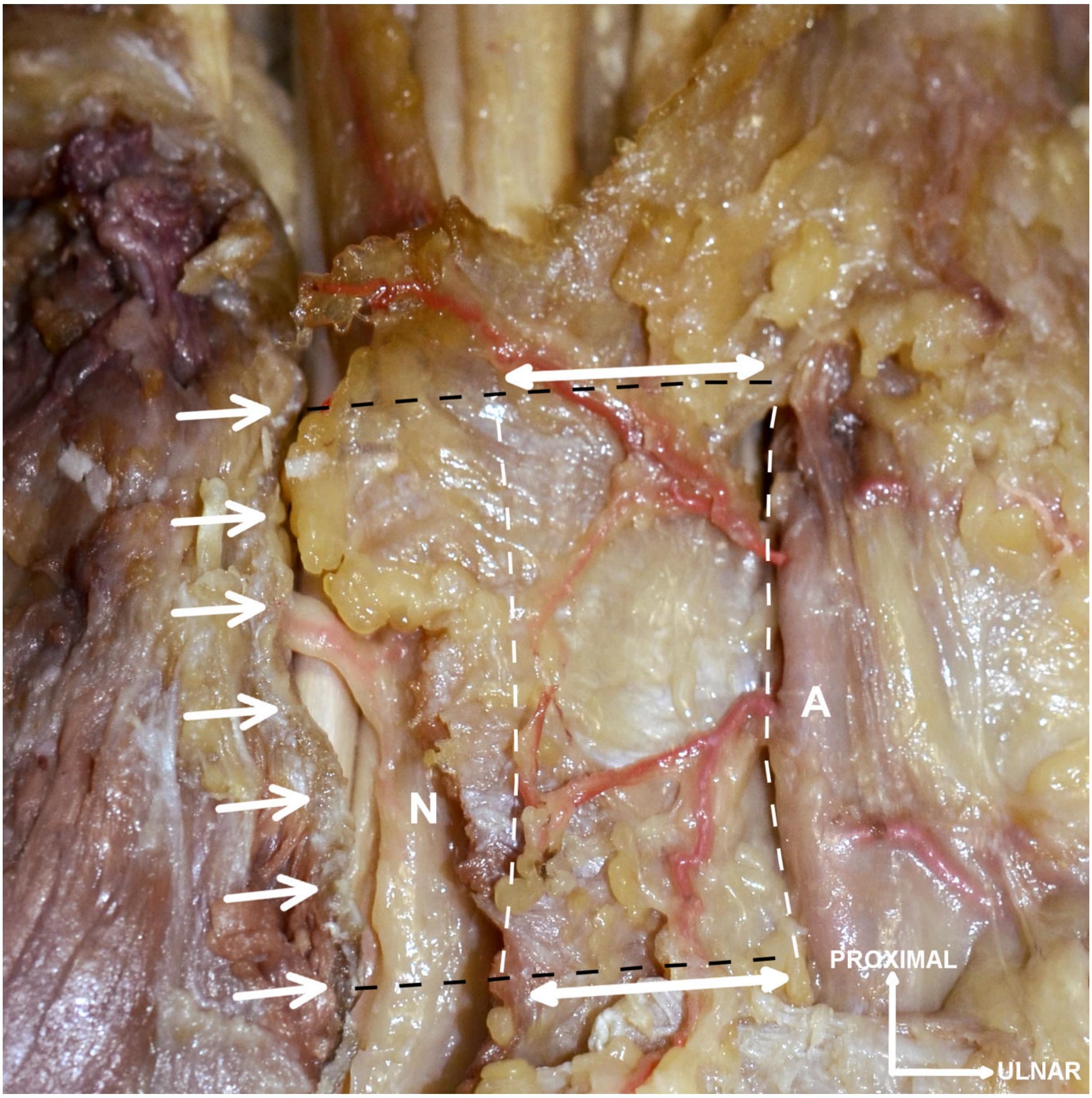


**Figure 6: Anatomical dissection showing the supra-retinacular region of the Safe Zone.** The flexor retinaculum (dissected) is depicted with white arrows and the proximal and distal limits of the carpal tunnel by black dotted lines. The limits of the safe zone are depicted with white dotted lines and double head arrows. N: median nerve; A: ulnar artery. Note the arterioles arising from the ulnar artery and running along the flexor retinaculum, clearly visible in the Safe Zone.

**Infra-retinacular region (deep aspect of the Safe Zone)**

When analyzing the 3 equally-distant areas of the deep aspect of the Safe Zone (infra-retinacular), several arterioles were seen in SMI, as detailed in Table 2.
The highest number of arterioles was seen on the median nerve side (area DN), with up to 21/54 wrists (38.9%) displaying arterioles in this area.
The lowest number of arterioles was seen in the distal aspect of the carpal tunnel, with no arterioles seen in levels 4 and 5 (0/54; 0%).

We finally noticed that arterioles were concentrated at the proximal levels of the Safe Zone (Table 2 - Levels 1 and 2) and, within these 2 levels, the closer to the median nerve the higher the concentration of arterioles. As we move away from the median nerve, the concentration of arterioles decreases (Levels 3 to 5). Indeed, 9/54 (16.7%) and 4/54 (7.4%) wrists had visible arterioles using SMI on the arterial side (area DA) of levels 1 and 2, versus respectively 21/54 (38.5%) and 12/54 wrists (22.2%) on the median nerve side (area DN).

| Area DN | Area DM | Area DA | |
|---|---|---|---|
| 21/54 (38.9%) | 15/54 (27.8%) | 9/54 (16.7%) | **Level 1 (proximal)** |
| 12/54 (22.2%) | 9/54 (16.7%) | 4/54 (7.4%) | **Level 2** |
| 3/54 (5.6%) | 2/54 (3.7%) | 0/54 (0.0%) | **Level 3** |
| 0/54 (0.0%) | 0/54 (0.0%) | 0/54 (0.0%) | **Level 4** |
| 0/54 (0.0%) | 0/54 (0.0%) | 0/54 (0.0%) | **Level 5 (distal)** |

**Table 2: Proportions and percentages of patients with arterioles seen on SMI in the infra-retinacular region of the Safe Zone, depending on the 3 equally-distant deep areas (DN, DM, DA) and on the 5 levels of ultrasonographic assessment.** Green: 0%; light green: 1-20%; yellow: 21-40%; orange: 41-60%; red: > 60%.

**Anatomical correlation (infra-retinacular region)**

These findings were concordant with the results seen on anatomical pieces (Figures 7 and 8). Two cadaver wrists (2/54; 40%) had visible arterioles under the flexor retinaculum in the Safe Zone. These vessels originated from the ulnar artery, had a proximal transverse course (that was seen either just above the proximal aspect of the flexor retinaculum, or at the proximal aspect of the carpal tunnel), then an oblique and/or longitudinal course eventually reaching the median nerve.

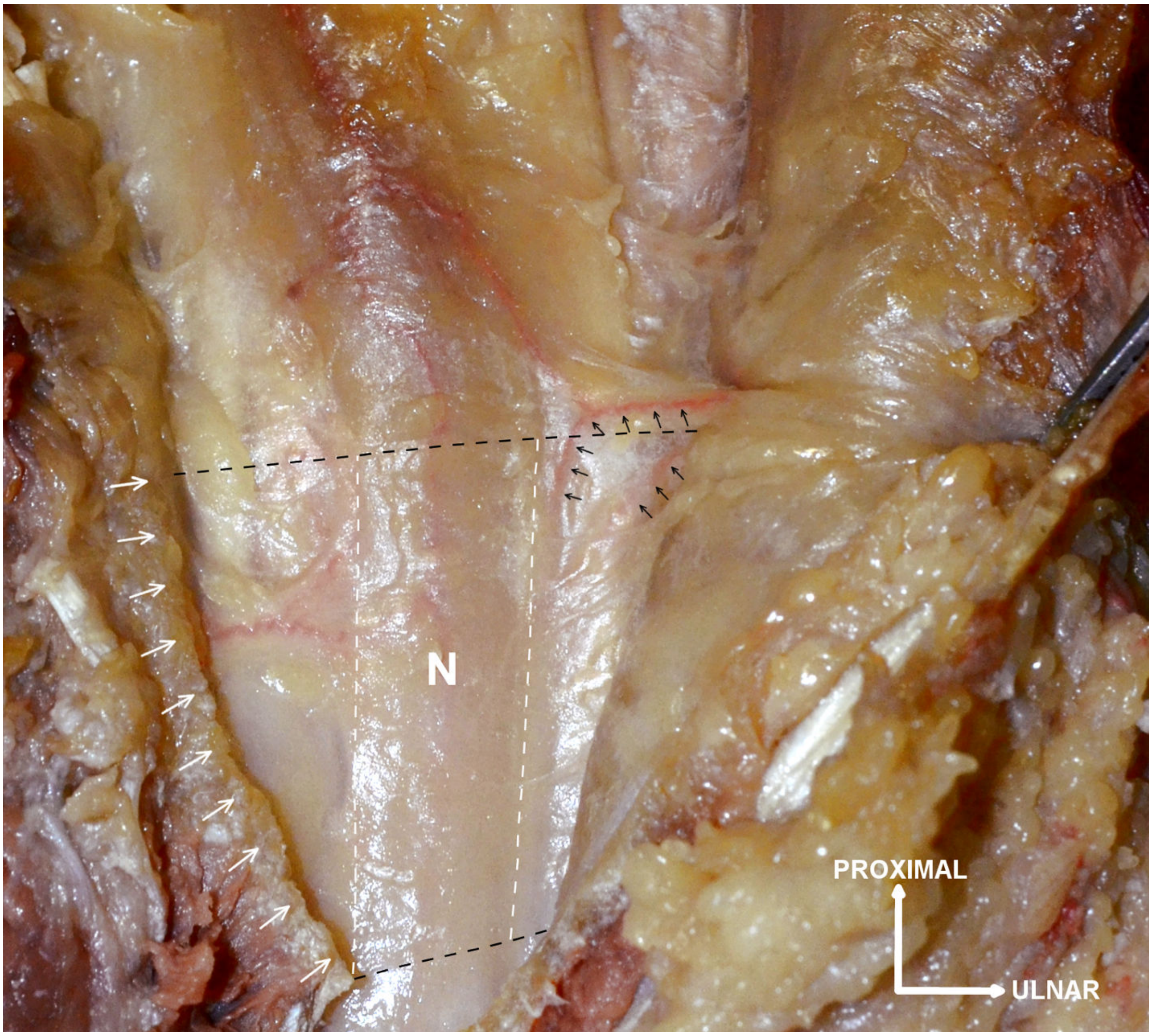


**Figure 7: Anatomical dissection showing the infra-retinacular region of the carpal tunnel**. The flexor retinaculum (reclined) is depicted with white arrows and the proximal and distal limits of the carpal tunnel by black dotted lines. The limits of the median nerve (N) are depicted with white dotted lines. Note the arterioles (black arrows) passing through the Safe Zone.

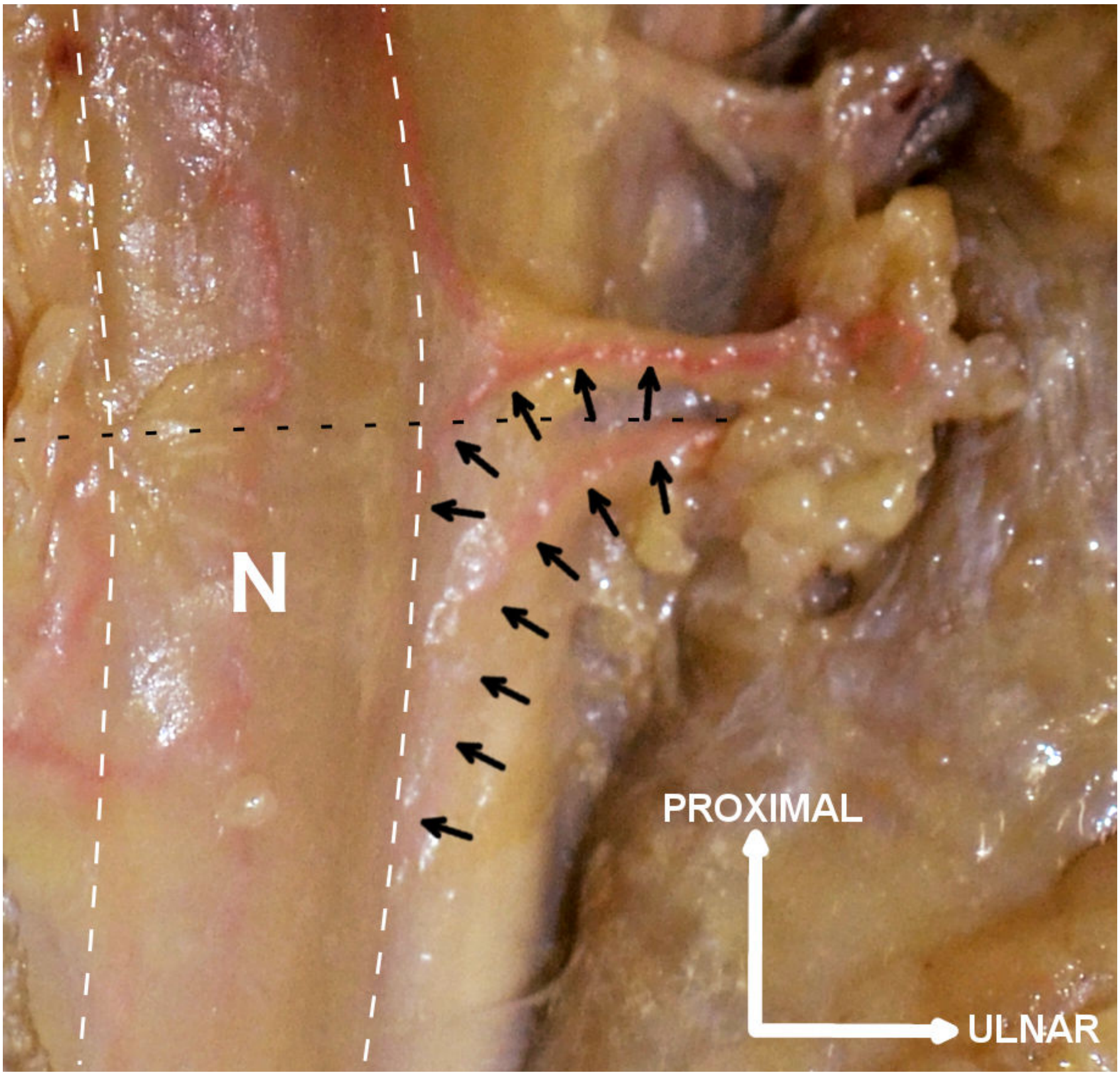


**Figure 8: Further dissection and magnification of the anatomical piece shown in Figure 7.** The proximal limit of the carpal tunnel is depicted with black dotted line. The limits of the median nerve (N) are depicted with white dotted lines. Note the arterioles (black arrows) passing through the Safe Zone, especially running along the ulnar side of the median nerve.

## DISCUSSION

Although the Safe Zone of the carpal tunnel has been described as a zone without any vascular structure visible on imaging, our study demonstrates that arterioles can be seen within it when using Superb Microvascular Imaging. Above the flexor retinaculum, arterioles can be seen in various locations and more frequently near the ulnar artery. Arterioles were also seen below the flexor retinaculum, especially in the proximal levels of the carpal tunnel and more frequently close to the median nerve.

These results concur with the anatomic literature regarding the fact that arterioles can cross the carpal tunnel in order to irrigate the median nerve (10–12), the flexor tendons sheaths (12, 13) and the flexor retinaculum, or perforate this retinaculum to supply its superficial side (12–14) and the skin (12). In studies from 1988 and 1996 based upon carpal tunnels dissections of fresh cadavers, Zbrodowski and al. showed that the blood supply of the flexor retinaculum comes from a superficial as well as a deep network. At the level of the carpal tunnel, the ulnar artery translates into transversal branches to constitute the main part of this superficial network. These branches can also perforate the flexor retinaculum and participate in the deep network (13, 14). These same authors also reported that the common synovial sheath for the flexor tendons is vascularized in part by the ulnar and the radial arteries (13). In other anatomical dissection studies, Zbrodowski and al. (in 1983) and Pecket and al. (in 1973) showed that the median nerve was partially supplied by branches of the ulnar or the radial artery in the carpal tunnel (10, 11).

Vascular-related complications during carpal tunnel release are rare, the most frequent being hematomas and hypertrophic scars. Those were described both in endoscopic and open surgery, yet not reported with the minimally ultrasound-guided procedure at this point. The endoscopic technique has a limited field of visualization which can increase the risk of damaging local neurovascular structures (the ulnar neurovascular bundle, the median nerve, the palmar cutaneous branch of the median nerve, the recurrent motor branch of the median nerve, the superficial palmar communication between the median and the ulnar nerves, the Berrettini branch and the superficial palmar arch) (17). Palmer and al. analyzed the complications of the endoscopic technique and found that the most frequent complications with this procedure are linked to vessel lacerations with ecchymosis, more frequently than ulnar or median nerve lacerations (18). Roux et al. noticed that vascular lacerations can occur with these two techniques (endoscopic and open surgery), especially when the procedure is executed with a tourniquet which hides arteries. As a consequence, vascular lacerations can create a hematoma causing adhesions and hypertrophic scar (19).

The arterioles seen on SMI acquisitions and located on the superficial aspect of the Safe Zone are likely to play a role in the vascularisation of the soft tissues, the skin and the flexor retinaculum. But, apart from a potential hematoma which remains a rare complication, the consequences of a lesion of these arterioles are likely to be benign.

Regarding the infra-retinacular region of the Safe Zone, the arterioles observed in our study are more frequently seen towards the median nerve and often have an oblique or a longitudinal course to reach the median nerve or the flexor tendons. This longitudinal course could lower the risk of damage since both surgical and radiological technique also have a longitudinal approach. The consequences of a lesion of these arterioles have never been described. However, some of these vessels probably play a role in the arterial vasculature of the median nerve as they seem to reach the epineurial region. Since the axons of the median nerve seem to be sensitive to ischemia in patients with carpal tunnel syndrome (20), we cannot rule out that a perioperative lesion of these small arterioles could play a role in further axonal ischemia. At the consequence the use of SMI could help detecting vessels at risk to be damaged.

Regarding the deep aspect of the carpal tunnel, no arterioles were seen in SMI in the distal levels (4 and 5). Although this seems to be in agreement with previous anatomic descriptions, it is unclear however if this could also be linked to a lack of gain and/or ultrasound signal in these deep areas.

Our study has several limitations:
Firstly, it was monocentric, retrospective and based upon the interpretation of ultrasound images by only two radiologists. The interpretation of ultrasound images *a posteriori* can be difficult, hence the rating phase jointly agreed by the two readers. Also, the interpretation in image reading may differ between various group of potential readers: this strategy did not enable inter- or intra-reader agreement, but seems adequate since this study only aimed at providing a better understanding of the local anatomy (and was not used as a tool to measure the intrinsic performances of SMI).
Secondly, Pulsed Doppler (PD) was used as a reference to make sure the images displayed in SMI were arterioles. However, several images had SMI acquisitions without PD spectrum. In that case, the readers agreed to not include these images as arterioles. It is possible that this could have led to an underestimation of the number of arterioles.
Finally, the number of patients and cadavers included was limited, which can lead to a variability in the observed percentages of arterioles. However, the population was consistent with the anatomical purpose of this study and a larger population would have certainly confirmed results.

## CONCLUSION

Although the safe zone of the carpal tunnel has been described as a zone without any vascular structure visible on imaging, our study demonstrates that arterioles can be seen within it using Superb Microvascular Imaging. Their majority are located above the flexor retinaculum. Arterioles can also be seen under the flexor retinaculum, especially in the proximal aspect of the carpal tunnel with a gradient towards the median nerve. The use of novel ultrasound techniques such as SMI, could thus help in having a better understanding of local microvasculature and an improved visualization on screen of small vessels at risk to be damaged: in particular, when located under the flexor reinaculum where consequences of perioperative lesions can be critical.

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**ABSTRACT**

*Introduction*
Numerous publications have studied the regional anatomy of the carpal tunnel to define a "Safe Zone" in order to reduce the risk of perioperative neurovascular complications. This zone is located between the ulnar neurovascular bundle and the median nerve. It is considered to be safe essentially because of the absence of vascular structures. This study aims at assessing the presence of arterioles within this area using Superb Microvascular Imaging ("SMI").

*Materials and Methods*
Twenty-seven patients underwent a bilateral routine wrist ultrasound, including SMI between January 28th and February 28th, 2019. The images from 54 wrists were retrospectively reviewed by two radiologists to evaluate presence and location of arterioles in the Safe Zone. In addition, 5 cadaveric wrists injected with intra-arterial red latex underwent a dissection of the carpal tunnel.

*Results*
In the Safe Zone, arterioles were seen above the flexor retinaculum in 36 wrists (36/54; 66.7%) and under the flexor retinaculum in 21 wrists (21/54; 38.9%). The arterioles located under the flexor retinaculum were more frequently located close to the median nerve (21/54; 38.9%) than to the ulnar artery (9/54; 16.7%). In cadaveric wrists, arterioles were seen above the flexor retinaculum in 3 wrists (3/5; 60%) and under the flexor retinaculum in 2 wrists (2/5; 40%).

*Conclusion*
Arterioles can be seen in the Safe Zone both above and under the flexor retinaculum. Under the retinaculum, these vessels are essentially observed in the proximal aspect of the carpal tunnel and more frequently close to the median nerve.

**Keywords**
Carpal tunnel release; ultrasonography; Superb Microvascular Imaging; Safe Zone; ulnar artery, median nerve.

**Key Points**

- Treatment of carpal tunnel syndrome is one of the most frequent wrist interventions, but is also a treatment in permanent improvement ;
- The Safe Zone located between the median nerve and the ulnar neurovascular bundle is targeted during these interventions, as it is considered to be avascular ;
- New imaging techniques such as SMI enables the visualization of arterioles within the Safe Zone (visible both above and under the flexor retinaculum) ;
- Arterioles were more frequently observed in the proximal aspect of the carpal tunnel ;
- Under the retinaculum, they were more frequently seen in proximity to the median nerve.

**Abbreviations and Acronyms**

- SMI: Superb Microvascular Imaging
  PRF: Pulse Repetition Frequency

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