Taking the Complexity out of Brachial Plexus MRI

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Introduction

Brachial plexus MRI scans are diagnostically highly relevant. However, the routine examination of the brachial plexus is made difficult by its structure and anatomy. Since imaging staff rarely perform such examinations, they often do so with trepidation and, as a result, may make errors. Moreover, the examination is most often described using a 3T MRI system [3–6]. In our multi-site structure in Annecy, France, consisting of 7 MRI scanners from Siemens Healthineers, this type of imaging, which was previously performed infrequently (0.06% in 2017), is requested and performed more often (0.13% in 2018 and 0.18% in 2019 [2]). Given the strong demographic pressure and subsequent growing demand for brachial plexus imaging [1], the optimization of protocols via the use of Dot engines, as well as new 3D acquisition techniques such as CAIPIRINHA SPACE, are required to better structure this examination, to reproduce it over time, and to homogenize it for our various MRI systems. In short, these protocols take the complexity out of brachial plexus imaging.

In this article, we share with you how we introduced brachial plexus MRI at 1.5T to cover 100% of indications by simplifying the work of radiology technologists, strengthening the analysis by radiologists (who do not perform this type of examination very often), and responding to the high demand for our activity.

1 Anatomical diagrams. [6]

The brachial plexus is formed by the union of the anterior branches of the last four cervical nerves (C5, C6, C7, C8) and the first thoracic nerve (T1). The union of these nerves contributes to the creation of the three primary trunks that form three secondary trunks and culminate in the terminal branches. Functionally, the posterior segment of the plexus largely corresponds to the plane of extension of the upper limb (shoulder, elbow, and wrist) and the anterior segment to the plane of flexion (elbow, wrist, and fingers).
Anatomical overview / indications

The indications for brachial plexus MRI are:
• **Trauma** (investigation of root avulsion): see Figures 7A, B.
• **Primary or secondary tumors**: see Figures 8A, B.
• **Inflammation** (radiculoplexus neuropathy, etc.): see Figure 9.
• **Thoracobrachial outlet syndrome**: see Figures 14, 15.

Investigation using MRI is complex:
• Multiple anatomical structures: arteries and veins, fat, bones, muscles, tendons, nerves;
• Inhomogeneities in the $B_0$ field related to air – neck – shoulders interfaces leading to difficulties in carrying out efficient $B_0$ adjustment (shimming); and,
• Proximity of the lungs: presence of motion artifacts related to breathing.

Robust acquisition techniques must therefore be applied.

Historically, our protocols have always been dependent on technologists/radiologists, who must choose from these options: T2w TSE 2D in 3 planes; or STIR TSE 2D or 3D; or T2w Dixon in 3 planes; or T1w TSE in 3 planes; CISS; postcontrast T1w TSE with fat saturation or water excitation; or T1w TSE Dixon; or T1w 3D Dixon VIBE.

The literature largely recommends the use of 3D TSE STIR (SPACE). However, such an application can be time consuming (8 to 12 minutes) [3, 4, 8] and is generally recommended for 3T. It would therefore appear to be inappropriate for our work, due to its impact in terms of time. In our structure, a 3T field only became available in September 2019, with the delivery of a MAGNETOM Lumina system, which is principally oriented toward neurological, abdominal, and pelvic imaging. Recent improvements in 3D techniques in general and the benefits of the CAIPIRINHA algorithm in particular, along with the systematic investigation protocol in the Dot Cockpit makes 3T MRI especially efficient and effective.

Brachial plexus investigation protocol

**Equipment**
The strategies described for each stage are applied and reproduced on our six 1.5T MRI scanners and our 3T MRI scanner, taking into account the technical constraints of each device.

• Choice of coils: Head/Neck 20ch/16ch + Body 18ch/12ch + Spine 24ch/32ch
• Investigation exclusively in 3D sequences: SPACE, FLASH, and Dixon VIBE techniques
• Creation of a Dot workflow dedicated to acquisition consoles
• Creation of a dedicated workflow on syngo.via

Our three MAGNETOM Aera systems use GRAPPA. For all the other MRIs, we were easily able to use the CAIPIRINHA technique for every 3D SPACE sequence.

**Patient positioning**
The patient is supine with their arms at their sides. The anterior element of the Head/Neck Coil can be removed with no loss of diagnostic quality. The Body Coil is placed contiguous to the NE1 element of the Head/Neck Coil.

In the case of brachial plexus pathologies originating in the last cervical vertebrae and following a path toward the arms, we apply cervical centering with an automatic movement of the table (for syngo MR E11 software) or “Select&GO” (for syngo XA software) cervical centering.

We routinely use three anterior elements and three posterior elements of the activated coils, which is ideal for CAIPIRINHA (high density of elements in the acquisition area).

As a first-line approach, we regularly use comparative bilateral anatomical coverage with a FOV of 300 mm, Phase FOV 125%, 120 slices at 1 mm thickness, and 20% phase oversampling to create reproducible images regardless of the patient, the user, or the system used.
**Acquisition**

1. **Dot Cockpit: Creating a Dot workflow for brachial plexus analysis**

The Dot Cockpit enables the establishment of different workflows to support the technologist and is fundamental in supporting this particular examination with the creation of strategies, alternatives, and the use of generic views for real-time reminders. Since 2014 (syngo MR E11), this tool adds real measurable value. Our Brachial Plexus Dot contains just a single strategy with a common core leading to four clinical decision points covering all medical indications for this anatomy (see Figure 3).

- On patient registration, our RIS Xplore (EDL, La Seyne Sur Mer, France) defines an examination label: “Brachial Plexus.”

All MRI systems from Siemens Healthineers are able to identify this label and to automate the selection of the dedicated Dot Engine. The starting protocol is, therefore, always the same with no time wasted on selection, while the likelihood of choosing an inappropriate protocol is reduced.
For technologists, the anatomical positioning of a 3D sequence is simple compared with the alternative positioning for the multiple 2D series required for this complex anatomical area.

All the copy references and automatic subtractions are enabled in the Dot Cockpit, resulting in a significant reduction in clicks.

Depending on the radiologist or the indication, the technologist merely has to follow the internally validated scheme: This is a single strategy with four alternatives defined as clinical decision points linked to the medical indication.

2. Choice of sequences

3D SPACE TSE technique

The 3D SPACE TSE technique is the most robust and reproducible [7] and is therefore indispensable. The main advantages are:

- Fine slice planes, possibility to map lesions or follow nerve paths in a mass;
- Choice of T2 or T1 weighting;
- Ability to use inversion recovery (IR) for homogeneous fat suppression;
- Image creation acceleration algorithms (GRAPPA and, especially, CAIPIRINHA);
- Not very sensitive to movement, i.e., acquisition with free breathing;
- No flow artifacts; arteries appear as a hypointense signal (black vessels);
- Possibility of wide anatomical coverage.

We use it with STIR, T1, and T2 weighting.

Coronal 3D SPACE STIR

In T2 weighting with fat suppression, the nerve roots appear hyperintense. A 3D STIR sequence is widely recommended for imaging the brachial plexus. The acquisition times are, however, often very long (8 to 10 minutes) [3, 4, 6, 8]. Our optimized MR imaging protocols on the 1.5T scanner are shown in Figure 4. They were defined in order to obtain optimal quality while keeping the acquisition time sequence below 5 minutes.

The benefits of CAIPIRINHA have enabled us to apply more qualitative parameters without compromises in terms of time, or actually to reduce the acquisition time for improved patient comfort and to limit movement during the examination.

Our radiologists have therefore been reassured about using the 3D STIR sequence. This sequence has also been spread across the whole fleet of MRI systems in order to improve our examinations of this anatomy (see Figure 5).

The next step is to work on suppressing some of the surrounding venous flows that appear as a hyperintense signal and can sometimes affect the radiologist’s analysis. The application of “black blood” gradients is an interesting option [5]. The flows are not suppressed completely and the signal of all tissues appears a little bit flat, although the differentiation of the roots is good (see Figure 6A–C). Otherwise, there is a simple technique that makes it possible to obtain a satisfactory result: the injection of gadolinium [6]. When the injection of a contrast agent is anticipated for an investigation of the brachial plexus, we use the 3D SPACE STIR sequence post contrast. In fact, after injecting a gadolinium contrast agent, the T1 relaxation time of the surrounding vessels becomes similar to the T1 relaxation time of the fatty tissues; the vessel signal is therefore flattened [6].

![Figure 4: Table of 3D SPACE STIR parameters used at our facility. The parameters that represent a gain compared with the first base sequences on MAGNETOM Aera 1.5T with GRAPPA are shown in bold.](siemens.com/magnetom-world)
6 3D STIR SPACE performed on the same patient aimed at saturation of the surrounding vascular signals (colored arrows). Avanto Fit 1.5T system, Tim4G.

(6A) 3D CAIPIRINHA SPACE STIR standard: Good analysis of the plexus and surrounding vessels in a T2-weighted series with hyperintense signal.

(6B) 3D CAIPIRINHA SPACE STIR with the application of “black blood” gradients: Analysis of the nerve roots forming the plexus is still satisfactory; the vessels in the T2-weighted series are attenuated. The signal from all tissues is flattened with no loss of quality for the nerve roots.

(6C) 3D CAIPIRINHA SPACE STIR after injection of contrast agent. Almost complete suppression of the surrounding vessels. Very good differentiation of nerve roots.
Various cases on pathologies of the brachial plexus – coronal 3D SPACE STIR sequences

(7A) A 17-year-old patient with deficit in areas C5–C6 and right C7, in the context of trauma sustained two months prior. 3D STIR SPACE coronal sequences. Results: Thickening in T2 hyperintense signal of C6 root on the right (arrow). Radicular avulsion of C7 root on the right with pseudomeningocele (asterisk). T2 hyperintense signal of C8 root on the right in the interscalene triangle (arrowhead).
MAGNETOM Aera 1.5T system, Tim4G.

(7B) Pre-therapeutic assessment of a 53-year-old patient with a history of trauma. 3D STIR SPACE coronal sequence, thick MIP. Results: No visualization of the C6, C7, and C8 roots (blue arrow) of the right brachial plexus suggesting a cervical lesion with distal retraction (red arrow) of the plexus roots at 4 cm from their cervical origin. Edema from Wallerian degeneration of the plexus trunks and fascicules downstream. Edema due to denervation of the supraspinatus, infraspinatus, small circular, larger circular, subscapularis, deltoid, and longissimus muscles.
Tumor
(8A) Thick MPR. Mapping of a neurofibroma (blue arrow) in contact with the right brachial plexus.
(8B) Thick MIP. Vascular malformation with slow flow.

Inflammation
A 55-year-old patient monitored due to breast cancer with loss of sensitivity in the left upper limb in the context of radiotherapy. Suspected plexitis. Result: Plexitis in the left root (arrow).
Coronal T1w 3D SPACE
We use this sequence because it enables an excellent anatomical and morphological analysis, (Fig. 10) including analysis of anatomical reports in 3D, assessment of nerve caliber, excellent muscle/fat/bone/nerve/black vessel contrast, and high signal reserve capacity.

The benefits of CAIPIRINHA make the T1w 3D SPACE technique an essential sequence due to its acquisition speed, the image quality, and enhanced patient comfort during the “arms raised” position (indicated for thoracobrachial outlet syndrome, as described below).

We apply it for 2 minutes 30 seconds on MRI systems equipped with the CAIPIRINHA algorithm (see table in Fig. 11).

### Comparative T1w 3D SPACE parameters for 1.5T and 3T MRI examinations at GIE IRM74, France

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Figure 11: Table showing T1w 3D SPACE parameters.

Axial T2w 3D SPACE
In indications of avulsions with pseudomeningocele, the benefits of T2w 3D SPACE provide an excellent complement (Fig. 12). It enables a myelographic study, depicting the intradural root segments, particularly in traumatic pathology, visualizing root avulsions. This sequence, which is always based on a basic 3D TSE SPACE with T2 weighting, provides good water (cerebrospinal fluid)/nerve contrast and submillimeter slices with the possibility of reconstructions in all planes [10].
Contrast-enhanced imaging: T1w SPACE or Dixon VIBE
The indications for contrast-enhanced MRI in the brachial plexus are inflammation, tumor, or angiography of the arteries (see thoracobrachial outlet syndrome below).

Our choice of post-contrast imaging comprises two alternatives: Coronal T1w 3D SPACE with automatic subtraction or T1w 3D Dixon VIBE (Fig. 13) for better management of fat saturation in this anatomy. It is recommended to avoid a fat saturation technique in this anatomical region. The B0 inhomogeneities are too significant, despite the use of a dedicated shim (Standard Neck).

3. Thoracobrachial outlet syndrome
The objective is to analyze the brachial plexus according to the same 3D SPACE STIR protocol associated with the T1w 3D SPACE, but also to compare the reduction of the costoclavicular space and the associated neurovascular compressions when in the dynamic “arms raised” position. Historically, most investigations have been performed using SAG T1w TSE for this indication [10]. We now have a T1w 3D SPACE sequence that is far more robust with respect to movements and different flows, making analysis possible in all planes (Fig. 15A–C). We systematically complement it with a 3D FLASH arterial angiography series in order to evaluate the caliber of the subclavian artery in the “arms raised” position (see Figures 14 and 15D).

Various cases on pathologies of the brachial plexus – coronal T1w 3D SPACE

Case 1: A 28-year-old patient presenting with left thoracobrachial outlet syndrome. Coronal FLASH 3D angio MIP with arms raised.

Results: Loss of flow in left subclavian artery at the level of the left costoclavicular pinching. The stenosis is evaluated at 90% according to the MRI scan.
Case 2: A 49-year-old patient presenting with left thoracobrachial outlet syndrome, with suspected plexus involvement.

15A) Coronal T1w 3D SPACE with arms raised, visualized in 3 planes at the level of the left subclavian artery.

15B) Analyzed area with arms at the side of the body in the sagittal plane (blue circle).

15C) Visualization with arms raised in the sagittal plane. Observation of the compression of the left subclavian artery (green arrow) between the clavicle (blue arrow) and the rib (red arrow).

15D) Coronal FLASH 3D Angio MIP (top) and VRT (bottom).

Results: Asymmetry in the caliber of the left subclavian artery (blue arrow) at the level of the costoclavicular pinching. Arms raised, stenosis evaluated at 60% according to the MRI scan.
Postprocessing with syngo.via

The benefits of 3D acquisition simplify the work of technologists in terms of anatomical positioning, while yielding a more extensive image volume for interpretation by radiologists. In addition, several image volumes are available for analysis. We have developed a dedicated flow for brachial plexus analysis in 3D. By default, the 3D STIRs are displayed in MIPs 3 mm thick. This flow comprises three main analysis steps:

• **1 morphological step** (see Figure 16): Synchronized visualization of the 3D STIR in comparison with the 3D T1 in the AX, COR, and SAG comparative planes. STIR – T1 – T1 arms raised.

• **1 angiography step** (see Figure 17): Comparative visualization in MIP of the angio performed with arms raised with the T1w morphological acquisition also performed with arms raised.

• **1 fusion angio step** (see Figures 18–20): The FLASH 3D angiography imagery is superimposed with gadolinium onto the morphological T1w 3D SPACE. The angiographic image will automatically be associated with a “hot body” scale look-up table (LUT). The window adjustment by the physician allows a T1 morphological analysis or post-injection angiography. The benefits of this image fusion are relevant for the correlation between the patient’s static anatomy and the dynamic angiographic analysis of the vessel of interest.

By configuring this syngo.via workflow in connection with the Dot acquisition, the radiologist is therefore automatically and immediately immersed in the image volumes. The differently configured synchronizations are very convenient in terms of the evolution of medical expertise (navigation, windowing, zoom, type of display, slice thickness). Handling becomes very simple and medical input is enhanced.
Third step in the syngo.via analysis with “hot body” T1w 3D SPACE and Angio FLASH 3D fusion window.

Compressive pathology: Fusion of contrast-enhanced angio FLASH 3D “hot body” window and T1w 3D SPACE arms raised images, centered on the compression zone of the left subclavian artery.

Compressive pathology in another patient: Fusion of contrast-enhanced angio 3D FLASH “hot body” window and T1w 3D SPACE images, centered on the compression zone of the right subclavian artery.
Conclusion

Within five years, we have greatly increased our diagnostic accuracy in examinations of the brachial plexus thanks to the new tools offered by Siemens Healthineers (Dot Cockpit, syngo.via VB30, the CAIPRINHA algorithm, and new XA interfaces), we have been able to:

- optimize our patient care time and reduce the amount of time they spend in the MRI scanner;
- systematize a protocol covering 100% of indications for this anatomy;
- simplify this complex application, thus reducing stress for technologists; and,
- improve radiologist’s analysis by optimizing and automating a maximum number of syngo.via post-processing tools for larger image volumes.

Our group has high expectations with respect to future developments in the field of brachial plexus imaging, and Compressed Sensing (CS SPACE) in particular. Since September 2019, the installation of our MAGNETOM Lumina 70 cm BioMatrix 3T MRI scanner has been the ideal tool to advance this investigation.

Acknowledgments

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References

2. Internal statistical data, GIE IRM74, Annecy, FRANCE