

NERVES ON MAGNETIC RESONANCE IMAGING

James D. Collins, MD, Marla L. Shaver, Poonam Batra, MD, and Kathleen Brown, MD
Los Angeles, California

Nerves are often visualized on magnetic resonance imaging (MRI) studies of the soft tissues of the chest and shoulder girdle. To learn the reasons for the contrast between the nerves and adjacent tissues, the authors obtained a fresh specimen containing part of the brachial plexus nerves from the left axilla and compared MRI with x-ray projections and photomicrographs of histologic sections. The results suggest that the high signals from the nerves stand out in contrast to the low signals from their rich vascular supply.

Several models of radiographic pathological correlation have been constructed to explore whether a density on a radiographic image represents an abnormal or normal fluid or tissue anatomical structure. Hoffman et al¹ constructed a model with balloons to demonstrate how intraluminal fluid with air could be mistaken as a sign of bowel wall separation. Collins et al found 25 mL to be the smallest effusion measured on the upright chest film² and also demonstrated the smallest detectable calcification on the plain chest radiograph.³ Moskowitz et al⁴ showed that 5 mL is the smallest effusion measurable on the lateral decubitus chest radiograph. All of these were

constructed to explain the radiographic correlation with clinical pathology.

Anatomical structures can be seen on medical images only if there is significant contrast between them and their immediate surroundings. Nerves can be seen in magnetic resonance imaging (MRI) studies of the abdomen, pelvis, extremities, chest, and shoulder girdle. It is not obvious why the nerves stand out from the surrounding tissues. To explore this, the authors have studied a fresh tissue specimen containing nerves, an artery, a vein, and lymphatics. It appears that the rich vasculature nourishing the nerves also provides sufficient contrast to make them visible in MRI studies of soft tissues.

Magnetic resonance signals display images of gross and surface anatomy not previously demonstrated by conventional x-ray. Surface anatomy structures, such as muscles of the chest, have been easily identified anatomically by fascial plane separation from surrounding anatomy in earlier reports.^{5,6}

The magnetic resonance images produced for this presentation correspond to the concentration, distribution, and flow density of hydrogen nuclei exhibiting nuclear magnetic resonance.⁷ Because all magnetic resonance images are somewhat dependent on proton density, tissues with a higher proton density provide a higher signal compared with tissues with a lower proton density.

Generally, a gray scale will show fat as a white image and muscle as shades of gray. Because excited protons are best imaged in the static state, the flowing state renders a dark or black signal because the excited protons have moved on and are not available for imaging. Therefore, blood is white (high signal) in the static state and black (low signal) in the flowing state.

The authors have constructed a model of soft tissue anatomy containing nerves, an artery, a vein, and lym-

From the Departments of Radiological Sciences, Pathology and Anatomy, UCLA School of Medicine, Los Angeles, California. Presented in part at the American Association of Anatomists 100th Annual Meeting in Washington, DC, May 10-14, 1987, and the National Medical Association's 92nd Annual Meeting in New Orleans, Louisiana, August 5, 1987. Requests for reprints should be addressed to Dr. James D. Collins, Department of Radiological Sciences, UCLA Center for the Health Sciences, Los Angeles, CA 90024.

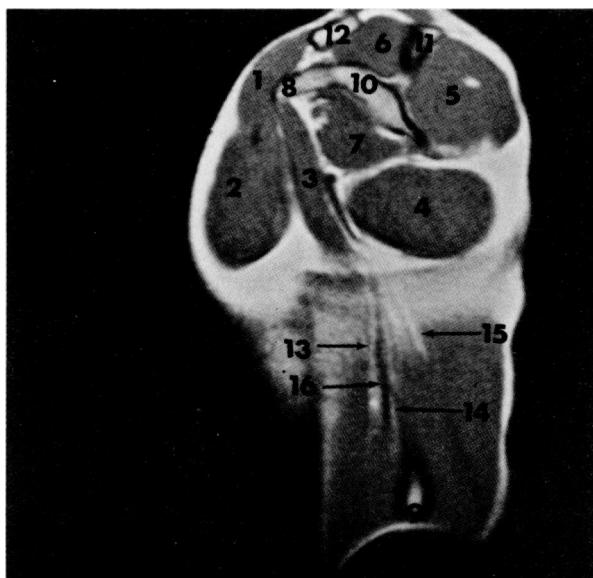


Figure 1. An MRI oblique sagittal view of the thorax and shoulder girdle obtained from the coronal view of the chest. (1) Anterior deltoid muscle, (2) pectoralis major muscle, (3) coracobrachialis muscle, (4) teres major muscle, (5) infraspinatus muscle, (6) supraspinatus muscle, (7) teres minor muscle, (8) coracoid process, (9) humerus, (10) scapula, (11) spine of the scapula, (12) clavicle, (13) median nerve, (14) ulnar nerve, (15) radial nerve, (16) brachial artery.

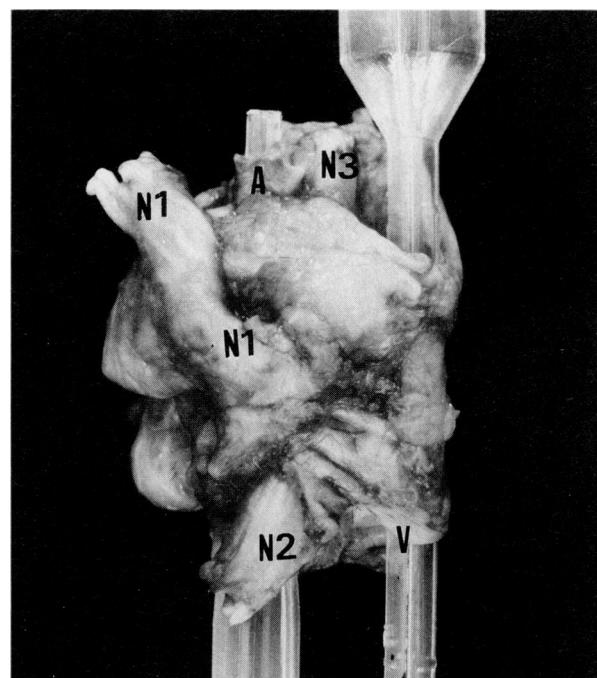


Figure 2. Gross specimen from the left axilla including artery (A), vein (V), and nerves (N1, N2, N3). A large plastic stent is in the artery and smaller stent in the vein. The arm of the nerve (N1) is to the left of the artery.

phatics to explain how soft tissue anatomy may be documented when displayed by MRI.

METHODS AND MATERIALS

A fresh tissue preparation containing parts of the brachial plexus nerves, axillary artery, a vein, lymphatics, and surrounding fat was obtained at autopsy (within 5 hours of patient's death) from the left axilla. A large plastic stent (tip diameter 3.3 mm, tubing diameter 8 mm) was placed in the artery and a smaller stent (tubing diameter 5 mm, bulb diameter 13 mm) in the vein to maintain the internal diameter of the two structures for correct identification. The entire preparation was then imaged by conventional x-ray (for radiographic and pathological correlation), photographed, and imaged with a 0.3 tesla Fonar permanent magnetic resonance unit on axial (transverse) and coronal planes. A saline solution was periodically sprayed on the tissue preparation to maintain moisture.

All images were recorded with a spin echo of TE=28, TR=500. Axial and coronal images were obtained in positive and negative modes to provide the best image of the structures in question. Color slide images were taken of the gross specimen prior to fixation for histological preparation. The plastic stents were left in position for the entire two-week fixation time to orient and maintain the internal caliber of the artery and vein. After fixation, the stents were removed and the specimen was prepared for microscopic observation. The transverse sections were stained with trichrome. The gross specimen, x-ray, MRI, and microscopic images were then correlated according to *Nomina Anatomica* terms.⁸

Six separate freshly autopsied brachial plexus specimens were obtained as described. Each specimen was carefully dissected and examined under the gross dissecting microscope.

RESULTS

The results are expressed as figures in the order of their completion. These images are a visual story of MRI soft tissue anatomy. Figures 2 through 7 demonstrate

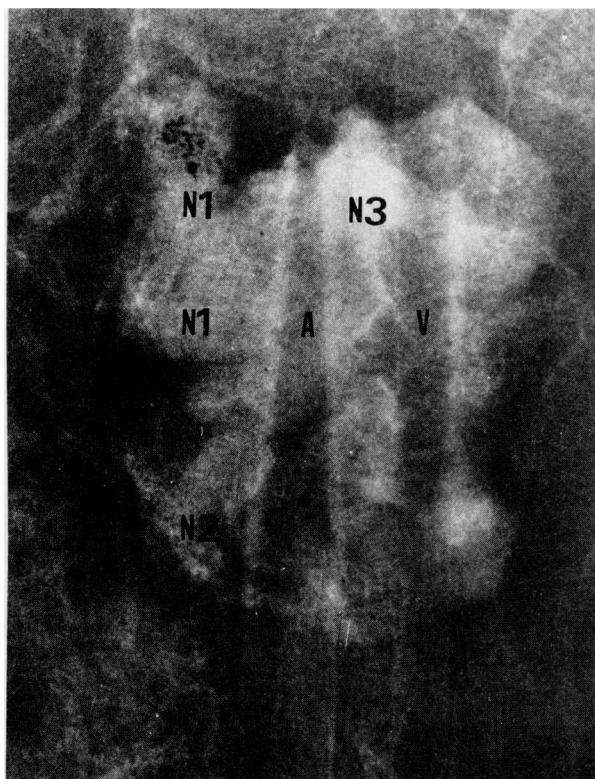


Figure 3. Conventional x-ray of the gross specimen (artery: A; vein: V; nerves: N1, N2, N3). The soft tissue structures are not sharply defined. The arm of the nerve cord is on the left of the artery. This image orients the viewer to the coronal magnetic resonance images.

consecutive steps by which the model was prepared.

Figure 1 shows an oblique sagittal view of the thorax to demonstrate the appearance of nerves in MRI studies of the chest. The anatomical structures are clearly labeled for landmark identification. Note the low signal (black) surrounding the brachial plexus (high signal). Figure 2 shows the gross specimen labeled with abbreviations (A, N1, N2, N3, V). The larger plastic stent is in the artery and the smaller stent is in the vein. The arm-like structure is the posterior cord (N1) of the brachial plexus and is used as the reference point for orientation to subsequent images. The medial nerve cord (N2) lies to the left of the artery, courses from left to right, branches over the artery and vein, crosses again to the left of the artery, and merges with soft tissues. The thick wall of the artery is easily identified because it contains the larger plastic stent.

Figure 3 is a conventional x-ray image of the soft

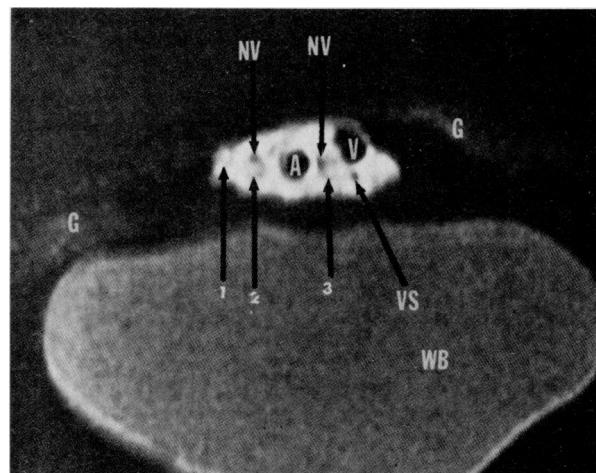


Figure 4. Axial MRI of the gross specimen (artery: A; vein: V; and nerves: 1, 2, 3). The nerves are identified by their relative intermediate signal. The nutrient artery (NV) superior to the brachial plexus nerves. The water soaked gauze (G) and water bag (WB) enhanced the imaging.

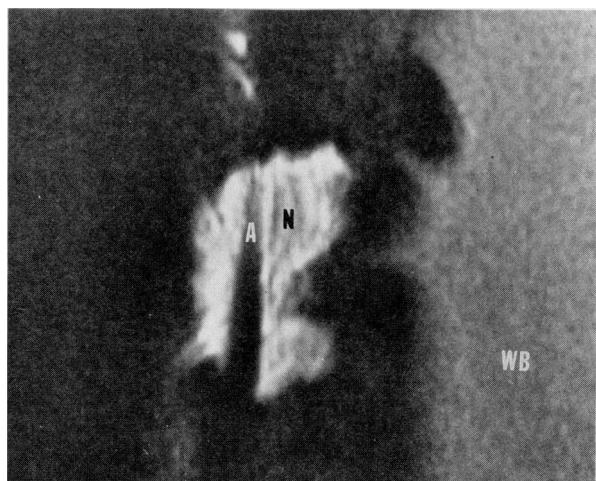


Figure 5. Positive coronal MRI of Figure 4. The intermediate signal of the nerves (N) are adjacent to the artery (A). The marginations between the nerves and deposited fat are well demarcated. The relative low signals represent vascular channels.

tissue specimen with the stents in place and labels for orientation. The specimen is overlaid by a moistened towel. Since the x-ray images of the soft tissues reflect their electron density, which are very similar for all soft tissue structures, the anatomical structures are not easily identified. The nerves (N1, N2, N3) are difficult to see.

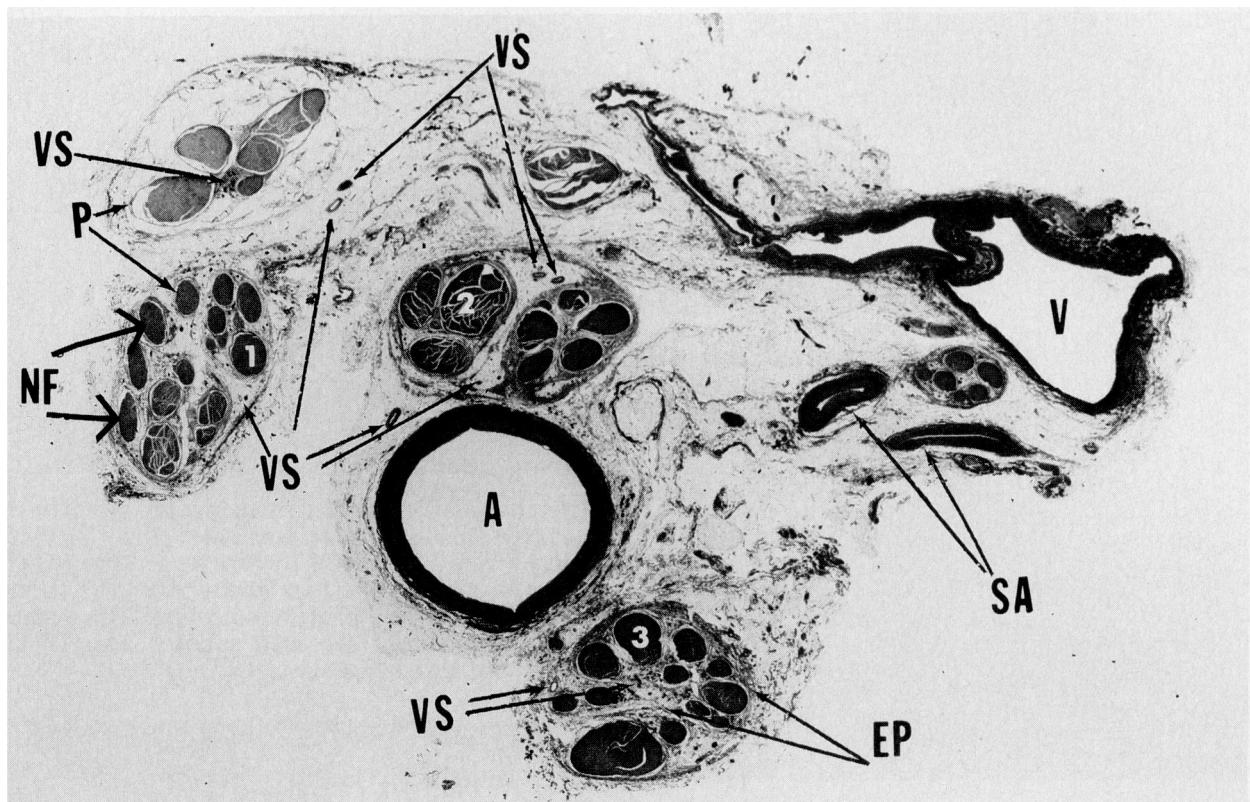


Figure 6A. This is the microscopic section of the gross specimen in Figure 2. The nerve bundles contain the fascicles (NF) and epineurium (EP) surrounds the nerve fascicles. Variable size vascular structures (VS) and small

arteries (SA) are present within the epineurium and perineurium (P), some still retain blood (black). (1) Posterior, (2) Medial, and (3) Lateral nerve cords. ($\times 12.5$)

Figure 4 is a midaxial (transverse section) MRI of the soft tissue specimen overlaid by a water-soaked gauze (G) dressing supported by a 500 mL intravenous plastic container of 5% dextrose and water (WB). The nerves (marked 1, 2, and 3) and the nutrient vessels (NV) can be seen. The aqueous solution was necessary to increase the signal from the model because the signal received would not allow the head coil surrounding the tissue to display the image within the magnetic resonance unit.

Void of blood and replaced by room air, the artery and vein are well outlined in Figure 4. The air substitutes for the blood flowing through the artery and vein, displaying a low signal (black) as if filled by rapidly flowing blood. Air has also replaced the fluid within a small vascular channel (VS) inferior to the vein (arrow). The nerves that lie between the blood vessels are faintly imaged by intermediate signals (arrows) overlaid by nutrient vessels (NV). Smaller vascular structures branch from the artery

(A) and vein (V) and are displayed as low signals similar to the vascular web surrounding the nerve cords.

Figure 5 is a 0.9 mm slice in a plane through the artery. It shows the artery with adjacent intermediate signals of the nerves marginated by vascular structures displayed as low signals (black). The vein is not displayed because the cursor line does not cross the same level of tissue.

Figure 6A is the histologic preparation in a cross section corresponding to the axial plane of the specimen displayed by Figure 4. The structures in Figure 6A are indicated by symbols accompanying the anatomical nomenclature, ie, nerve fascicles (NF), perineurium (P), epineurium (EP), artery (A), vein (V), small artery (SA), and vascular structures (VS). The epineurium surrounds a large bundle of nerves and interlaces between the nerve fascicles. Larger vascular structures are identified (VS). The web-like anastomosing smaller vascular supply is

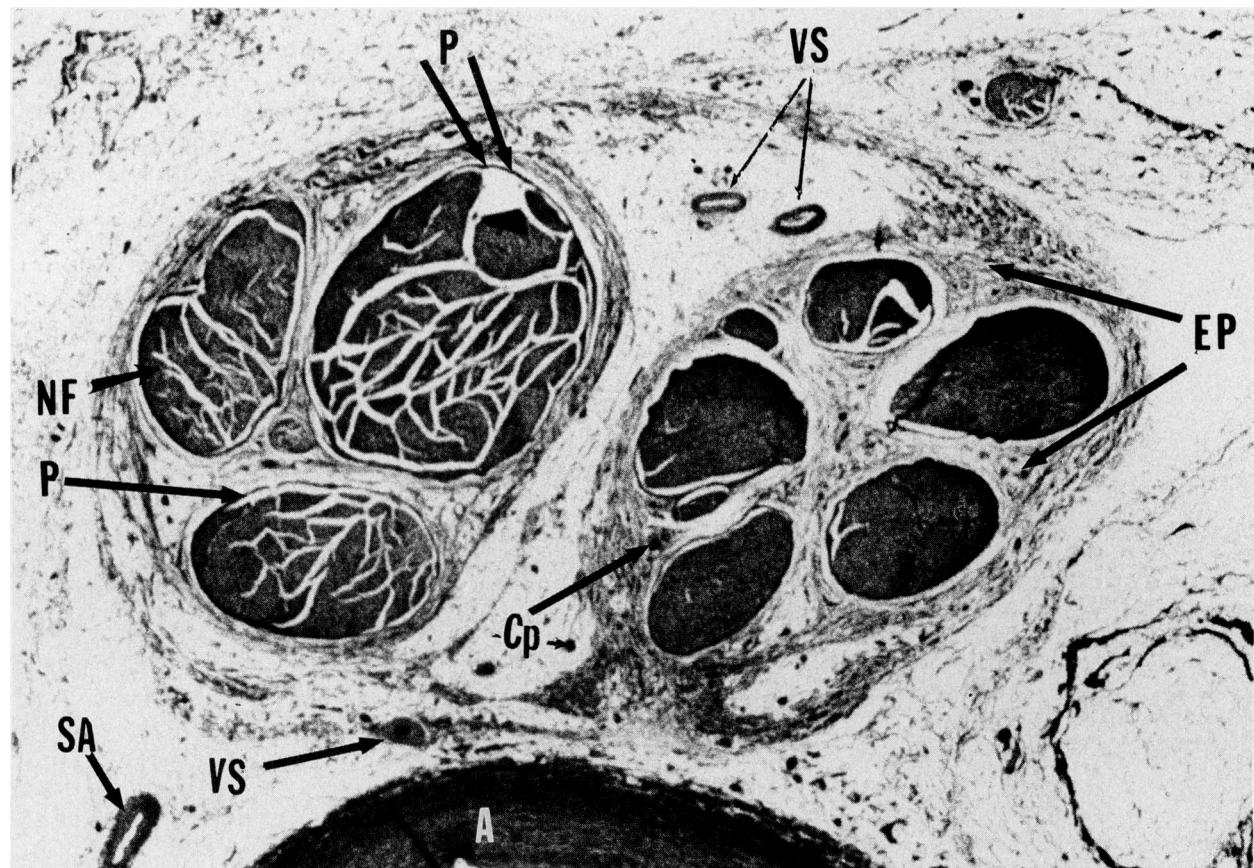


Figure 6B. This is the magnified medial nerve cord of Figure 6A. Note the variation in the size of the vascularity. Arrows indicate vascular structures (VS) within the epineurium (EP).

Nerve fasicles (NF), axillary artery (A), perineurium (P), capillaries (Cp), and small arteries (SA). (x60)

demonstrated by the many smaller black "dots" that are scattered throughout the connective tissue surrounding the nerve cords (1, 2, 3) and within the epineurium (EP). These small abundant vascular structures are islands of red blood cells within connecting arterioles and veins (magnified 12.5 \times specimen).

Figure 6B is the magnified microscopic section of the medial cord (Figure 6A). Small arteries, veins, and smaller vascular structures are scattered within the surrounding connective tissue sheath. This demonstrates the smaller dark vascular structures (VS) inside and outside the epineurium. Smaller vascular structures (Cp) are identified within the epineurium (EP) (60 \times gross specimen).

Figure 7 is the negative mode of Figure 4, which demonstrated the large nutrient vessels (NV) imaged as white structures overlying the nerve cords (1, 2, 3) and small vascular structures inferior to the vein. Fat is

displayed as a low signal (black) in the negative mode highlighting the nerves and blood vessels.

DISCUSSION

A peripheral nerve receives its blood supply from a succession of vessels along its entire length. The intraneurial arterial division anastomosis within the nerve is like a continuous spider web. A nutrient artery may supply blood directly from the main artery or indirectly from muscular or subcutaneous branches. The nutrient artery may run longitudinally on the surface of the nerve, branching into separate divisions, or it may divide into parallel longitudinal channels within the epineurium. In general, the emergence of veins from the nerve and the intraneurial pattern corresponds to the arterial distribution. The veins are usually larger and do not always run together with the artery, either inside or outside the nerve.⁹

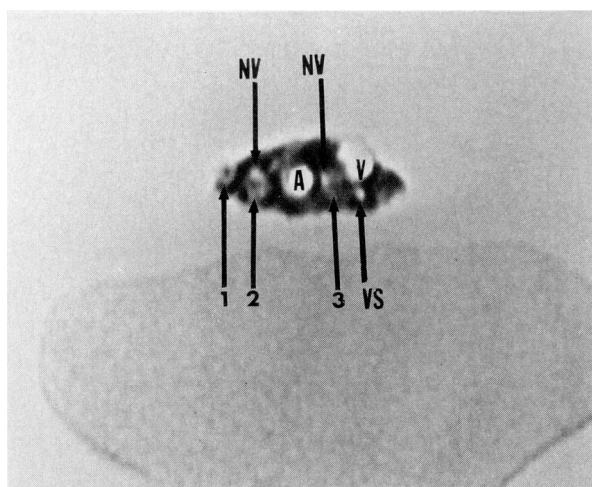


Figure 7. This is the negative mode of Figure 4. The nerve cords (1, 2, 3), axillary artery (A), and vein (V) are easily identified. The vascular structures (VS) illustrate the nutrient arteries (NV) overlying the nerves. This image supports the known anatomy as discussed in the text. Blood and air are displayed by MRI as low signals (black) in the positive mode and white in the negative mode.

In this model, the nerves are outlined as an intermediate signal on the axial plane (arrows) in Figure 4. Vascular structures (nutrient vessels), which are normally filled with flowing blood, overlay the nerve cords and appear as dark lines enhancing the separation of the nerves from the surrounding soft tissues. The microscopic section (Figure 6A) illustrates the nerve cords with vascular structures of varying sizes in the adjacent connective tissue. Two smaller parallel nutrient vessels lie within the epineurium of the medial cord between two nerve bundles. Microscopically, this section reveals many small arterioles and precapillaries inside and outside the epineurium (small black). Sunderland⁹ in 1945 described these structures as part of the intraneurial space. These dark vascular channels are referred to as capillaries (Cp) indicated in Figure 6B.

The medial cord in Figure 6B demonstrates two parallel vascular structures within the epineurium adjacent to the nerve bundles as seen in Figure 6A. Capillaries (Cp) are present in the epineurium and in the interfascicular spaces.⁹ Inferior and adjacent to the nerve cord is the larger axillary artery (A) and a smaller artery (SA). Sunderland⁹ demonstrated a rich vascular network in the intraneurium and the median nerve. Thus, the rich blood

supply within and outside the nerve would seem to be the major contributor to the contrast (low signal) separating nerves from surrounding fat and other soft tissues. Dyck et al¹⁰ substantiated that lymphatic channels lie within the intraneurial layers of tissue. Perhaps the lymphatics also play a role in the margination of nerves while imaging soft tissues.

CONCLUSION

This article offers one explanation why nerves are imaged by MRI. The authors are aware that tendonous insertions on MRI are displayed as low signals (black). Connective tissue may also image as low contrast to nerves. However, tendons are anatomically well defined and are not included in the model as described.

Connective tissue surrounding nerves is loosely applied. The rich blood supply within the connective tissue penetrates the nerves and seems responsible for the low signal (black) marginating nerves on MRI.

The images presented in this article are representative images to display soft tissue anatomy, and MRI has allowed our team to appreciate this definition.

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