Chapter 7

Central Nervous System: MRI Protocols, Imaging Parameters, and Graphical Prescriptions

Central nervous system clinical applications are one of the most important and most common MRI imaging procedures as of today according to number of requests. Central nervous system can be divided to *head*, *neck* and *spine* applications. In this chapter, central nervous imaging applications will be covered in the same order for easier organization and follow up. For each section, we will discuss patient preparation, patient positioning, routine imaging protocols, additional imaging protocols for specific needs, graphical prescriptions and MR imaging protocol parameters.

Head Imaging

A step-by-step approach to head and brain MR imaging is given below:
Patient Preparation: The patient consent form should be given to the patient with a detailed explanation on the content. The form should be carefully read, all questions must be answered with clear answers such as "YES" or "NO," and additional clarifications should be written. It must be signed by the patient or legal guardians and confirmed by MR personnel. If there are any surgical implants, radiologist on duty has to make a decision based on implant type and MR compatibility. *If there is any suspicion or lack of information on the implant, do not take any risk with the patient safety and do not scan the patient*. If the form is complete with all the information, the patient should change to MR gown and remove any clothing with any metal. It is always a good practice to remove the

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Figure 7.1 A sample patient positioning in an eight channel brain coil.

jewelry as well. As the last line of patient safety, it is also a good practice to scan patient with a handheld metal detector before taking the patient to MRI room.

Patient Positioning: Patient head should be centered at the brain coil, chin pointing upward as shown in the figure below. Patient should use earplugs for hearing protection with additional headsets and/or immobilization pads should be placed around the head to reduce the noise and gross patient motion. The head should also be fixed with additional straps for further patient motion reduction while keeping patient safety and comfort as a priority. We also recommend placing the leg support pads for patient comfort. Alarm bell should be given to patient and tested. After landmarking the center of the brain coil or just below the eyes using laser marker lights (while the eyes are closed) or touch sensors, you can send the patient in and start the exam (Fig. 7.1).

Let's take a look at the most frequently used protocols and graphical prescriptions:

Routine Brain

Sample Imaging Protocols

Routine brain imaging is used for the patients referred to MRI without any specific diagnosis and it can be applied for general nonspecific headache, check-up, or similar control purpose scanning (Table 7.1).

Tips and Tricks

- Sagittal T1 can be replaced by a sagittal T2 sequence that might be more informative for visualizing craniocervical lesions (e.g., MS plaques, Chiari

Table 7.1 Routine brain protocols and prescription planes.

Sequences	Comments	Slice order
Three plane localizer	Acquire 1–3 slices minimum in each plane	
Axial T2	Parallel to anterior and posterior tips of corpus callosum (CC)	S-I
Axial T1	Parallel to anterior and posterior tips of CC	S-I
Axial T2 flair	Parallel to anterior and posterior tips of CC	S-I
Sagittal T1	Parallel to midbrain line and orthogonal to axial and coronal slice prescription	R-L
Coronal T2	Choose the middle sagittal slice and prescribe slices parallel to brain stem	A-P
Postinjection	***If you decide to inject***	
Axial T1	Same as axial slice prescription as above	S-I
Coronal T1	Same as coronal slice prescription as above	A-P
Sagittal T1	Same as sagittal slice prescription as above	R-L

malformations). Recently, diffusion weighted imaging (DWI) has been added to routine brain imaging as well. It can also be routinely acquired for older patients.

- It is also important to remind that T1 flair as an alternative to T1 imaging can be used for routine brain imaging. T1 flair sequence provides better gray-white matter contrast and has shorter acquisition times due to higher echo train length. It also further suppresses the CSF resulting in better image quality. However, due to inversion pulse associated with the T1 flair sequence, there are considerable worries regarding postcontrast use of T1 flair sequence.

Sample Imaging Parameters

These imaging parameters are given to provide an optimum tradeoff between higher resolution and shorter scan time.

1.5 T Parameters (Table 7.2).
3.0 T Parameters (Table 7.3).

Graphical Prescription

Axial, sagittal, and coronal imaging protocols are given below. The slice coverage in each image is shown in white color and reference landmarks are shown in red for easy follow-up (Figs. 7.2–7.4).

Table 7.2 Routine imaging parameters for an eight channel brain coil.

	T2	T2 flair	T1	T2	T1 flair	T2	Diffusion
Plane	Axial	Axial	Axial	Coronal	Sagittal	Sagittal	Axial
Sequence type	FRFSE	FSE	SE	FRFSE	FSE	FRFSE	EPI
TE	85	150	14	85	MinFull	85	Min
TR	3,360	8,000	460	4,680	2,384	4,860	6,000
ETL	16	Auto		18	7	22	
BW	31.25	31.2	19.2	31.2	27.8	41.67	250
Slice thickness	5.5	5.5	5.5	5.5	5	4.0	5.5
Slice spacing	1.5	1.5	1.5	1.5	1.5	1.0	1.5
FOV	24	24	24	24	24	22	24
Matrix	416 × 416	352 × 224	320 × 224	416 × 384	320 × 224	352 × 352	128 × 128
NEX/NSA	2	2	2	1	2	2	2
Freq Direction	A-P	A-P	A-P	S-I	S-I	S-I	R-L
TI/b value		2,000			750		1,000

Table 7.3 Routine brain imaging parameters for an eight channel brain coil.

	T2	T2 flair	T1	T2	T1 flair	T1 flair	Diffusion
Planes	Axial	Axial	Axial	Coronal	Sagittal	Axial	Axial
Sequence type	FRFSE	FSE	SE	FRFSE	FSE-IR	FSE-IR	EPI
TE	85	125	MinFull	85	MinFull	Minfull	Min
TR	4,000	9,000	875	3,050	2,400	2,500	8,000
ETL	20	Auto		24	7	7	
BW	62.5	31.2	31.25	41.67	62.5	62.5	250
Slice thickness	5	5	5	5	5	5	5
Slice spacing	1.5	1.5	1.5	1	0.5	1.5	1.5
FOV	24	24	24	24	24	24	24
Matrix	512 × 512	352 × 224	384 × 224	416 × 416	384 × 256	480 × 288	192 × 192
NEX/NSA	1	1	1	1	1	1	1
Freq Direction	A-P	A-P	A-P	S-I	S-I	A-P	R-L
TI/b value		2,250			920	920	1,000

Stroke Protocol

Sample Imaging Protocols

Sample protocol for acute or chronic stroke patient is given below. For stroke patients, DWI sequence is one of the most important sequences. Therefore, DWI sequence is prescribed right after the localizer images before potential gross patient motion makes the MR imaging very difficult (Table 7.4).

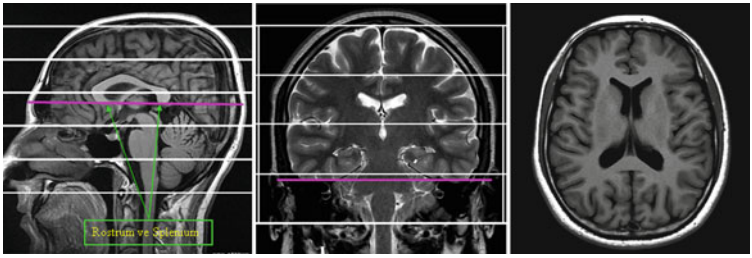

Figure 7.2 Axial brain planning from sagittal and coronal images.

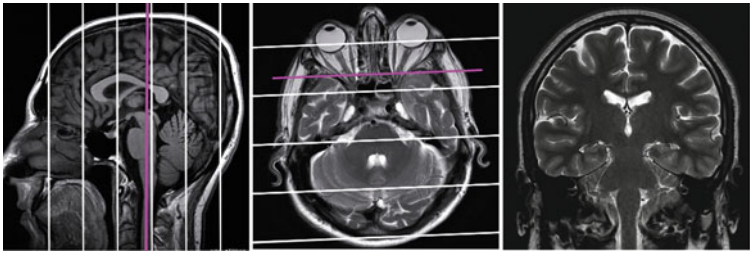

Figure 7.3 Coronal brain planning from sagittal and axial images.

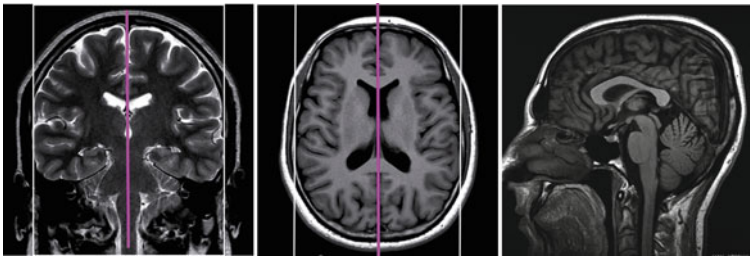

Figure 7.4 Sagittal planning from coronal and axial images.

Table 7.4 Brain stroke protocols and prescription planes.

Sequences	Comments	Slice order
Three plane localizer	Acquire 1–3 slices minimum in each plane	
Axial diffusion	Typically a ***b*** value of 1000 mm^2/sec is chosen for DWI	S-I
Axial T2	Parallel to anterior and posterior tips of CC	S-I
Axial T2 flair	Parallel to anterior and posterior tips of CC	S-I
Axial T2* GRE	Parallel to anterior and posterior tips of CC	S-I
Coronal T2	Choose the middle sagittal slice and prescribe slices parallel to brain stem	A-P
Sagittal T1 flair	Parallel to midbrain line and orthogonal to axial and coronal slice prescription	R-L
Axial 3D TOF	Prescribe for Circle of Willis and make it as short as possible	S-I
Postinjection	***If it is decided to inject***	
Perfusion EPI	EPI GRE T2* sequence prescribed to cover the whole brain with a 5–7 mm slice thickness and 1.5–2.0 s scan time per phase (total of 40 phases)	S-I
Axial T1	Same as axial slice prescription as above	S-I
Coronal T1	Same as coronal slice prescription as above	A-P
Sagittal T1	Same as sagittal slice prescription as above	R-L

Tips and Tricks

- GRE is T2* weighted sequence is very sensitive to local magnetic field inhomogeneities induced by iron in the blood and blood-breakdown products. Therefore, it is preferred in stroke cases for detecting acute or chronic hemorrhage. To take this advantage and further reduce the total scan time, coronal T2* can be prescribed instead of coronal T2.
- Parallel MR imaging is recommended at least for DWI imaging to reduce the susceptibility artifacts around posterior fossa. If it is available, non-EPI–based diffusion imaging techniques (e.g., PROPELLER DWI) can be used to further reduce the susceptibility artifacts as shown in Figs. 7.5 and 7.6.
- *Perfusion MRI*: Perfusion imaging can be performed either with gradient echo–based (GRE) EPI sequences or spin echo (SE)–based EPI sequences. Perfusion imaging, combined with DWI, is used to define ischemic core and ischemic penumbra. In addition, there is a large volume of research indicating that it can be used for tumor grading as well. From perfusion imaging, it is also possible to calculate hemodynamic maps such as cerebral blood volume (CBV), cerebral blood flow (CBF), mean transit time (MTT), and time to peak (TTP).

Sample Imaging Parameters for 1.5 T

See Table 7.5

Graphical Prescription

Axial, coronal, and sagittal planning is same as routine brain as you can expect. The slice coverage and orientation for the 3D TOF sequence is shown below.

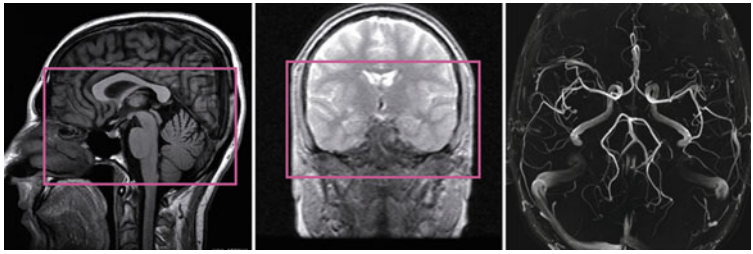

Figure 7.5 Axial 3D TOF MR angiography planning from sagittal and coronal images is shown.

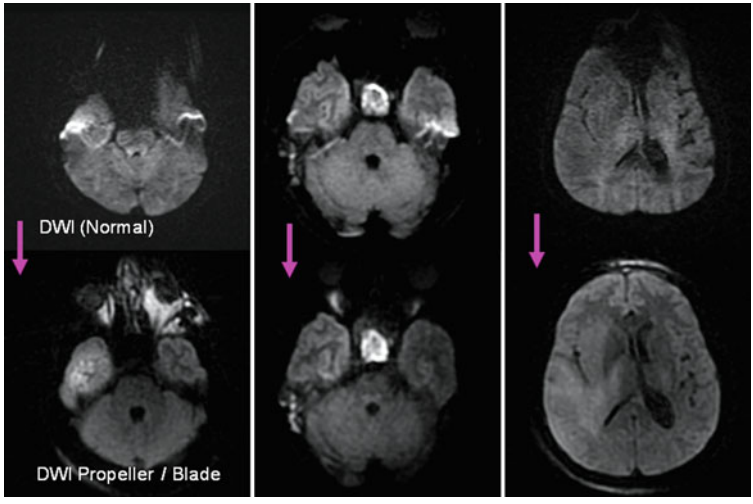

Figure 7.6 Comparison of EPI DWI and non-EPI DWI (PROPELLER DWI) images shows significant reduction in MR susceptibility artifacts.

Table 7.5 Brain stroke imaging parameters for an eight channel brain coil.

	Diffusion	Fast T2	T2 flair	T2*	T2	T1 flair	3D TOF	Perfusion
Planes	Axial	Axial	Axial	Coronal	Coronal	Sagittal	Axial	Axial
Sequence type	EPI	FRFSE	FSE	GRE	FRFSE	FSE	TofSPGR	EPI
TE	Min	85	150	25	85	MinFull	Min	40
TR	6,000	4,040	8,000	725	4,680	2,384	Min	1,500
ETL		27	Auto		18	7		
BW	250	62	31.2	10.0	31.2	27.8	20.0	Auto
Slice thickness	5.5	5.5	5.5	5.5	5.5	5	1.2	5.5
Slice spacing	1.5	1.5	1.5	1.5	1.5	1.5	–0.6	1.5
FOV	24	24	24	24	24	24	24	27
Matrix	128 × 128	352 × 352	352 × 224	288 × 224	416 × 384	320 × 224	352 × 224	128 × 128
NEX/NSA	2	1	1	1	1	2	1	1
Freq Direction	R-L	A-P	A-P	S-I	S-I	S-I	A-P	R-L
TI/b value/FA/Zip	$b = 1{,}000$		$b = 2{,}000$	FA: 25		TI: 750	Zip2	

Epilepsy

Epilepsy is a somewhat common neurological disorder characterized by sudden unprovoked seizures. Several disorders, such as trauma, cysts, tumors, arteriovenous malformations, which can cause epilepsy, can be visualized reliably with MR imaging. However, if there is no obvious disorder, MR imaging should be done in a specific way to better visualize the temporal love structures in oblique coronal view. In those cases, we recommend starting the MR imaging with sagittal plane rather than axial to save time and better plan the oblique coronal prescriptions. After the sagittal plane, routine axial plane images and high resolution oblique coronal images are prescribed.

Sample Imaging Protocols

See Table 7.6

Table 7.6 Sample sequences for brain epilepsy protocol.

Sequences	Comments	Slice order
Three plane localizer	Acquire 1–3 slices minimum in each plane	
Sagittal T1 flair	Parallel to midbrain line and orthogonal to axial and coronal slice prescription	R-L
Axial T2	Parallel to anterior and posterior tips of CC	S-I
Axial T2 flair	Parallel to anterior and posterior tips of CC	S-I
Axial T1 flair	Parallel to anterior and posterior tips of CC	S-I
Coronal T2 flair	Perpendicular to temporal lobes, specifically to hippocampus with a 3–4 mm slice thickness	A-P
Coronal T2-IR	Perpendicular to temporal lobes, specifically to hippocampus with a 3–4 mm slice thickness	A-P
Coronal T2	Perpendicular to temporal lobes, specifically to hippocampus with a 3–4 mm slice thickness	A-P
Coronal 3DT1-IR	Whole brain is scanned with the same coronal angle as above with 2–3 mm slice thickness	A-P
Postinjection	***No injection is needed if there is no lesion***	
Axial T1	Same as axial slice prescription as above	S-I
Coronal T1	Same as coronal slice prescription as above	A-P
Sagittal T1	Same as sagittal slice prescription as above	R-L

Sample Imaging Parameters for 1.5 T

The imaging parameters for the epilepsy protocol are shown below for a 1.5-T system. Please note that the protocols that are same as the routine brain imaging are not shown in Table 7.7.

Graphical Prescription

Axial and sagittal brain prescriptions are same as routine brain, and oblique coronal imaging prescription planes should be perpendicular to hippocampus as shown in Fig. 7.7.

Hemorrhage

Sample Imaging Protocols

It is important to complete the MRI scan for hemorrhage patients. Therefore, only the most critical sequences are prescribed in as short scan time as possible. If you plan to run MR angiography, please remember that hemorrhage looks hyperintense on time-of-flight (TOF) technique and it can be quite difficult to visualize vascular structure in hemorrhagic regions. Therefore, we recommend phase contrast (PC)–based MRA sequences with a proper velocity encoding (venc) in order to visualize the flowing protons only.

Sample protocols for hemorrhagic patients are shown in Table 7.8.

Sample Imaging Parameters for 1.5 T

See Table 7.9

Graphical Prescription

All the graphical prescriptions are same as routine brain imaging.

MS (Multiple Sclerosis) and Demyelination Diseases

Sample Imaging Protocols

Multiple sclerosis or the broader demyelinating diseases are the diseases of nervous system in which the myelin sheath around the neurons has been damaged. Unfortunately, the demyelinating diseases are on the rise globally and there is a strong chance that you will be scanning patients suffering from this type of disease using MR imaging. MRI examination on those patients usually includes contrast agent injection and postcontrast scanning in a later time (5–10 min after the injection). For MS patients, in addition to routine brain imaging, magnetization transfer (MT) pulse applied T1 sequence can

Table 7.7 Epilepsy protocol imaging parameters for an eight channel brain coil is shown.

	T2 flair	T2-IR	3DT1-IR	T2	T1 flair	T1 flair	Diffusion
Plane	Coronal	Coronal	Coronal	Coronal	Sagittal	Axial	Axial
Sequence type	FRFSE	FSE-IR	FSPGR	FRFSE	FSE	FSE	EPI
TE	150	35	MinFull	85	MinFull	Minfull	Min
TR	8,002	3,840	Min	4,680	2,384	2,366	6,000
ETL	Auto	8–12		18	7	7	
BW	31.2	41.67	15.63	31.2	27.8	27.8	250
Slice thickness	4	4	2	4	5	5.5	5.5
Slice spacing	0.5	0.5	–1	0.5	1.5	1.5	1.5
FOV	22	22	22	24	24	24	24
Matrix	288 × 224	352 × 320	288 × 288	416 × 320	320 × 224	320 × 224	128 × 128
NEX/NSA	2	2	1	4	2	2	2
Freq Direction	S-I	S-I	S-I	S-I	S-I	A-P	R-L
TI/b value/FA	TI: 2,000	TI: 120–200	TI: 400 FA: 12		TI: 750	TI: 750	$b = 1{,}000$

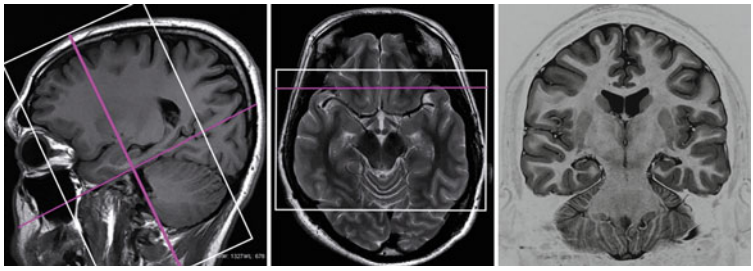

Figure 7.7 Oblique coronal imaging prescriptions for temporal lobe are shown.

Table 7.8 Sample protocol for hemorrhage patients.

Sequences	Comments	Slice order
Three plane localizer	Acquire 1–3 slices minimum in each plane	
Axial diffusion	Parallel to anterior and posterior tips of CC	S-I
Axial T2 fast	Parallel to anterior and posterior tips of CC	S-I
Axial T2 flair	Parallel to anterior and posterior tips of CC	S-I
Coronal T2*GRE	Choose the middle sagittal slice and prescribe slices parallel to brain stem	A-P
Sagittal T1 and PD	Parallel to midbrain line and orthogonal to axial and coronal slice prescription	R-L
Axial PCA	A proper venc selection is important for PC techniques	S-I

be added as well. MT pulse is a longer duration and off resonance (1,000–2,000 Hz away from resonant frequency) suppresses the proteins in the brain and delineates the MS plagues with a very good contrast. Since postcontrast scanning may lead to enhancement of different lesions, we recommend scanning MT T1 precontrast as well. It is also important to remember that MS and demyeliniating diseases are an active area of clinical research and you may add new sequences to your routine based on the slid information from recent literature.

The recommended protocols for MS and demyelinating diseases are given in sample protocol I and II, respectively.

Table 7.9 Hemorrhage protocol parameters for an eight channel brain coil are shown.

	Diffusion	Fast T2	T2 flair	T2*	PD	T1 flair	3D PC Art/Ven
Planes	Axial	Axial	Axial	Coronal	Sagittal	Sagittal	Axial
Sequence type	EPI	FRFSE	FSE	GRE	FSE	FSE	PC
TE	Min	85	150	25	MinFull	MinFull	Min
TR	6,000	4,040	8,000	725	1,500	2,384	20
ETL/VENC		27	Auto		5	7	10–60
BW	250	62	31.2	10	41	27.8	15.63
Slice thickness	5.5	5.5	5.5	5.5	5.5	5	3
Slice spacing	1.5	1.5	1.5	1.5	1.5	1.5	0
FOV	24	24	24	24	24	24	22
Matrix	128 × 128	352 × 352	352 × 224	288 × 224	416 × 384	320 × 224	256 × 192
NEX/NSA	2	1	1	1	1	2	1
Freq Direction	R-L	A-P	A-P	A-P	S-I	S-I	S-I
Gating/Venc							PG: 80/20
TI/b value/FA	1,000		2,000	25		750	FA: 20

Protocol I for MS patients
See Table 7.10

Protocol II for general demyelinating diseases
See Table 7.11

Table 7.10 A sample protocol for MS patients is given.

Sequences	Comments	Slice order
Three plane or scout	Acquire 1–3 slices minimum in each plane	
Axial T2	Parallel to anterior and posterior tips of CC	S-I
Axial T2 flair	Parallel to anterior and posterior tips of CC	S-I
Axial T1 flair	Parallel to anterior and posterior tips of CC	S-I
Axial T1 MT	Should be same as axial T2 prescription	S-I
Sagittal T2 flair	Parallel to midbrain line and orthogonal to axial and coronal slice prescription	R-L
Coronal T2	Choose the middle sagittal slice and prescribe slices parallel to brain stem	A-P
Postinjection	***If it is decided to inject, start scan 5 min after the injection***	
Axial T1 MT	Same as axial slice prescription as above	S-I
Coronal T1	Same as coronal slice prescription as above	A-P
Sagittal T1	Same as sagittal slice prescription as above	R-L

Table 7.11 Sample protocols MS and other demyelinating diseases.

Sequences	Comments	Slice order
Three plane or scout	Acquire 1–3 slices minimum in each plane	
Axial T2 flair	Parallel to anterior and posterior tips of CC	S-I
Axial T1 SE	Parallel to anterior and posterior tips of CC	S-I
Injection	***If it is decided to inject, scan at least two different planes***	
Sagittal T2	Parallel to midbrain line and orthogonal to axial and coronal slice prescription	R-L
Axial T2	Parallel to anterior and posterior tips of CC	S-I
Coronal T2	Choose the middle sagittal slice and prescribe slices parallel to brain stem	A-P
Coronal T1 SE	Same as coronal slice prescription as above	A-P
Axial T1 SE	Same as axial slice prescription as above	S-I

Tips and Tricks

- T2 flair: T2 FLAIR sequence is one of the most important sequences for MS patients. We recommend running T2 flair with interleaved acquisitions. This way, the slice crosstalk and CSF flow artifacts can be reduced further.
- 3D T2 Flair sequence may provide more details compare to 2D Flair sequence. Some of the recent studies showed that smaller WM lesions can be easily detected by using 3D T2 Flair with Fat Saturation.
- Injection time: In the second protocol, injection is done right after T1 weighted sequences to extend the time for postcontrast T1 sequences. However, the effect of contrast on sagittal and coronal T2 is negligible.

Sample Imaging Parameters for 1.5 T

See Table 7.12

Graphical Prescription

All the graphical prescriptions are same as routine brain imaging.

Trigeminal Neuralgia (TN)

Sample Imaging Protocols

The protocols for the patients referred to MRI for trigeminal neuralgia are almost similar to routine brain imaging. However, additional thin slice 2D T2 and T1 or 3D volume acquisitions should be added for trigeminal nerves. Even though most of the new MRI systems have quite impressive 3D balance GRE sequences, we recommend the imaging protocols with 3D sequences (Protocol I) and without 3D sequences (Protocol II) to cover all systems.

Protocol I using 3D Volume Imaging Sequences

See Table 7.13

Protocol II using only 2D Imaging Sequences

See Table 7.14

Sample Imaging Parameters for 1.5 T

See Table 7.15

Graphical Prescription

All the graphical prescriptions are same as routine brain imaging. Thin slice 2D and 3D sequences should be planned specifically for trigeminal nerves as shown in Figs. 7.8 and 7.9a.

Table 7.12 MS protocol imaging parameters for an eight channel brain coil is shown.

	T2	T2 flair	T2	T2 flair	T1 MT	T1	T2
Planes	Sagittal	Sagittal	Axial	Axial	Axial	Axial	Coronal
Sequence type	FRFSE	FSE	FRFSE	FSE	SE	SE	FRFSE
TE	85	150	85	150	MinFull	14	85
TR	6,040	8,000	4,680	8,800	500	460	4,680
ETL	22	Auto	23	Auto			18
BW	41	31.2	41.7	31.2	31	19.2	31.2
Slice thickness	4	4.0	5.5	5.5	5.5	5.5	5.5
Slice spacing	0.5	0.5	1.5	1.5	1.5	1.5	1.5
FOV	22	24	24	24	24	24	24
Matrix	352 × 352	352 × 224	416 × 416	352 × 224	320 × 224	320 × 224	416 × 384
NEX/NSA	2	1	2	2	2	2	1
Freq Direction	S-I	A-P	A-P	A-P	R-L	A-P	S-I
SAT band/zip							
TI/b value/FA		TI: 2,000		TI: 2,200	FA: 72		

Table 7.13 Sample TN protocols using 2D and 3D sequences.

Sequences	Comments	Slice order
Three plane localizer	Acquire 3–5 slices minimum in each plane	
Axial T2	Parallel to anterior and posterior tips of CC	S-I
Axial T2 flair	Parallel to anterior and posterior tips of CC	S-I
Axial 3D fiesta/CISS	Use 1–2 mm slice thickness and include posterior fossa	S-I
Axial 3D T1	Use 1–2 mm slice thickness and include posterior fossa	S-I
Sagittal T2	Parallel to midbrain line and orthogonal to axial and coronal slice prescription	R-L
Coronal 3D fiesta	Choose the middle sagittal slice and prescribe slices p arallel to brain stem	A-P
Postinjection	***If it is decided to inject!***	
Axial 3DT1	Same as axial 3D slice prescription as above 1–2 mm	S-I
Coronal T1	Same as coronal slice prescription as above	A-P

Table 7.14 Sample TN protocols using only 2D sequences.

Sequences	Comments	Slice order
Three plane localizer	Acquire 3–5 slices minimum in each plane	
Axial T2	Parallel to anterior and posterior tips of CC	S-I
Axial T2 flair	Parallel to anterior and posterior tips of CC	S-I
Axial T2 thin slice	Use 2–3 mm slice thickness and include posterior fossa	S-I
Axial T1 thin slice	Use 2–3 mm slice thickness and include posterior fossa	S-I
Sagittal T2	Parallel to midbrain line and orthogonal to axial and coronal slice prescription	R-L
Postinjection	***If it is decided to inject!***	
Axial T1 thin slice	Same as axial slice prescription as above	S-I
Coronal T1 thin slice	Same as coronal slice prescription as above	A-P

Brain Tumors (TM)

Sample Imaging Protocols

There are several types of brain tumors and MRI scanning should provide as much information as possible for the type and size of the tumor. Therefore, it is important to scan multiple planes to better visualize the tumor particularly postinjection of contrast agent. The protocols given below are used to provide as much detail as possible for the clinicians in relatively shorter scan time. Please note that we provided two different commonly used protocols for tumor

Table 7.15 Hemorrhage protocol imaging parameters for an eight channel brain coil is shown.

	T2	T2	T2 flair	3DT2	3DT1	T2	T1
Planes	Sagittal	Axial	Axial	Axial	Axial	Axial	Axial
Sequence type	FRFSE	FRFSE	FSE	Fiesta	FSPGR	FRFSE	FSE
TE	85	85	150	Min	MinFull	120	MinFull
TR	6,040	4,680	8,800	Auto	Auto	3,080	660
ETL	22	23	Auto			22	3
BW	41	41.7	31.2	83	15	31.2	31.2
Slice thickness	4	5.5	5.5	1.2	1.6	2.5	2.5
Slice spacing	0.5	1.5	1.5	–0.6	–0.8	0.5	0.5
FOV	22	24	24	22	18	18	18
Matrix	352 × 352	416 × 416	352 × 224	384 × 384	256 × 256	288 × 288	288 × 256
NEX/NSA	2	2	2	4	1	6	3
Freq Direction	S-I	A-P	A-P	A-P	A-P	A-P	A-P
SAT band/zip				Zip2	Zip2		
TI/b value/FA			2,200	FA65	Auto/15		

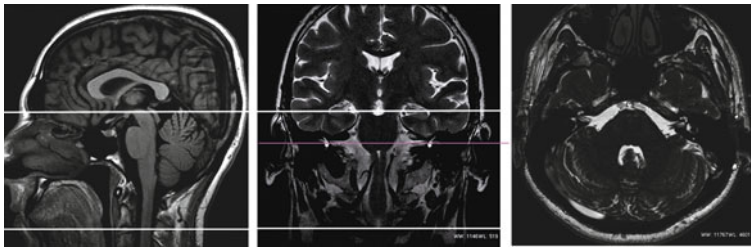

Figure 7.8 Thin slice axial prescription for trigeminal nerves is shown.

Table 7.16 A standard brain tumor protocol is given.

Sequences	Comments	Slice order
Three plane localizer	Acquire 1–3 slices minimum in each plane	
Axial T2	Parallel to anterior and posterior tips of CC	S-I
Axial T2 flair	Parallel to anterior and posterior tips of CC	S-I
Axial T1	Parallel to anterior and posterior tips of CC	S-I
Coronal T1	Choose the middle sagittal slice and prescribe slices parallel to brain stem	A-P
Post injection	*Scan at least in two planes post contrast*	
Axial T1	Same as axial slice prescription as above	S-I
Coronal T1	Same as coronal slice prescription as above	A-P
Sagittal T1	Parallel to midbrain line and orthogonal to axial and coronal slice prescription	R-L

patients. We also encourage our readers to explore the recently developed Fast Spin Echo 3D T2 and Fast Spoiled GRE T1 weighted protocols as alternative or additional information to 2D protocols in use today.

Protocol I
See Table 7.16

Protocol II
See Table 7.17

Sample Imaging Parameters for 1.5 T
See Table 7.18

Table 7.17 Imaging parameters for an eight channel brain coil is shown.

	T2	T2 flair	T1	T1	T1 flair	T2 flair	Diffusion
Plane	Axial	Axial	Axial	Coronal	Sagittal	Coronal	Axial
Sequence type	FRFSE	FSE	SE	SE	FSE	FSE	EPI
TE	85	150	MinFull	MinFull	MinFull	150	Min
TR	4,680	8,800	420	420	2,384	8,000	6,000
ETL	23	Auto			7	Auto	
BW	41.7	31.2	27	27	27.8	31.2	250
Slice thickness	5.5	5.5	5.5	5.5	5	5.5	5.5
Slice spacing	1.5	1.5	1.5	1.5	1.5	1.5	1.5
FOV	24	24	24	24	24	24	24
Matrix	416 × 416	352 × 224	384 × 224	320 × 224	320 × 224	352 × 224	128 × 128
NEX/NSA	2	2	3	2	2	2	2
Freq Direction	A-P	A-P	A-P	S-I	S-I	S-I	R-L
TI/b value/FA		2,200			750	2,000	1,000

Table 7.18 An additional brain tumor protocol is given.

Sequences	Comments	Slice order
Three plane localizer	Acquire 1–3 slices minimum in each plane	
Axial T2	Parallel to anterior and posterior tips of CC	S-I
Axial T1	Parallel to anterior and posterior tips of CC	S-I
Coronal T2 flair	Choose the middle sagittal slice and prescribe slices parallel to brain stem	A-P
Post injection	***Scan at least in 2 planes post contrast***	
Axial T1	Same as axial slice prescription as above	S-I
Coronal T1	Same as coronal slice prescription as above	A-P
Sagittal T1	Parallel to midbrain line and orthogonal to axial and coronal slice prescription	R-L

Tips and Tricks

- 3D T2 and T1 weighted isotropic sequences are valuable in brain TM imaging if they are available in your system.

Graphical Prescription

All the graphical prescriptions are same as routine brain imaging.

Orbits

Patient Preparation and Positioning

Patient Preparation: In addition to patient preparation for brain imaging, please make sure you remove any removable metallic dental implants, piercing and remove the makeup, especially eyeliner.

Patient Positioning: If you have only the brain coil, the patient positioning will be identical to routine brain imaging (see Fig. 7.1). However, if your site has loop coil with the setup attachment (also called as TMJ coil), you position the coil as close as possible to orbits and make sure that each loop is well centered as shown in the figure below. Please note that the loop coils usually have shorter signal penetration depth but remarkably higher SNR than a general brain coil (Figs. 7.9b,c).

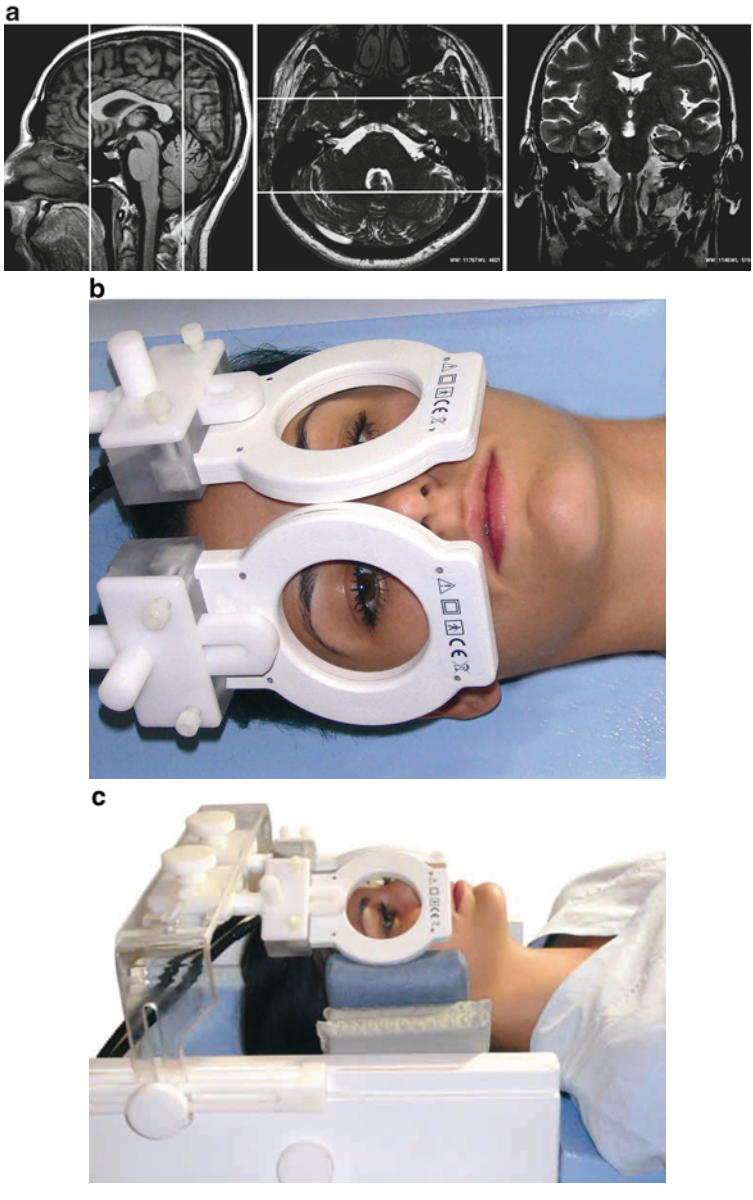

Figure 7.9 (a) Thin slice coronal prescription for trigeminal nerves is shown. (b) Orbital patient positioning using the loop coils. (c) Orbital patient positioning using the loop coils.

Table 7.19 Sample protocols for routine orbital imaging.

Sequences	Comments	Slice order
Three plane localizer	Acquire 9–11 slices in each plane	
Sagittal T2	Prescribe as a localizer to cover the whole brain	R-L
Axial T2 fat sat	Parallel to optical nerves with 2–3 mm slice thickness	S-I
Axial T1	Parallel to optical nerves with 2–3 mm slice thickness	S-I
Coronal T2 or STIR	Plan from axial view to include optic chiasm and globes	A-P
Sagittal T2	Prescribe two different sagittal slice groups, each group should be parallel to each optic nerve	R-L
Post injection	**Scan at least two planes post contrast*	
Axial T1	Same as axial slice prescription as above	S-I
Axial T1 fat sat	Same as axial slice prescription as above	S-I
Coronal T1 fat sat	Choose the middle sagittal slice and prescribe slices parallel to brain stem	A-P

Sample Imaging Protocols

Depending on the patient referral whether it is for orbital globes, optic nerves, or thyroid ophthalmology, different protocols shall be used. Below, a commonly used general protocol you can use for orbital scanning is given as a sample protocol (Table 7.19).

Tips and Tricks

- High resolution coronal T1-w is the best sequence for muscle volume measurements for patients with thyroid ophthalmopathy.
- If you are scanning mainly for globes, use a T1 Fat sat imaging and repeat it postcontrast.
- For MS or trauma patients, you can add Coronal STIR sequence in addition to Coronal T2.
- Always keep the FOV smaller to cover orbits only, increasing the FOV will have negative effect on fat sat imaging, although will decrease the resolution.

Sample Imaging Parameters for 1.5 T

See Table 7.20

Table 7.20 Imaging parameters for an eight channel brain coil is shown.

	T2FS	T1	T1FS	STIR	T2	T1	T2
Planes	Axial	Axial	Axial	Coronal	Coronal	Coronal	Sagittal
Sequence type	FRFSE	FSE	FSE	FSE-IR	FRFSE	FSE	FRFSE
TE	85	MinFull	MinFull	40	120	MinFull	85
TR	4,240	620	480	6,000	3,080	740	3,110
ETL	24	2	3	12	22	3	24
BW	20.83	20.83	16.67	20.83	31.2	20.83	20.83
Slice thickness	3	3	3	3	3	3	3
Slice spacing	0.3	0.3	0.3	0.3	0.3	0.3	0.3
FOV	16	16	16	16	16	16	12
Matrix	320 × 256	288 × 256	288 × 224	288 × 224	288 × 288	352 × 224	288 × 224
NEX/NSA	4	3	3	3	4	2	4
Freq Direction	A-P	A-P	A-P	S-I	S-I	S-I	S-I
SAT band/zip	S-I	S-I	S-I	S-I	S-I	S-I	S-I
TI/FA				140–160			

Graphical Prescription

Graphical prescriptions for orbital imaging are shown in Figs. 7.10–7.12.

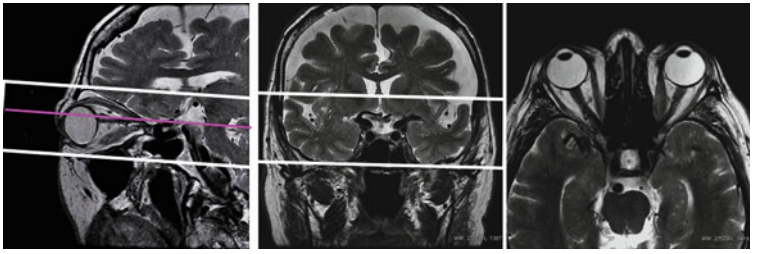

Figure 7.10 Axial slice prescription from sagittal and coronal images is shown.

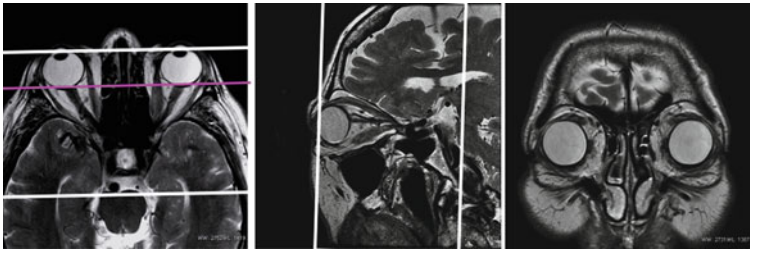

Figure 7.11 Coronal slice prescription from sagittal and axial images is shown.

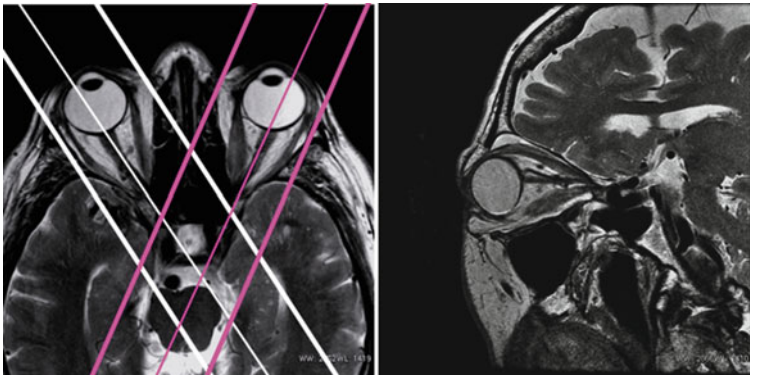

Figure 7.12 Oblique sagittal slice prescriptions from axial images are shown.

Internal Acoustic Canal (IAC)

Patient Preparation and Positioning

It is same as brain (please refer to Head Imaging).

Sample Imaging Protocols

Patients referred for IAC MRI exam usually suffer from tinnitus, hearing loss, or acoustic neurinoma. In general, the sample protocol below would be appropriate for these clinical requests. However, depending on the patient condition and clinical history, you might add additional sequences to this protocol.

- If the 3D sequences are not supported by your system, they might be replaced by 2D sequences.
- Balanced GRE sequences (Fiesta, CISS) provide unique tissue contrast known as T2/T1 for excellent delineation of nerves and fluid. However, tissue with closer T1 and T2 time will not be visualized on these sequences due to this division! Therefore, it should be carefully used for brain tissue–related lesions, which may not be even seen on these sequences (Table 7.21)!

Table 7.21 A routine IAC protocol.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5–7 slices in each plane	
Axial T2	For general routine brain imaging	S-I
Axial 3D fiesta	Cover only IAC with a slice thickness of 1–2 mm	S-I
Axial 3D T1 FS	Cover only IAC with a slice thickness of 1–2 mm	S-I
Coronal 3D fiesta	Plan from axial images to cover only IAC with a slice thickness of 1–2 mm	A-P
Injection	*Contrast injection is recommended if there is no contraindication*	
Axial 3D T1 FS	Same as above	S-I
Coronal 3D T1FS	Plan from axial images to cover only IAC with a slice thickness of 1–2 mm	A-P

Sample Imaging Parameters for 1.5 T

See Table 7.22

Graphical Prescription

Graphical prescriptions for IAC imaging are shown in Figs. 7.13 and 7.14.

Table 7.22 Imaging parameters for an eight channel brain coil is shown.

	3D fiesta	3D T1FS	3D fiesta	T2	T1	T2
Planes	Axial	Axial	Coronal	Axial	Axial	Coronal
Sequence type	Balanced GRE	SPGR	Balanced GRE	FRFSE	FSE	FRFSE
TE	Min	MinFull	Min	120	MinFull	120
TR	Auto	Auto	Auto	3,080	660	3,080
ETL				22	3	22
BW	83	15	83	31.2	31.2	31.2
Slice thickness	1.2	1.6	1.2	2.5	2.5	2.5
Slice spacing	–0.6	–0.8	–0.6	0.5	0.5	0.5
FOV	22	18	22	18	18	18
Matrix	384 × 384	256 × 256	384 × 384	288 × 288	288 × 256	288 × 288
NEX/NSA	4	1	4	6	3	6
Freq Direction	A-P	A-P	S-I	A-P	A-P	S-I
SAT band/zip	Zip2	Zip2	Zip2		S-I	
TI/FA	FA: 65	Auto/FA:13	FA: 65			

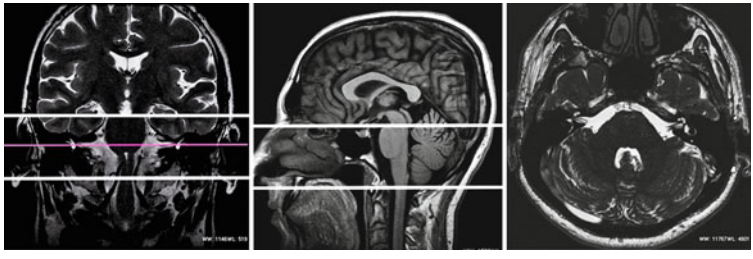

Figure 7.13 Axial slice prescription from coronal and sagittal images is shown.

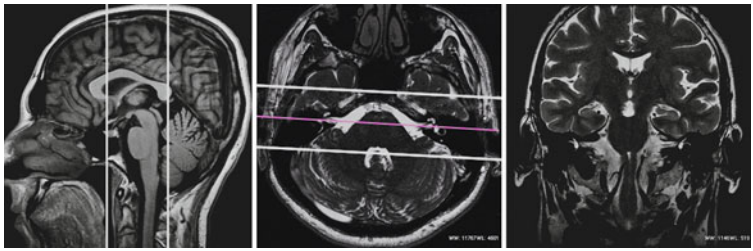

Figure 7.14 Coronal slice prescription from sagittal and axial images is shown.

Pituitary Gland (Hypophysis)

Pituitary gland MRI should be done with thinner slices and preferably with dynamic contrast injection to catch microadenomas (assuming there is no contraindication for contrast injection). Due to the potential effects of hormonal changes on the hypophysis MR imaging, the scan should be performed 7–10 days from initiation of menstruation period for female patients (general recommendation but not necessary).

The decision to include dynamic imaging for patients with pituitary macroadenoma and/or tumor has to be made by the radiologist. If you want to perform the dynamic scanning, you need to scan at least one precontrast phase and then acquire 3–5 more phases/repetitions from initiation of the injection of contrast agent. T1 Fat sat is helpful to delineate the enhancement patterns in patients with macroadenoma before and after operation.

Sample Imaging Protocols

See Table 7.23

Sample Imaging Parameters for 1.5 T

See Table 7.24

Graphical Prescription

Graphical prescriptions for hypophysis imaging are shown in Figs. 7.15 and 7.16.

Table 7.23 A standard pituitary dynamic MRI protocol is given.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5–7 slices in each plane	
Sagittal T1	Parallel to brain midline, covering the pituitary gland with a slice thickness of 2–3 mm	R-L
Coronal T2	Plan from sag images to cover only pituitary gland with 2–3 mm slice thickness, preferably in parallel to pituitary stalk	A-P
Coronal T1	Plan from sag images to cover only hypophysis with a 2-mm slice thickness, preferably in parallel to pituitary stalk	A-P
Dynamic coronal T1	Prescribe 3–5 slices only for pituitary gland. Acquire 1 precontrast and 4–5 postcontrast phases	A-P
Coronal T1	Same as above	A-P
Sagittal T1	Same as above	R-L

Table 7.24 Imaging parameters for an eight channel brain coil is shown.

	T1	T2	T1	Dynamic
Plan	Sagittal	Coronal	Coronal	Coronal
Sequence type	FSE	FRFSE	FSE	FSE
TE	MinFull	113	MinFull	MinFull
TR	560	3,300	560	400
ETL	3	23	3	3
BW	20.8	20	20	10.4
Slice thickness	3	2	2	3
Slice spacing	0.3	0.2	0.2	0.3
FOV	16	16	22	20 × 17
Matrix	224 × 224	352 × 320	288 × 224	224 × 224
NEX/NSA	5	6	6	1
Freq Direction	S-I	S-I	S-I	S-I
SAT band/zip	Oblique inferiorly/zip 512		Oblique inferiorly	O. inferiorly/Z512

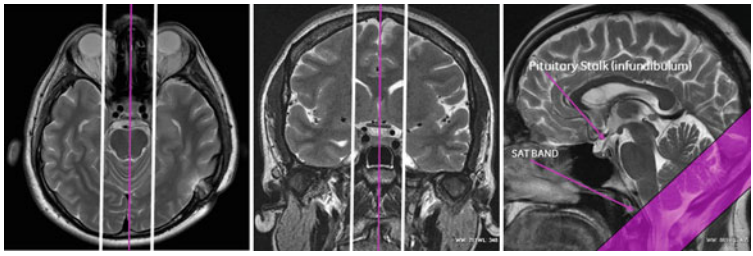

Figure 7.15 Sagittal slice prescription from axial and coronal images is shown. Please notice the additional saturation band placement inferoposteriorly.

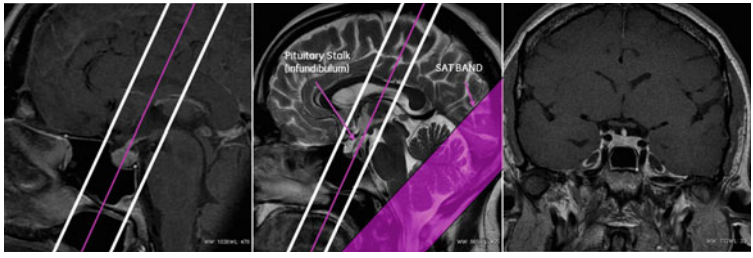

Figure 7.16 Coronal slice prescription from sagittal images is shown. Please notice the additional saturation band placement inferoposteriorly.

Cerebro Spinal Fluid (CSF) Flow Measurement

CSF flow measurements were done more frequently in the past and still there is a strong interest in different regions. Therefore, we decided to include CSF flow measurement protocol in this chapter as well.

Like other flow measurements, CSF flow measurement is done using a GRE PC imaging. As we mentioned in Chap. 4, PC imaging is used because of a simple physical rule in MRI: *flowing spins in the blood*, *body fluids such as*

CSF cause a phase change (*proportional to absolute flow*) *compared to nearby stationary* (*nonmoving*) *spins*. From this phase change, we can measure absolute flow in MRI quite easily. However, as an MR operator, we need to ensure that we place the slice perpendicular to the direction of flow and choose an appropriate velocity encoding for accurate results. Velocity encoding (venc) here is the key to reduce the user-dependent errors and related underestimation of absolute flow and velocity measurements. Let's explain a bit more on the role of venc for flow measurements:

Any MR image would consist of a magnitude and phase image. For any routine imaging, we simply discard the phase image since magnitude image gives as the majority of information. However, in flow measurements, we keep the phase image in addition to magnitude image. In this case, magnitude imaging is kept as an anatomical landmark but phase image would be critical. A phase image would have a phase range from −180° to +180°. As we mentioned above, if there is no flowing spins, we expect to have a 0 (zero) phase in that pixel. If we have flowing spins in the pixel, we will have a phase value proportional to the amount of velocity in the pixel. For example, if we choose a venc of 100 cm/s, we will have a phase value of 180° in that pixel assuming that the spins are moving at a velocity of 100 cm/s. If we have spins moving at 50 cm/s, then our phase image will give us 90° instead of 180° assuming that we use the same venc. However, if we rescan the same location using a venc of 50 cm/s, then I will end up with a phase value of 180° simply because I set up my dynamic range to map 50 cm/s to 180°. As an MR operator, it is our responsibility to choose the proper venc, so that we can map the maximum velocity in the region of interest to a 180°.

The velocity of CSF fluid in aqueduct (of Sylvius) can range from 2 to 9 cm/s (in normal healthy individuals) and, therefore, choosing a venc of 10 cm/s is usually a good choice. However, if you choose a very low venc value such as 5 cm/s in this case, then you will be getting flow aliasing artifact and would get incorrect results. This problem is easily visible when you look at the resulting phase images. You will see some darker spots (in systolic phases) or white spots (in diastolic phases) in the middle of aqueduct canal for CSF. This problem can be corrected by scanning with a higher venc choice. Notice that we did not mention much on positive or negative flow in the above discussion. The positive or negative phase simply indicates the direction of flow in respect to the chosen flow direction. Some of you might also be confused about the term flow and velocity. We usually measure flow and use the term flow since it is closely connected to velocity. Flow simply means the velocity (cm/s) of the blood within the vessel multiplied by the area (cm2) of the vessel. The units of flow will be mL/s.

Table 7.25 Sample CSF flow protocol.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5 slices in each plane	
Sagittal 3D fiesta/ CISS/or T1	Parallel to brain midline, covering optic chiasm with a slice thickness of 1–3 mm	R-L
2D cine PC for flow measurement	A single slice perpendicular to cerebral aqueduct (of sylvius) with a slice thickness of 5–7 mm and venc of 10 cm/s	S-I
Sagittal 2D PCA for flow visualization	A single slice exactly on the brain midslice with a slice thickness of 5–7 mm and venc of 10 cm/s	R-L

Table 7.26 Imaging parameters for an eight channel brain coil is shown.

	3D fiesta	T1 flair	2D flow	2D flow
Plane	Sagittal	Sagittal	Oblique axial	Sagittal
Sequence type	Balanced GRE	FSE	Cine PC	Cine PC
TE	Min	24	Min	Min
TR	Auto	2,500	Auto	Auto
ETL		7		
BW	83.33	31.2	15.63	15.63
Slice thickness	1.0	3	7	7
Slice spacing	0.0	0.3	0	0
FOV	22	22	16	20
Matrix	384 × 384	288 × 224	256 × 256	256 × 256
NEX/NSA	3	2	8	8
Freq Direction	S-I	S-I	A-P	S-I
VPS/VENC			8/10	8/10
TI/N.phases/FA	FA: 65	TI: 760	20/20	20/20

All the flow measurements should be done with cardiac ECG or PG gating devices and acquire 15–30 phases. Resulting PC image has to be processed with dedicated software for the absolute flow quantification.

Sample Imaging Protocols

See Table 7.25

Sample Imaging Parameters for 1.5 T

See Table 7.26

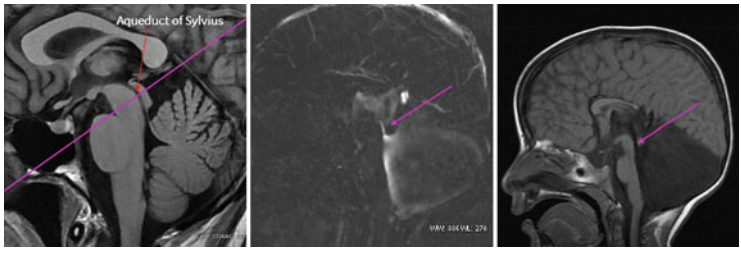

Figure 7.17 Oblique axial slice prescription of 2D cine PC slice from sagittal image. Please notice that oblique slice angle is adjusted to make it perpendicular to aqueduct.

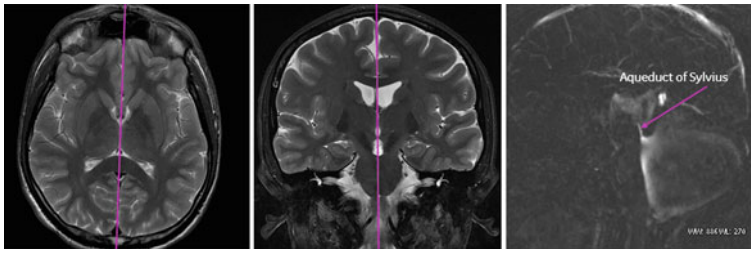

Figure 7.18 Oblique sagittal slice prescription from axial and coronal images is shown.

Graphical Prescription

Graphical prescriptions for CSF flow imaging are shown in Figs. 7.17 and 7.18.

Neck Imaging

Neck imaging is a challenge for MRI due to inhomogeneous anatomical structure of the neck and involuntary patient motion. In this section, we would like to share our experience on how to optimize the neck imaging and improve the MRI image quality for everyday scanning.

In neck imaging, swallowing, gross patient motion, and deep breathing are the main sources of motion-related artifacts. A better attention to patient comfort, utilizing faster sequences (for shorter scan time) reduces the motion-related artifacts resulting from voluntary and involuntary patient

motion. Moreover, potential dielectric artifacts can also degrade image quality and may cause regional signal drops in the neck imaging. Even though better understanding dielectric artifacts and developing efficient hardware/software reduces those artifacts greatly, we also recommend using dielectric pads for older 3 T scanners. The sample dielectric pads and how to place them are shown below for your convenience.

Patient Preparation and Positioning

Patient Preparation: The patient consent form should be given to the patient with a detailed explanation on the content. The form should be carefully read, all questions must be answered with clear answers such as "YES" or "NO," and additional clarifications should be written. It must be signed by the patient or legal guardians and confirmed by MR personnel. If there are any surgical implants, radiologist on duty has to make a decision based on implant type and MR compatibility. *If there is any suspicion or lack of information on the implant, do not take any risk with the patient safety and do not scan the patient*. If the form is complete with all the information, the patient should change to MR gown and remove any clothing with any metal. Before the MR exam, explain the nature and duration of the MR exam they will undergo. Also explain that patient motion will make a negative effect on image's quality. Make a habit of informing the patient before every sequence and communicate often to comfort the patient. It is always a good practice to remove the jewelry as well. As the last line of patient safety, it is also a good practice to scan patient with a handheld metal detector before taking the patient to MR room.

Patient Positioning: The neck coil should be centered on the coil. Patient should be in supine position and larynx being centered on the coil center. For better patient comfort and easier breathing, leg support pads should be placed under patient knees. Patient protection headsets and/or immobilization pads should be placed around the head to reduce the noise and gross patient motion. After handing the patient alarm to patient and testing it, you are ready to start the exam. After landmarking the center of the brain coil or just below the eyes using laser marker lights or touch sensors, you can send the patient in and start the exam (Figs. 7.19–7.21).

Let's take a look at the most frequently used protocols and graphical prescriptions for neck imaging:

Figure 7.19 Patient positioning on an eight channel spine (CTL) coil.

Figure 7.20 A sample dielectric pad and its proper placement on a spine coil on 3.0 T scanner.

Figure 7.21 Patient positioning on an eight channel neurovascular coil.

Routine Cervical Imaging

Sample Imaging Protocols

A sample routine cervical spine imaging protocol is given in Table 7.27.

Sample Imaging Parameters for 1.5 T

See Table 7.28

Table 7.27 A typical standard cervical spine protocol.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5 slices in each plane	
Sagittal T2	Plan 3 mm sagittal slices over coronal image where you can see the spinal cord to cover the whole spinal canal	R-L
Sagittal T1	Same as above	R-L
Axial T2*GRE/MERGE	Plan 3 mm oblique axial slices from sagittal plane. The slices should be crossing vertebral junctions	S-I

Table 7.28 Imaging parameters for an eight channel spine coil is shown.

	T2	T1	T2*	T1 flair	T2*GRE	T2	T1
Plane	Sagittal	Sagittal	Axial	Sagittal	Axial	Axial	Axial
Sequence type	FRFSE	FSE	GRE	FSE	MERGE	FRFSE	FSE
TE	85	MinFull	13.3	24	MinFull	130	MinFull
TR	3,140	640	509	2,250	500	3,500	720
ETL	27	3	4	7	Auto	25	3
BW	41.67	31.2	31.2	31.2	31.25	31.2	31.2
Slice thickness	3	3	3.0	3	3.5	3.5	3.5
Slice spacing	0.5	0.5	0.5	0.5	0.5	1.5	1.5
FOV	24	24	17	24	19	14	14
Matrix	352 × 256	320 × 224	288 × 224	288 × 224	320 × 192	256 × 256	256 × 256
NEX/NSA	4	4	2	4	2	4	2
Freq Direction	A-P	A-P	R-L	A-P	R-L	A-P	A-P
SAT band	A	A	A	A		R-L	R-L
TI/FA			FA: 30	TI: 750			

Sample Imaging Parameters for 3.0 T

See Table 7.29

Graphical Prescription

Graphical prescriptions for cervical spine imaging are shown in Figs. 7.22 and 7.23.

Table 7.29 Imaging parameters for an eight channel spine coil is shown.

	T2	T1	T2*	T1 flair	STIR	T2	T1
Plane	Sagittal	Sagittal	Axial	Sagittal	Sagittal	Axial	Axial
Sequence type	FRFSE	FSE-XL	MERGE	FSE	FSE-IR	FRFSE	FSE-XL
TE	110	MinFull	MinFull	MinFull	42	102	Minfull
TR	4,000	685	575	2,500	3,400	3,000	900
ETL	24	3		7	12	21	3
BW	31.25	41.7	31.25	62.5	31.25	50.0	41.7
Slice thickness	3.0	3.0	3.0	3.0	3	3.5	3.5
Slice spacing	0.5	0.5	0.5	0.5	0.5	1.5	1.5
FOV	26	26	20	26	24	20	20
Matrix	512 × 256	512 × 224	320 × 224	384 × 224	320 × 224	384 × 256	320 × 256
NEX/NSA	4	4	2	2	4	4	3
Freq Direction	A-P	A-P	R-L	A-P	A-P	A-P	R-L
SAT band			R-L			R-L	
TI/FA			FA: 20	TI: 860	FA: 145		

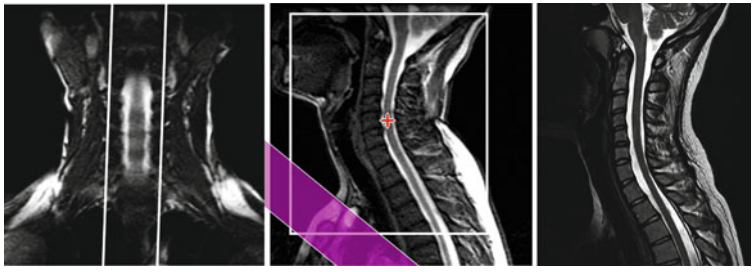

Figure 7.22 Sagittal slice prescription from coronal slices with saturation band is shown.

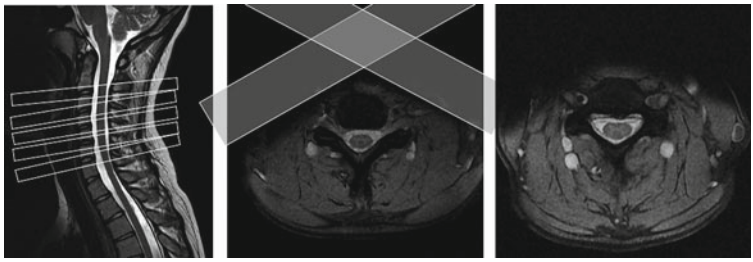

Figure 7.23 Axial slice prescription from sagittal and axial localizer slices with placement of saturation bands is shown.

Table 7.30 Cervical trauma protocol.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5 slices in each plane	
Sagittal T2	Plan 3 mm sagittal slices over coronal image where you can see the spinal cord to cover the whole spinal canal	R-L
Sagittal T1	Same as above	R-L
Sagittal STIR	Same as above	R-L
Sagittal T2*GRE	MERGE or MEDIC type (multiecho recalled gradient echo) sequences are recommended	R-L
Axial T2*GRE	Plan from the sagittal images a continuous block of 3 mm slices from cervical C1 to C7	S-I
Axial T2FS	Plan from the sagittal images a continuous block of 3 mm slices from cervical C1 to C7	S-I
Axial T1	Plan from the sagittal images a continuous block of 3 mm slices from cervical C1 to C7	S-I

Cervical Trauma

Sample Imaging Protocols

The sample protocol for cervical trauma patients can be used (Table 7.30).

Sample Imaging Parameters for 1.5 T

See Table 7.31

Graphical Prescription

Sagittal planning for trauma patients is same as cervical spine imaging. Axial planning is shown in Fig. 7.24.

Table 7.31 Imaging parameters for an eight channel spine coil is shown.

	T2	T1	T2*	STIR	T2*GRE	T2FS	T1
Plan	Sagittal	Sagittal	Sagittal	Sagittal	Axial	Axial	Axial
Sequence type	FRFSE	FSE	MERGE	FSE-IR	MERGE	FRFSE	FSE
TE	85	MinFull	Auto	42	MinFull	102	MinFull
TR	3,140	640	440	3,400	500	3,460	720
ETL	27	3	6	12	Auto	25	3
BW	41.67	31.2	62.5	31.25	31.25	31.25	31.25
Slice thickness	3.0	3	3.0	3.0	3.5	4.0	4.0
Slice spacing	1.0	1.0	1.0	1.0	0.5	0.5	0.5
FOV	24	24	24	24	19	16	16
Matrix	352 × 256	320 × 224	320 × 192	288 × 224	320 × 192	256 × 256	256 × 256
NEX/NSA	4	4	2	4	2	2	2
Freq Direction	A-P	A-P	A-P	A-P	R-L	A-P	A-P
SAT band	A	A	A	A		R-L	R-L
TI/FA				TI: 145			

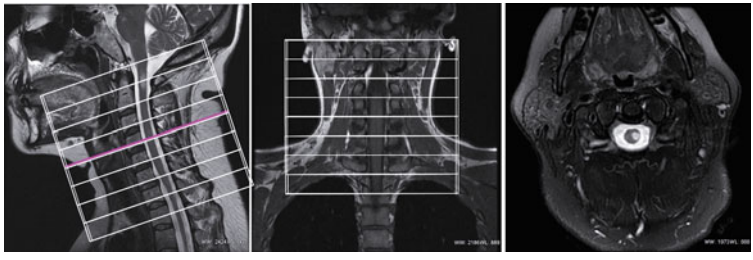

Figure 7.24 Axial slice prescription from sagittal and coronal slices is shown.

Cervical Metastases

Sample Imaging Protocols

The sample protocol for cervical metastases patients is given in Table 7.32.

Sample Imaging Parameters for 1.5 T

See Table 7.33

Table 7.32 A sample protocol for cervical metastases.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5 slices in each plane	
Sagittal T2	Plan 3 mm sagittal slices over coronal image where you can see the spinal cord to cover the whole spinal canal	R-L
Sagittal T1	Same as above	R-L
Sagittal STIR	Same as above	R-L
Axial T2 fat sat	Plan from the sagittal images a continuous block of 4 mm slices from cervical C1 to T1	S-I
Axial T1 fat sat	Same as above	S-I
Coronal T1	Plan from the sagittal images a continuous block of 4 mm slices covering vertebral column	A-P
Postinjection	*Scan at least two planes for postcontrast*	
Axial T1 fat sat	Same as above	S-I
Coronal T1	Same as above	A-P

Table 7.33 Imaging parameters for a eight channel spine coil is shown.

	T2	T1	STIR	T2FS	T1	T1
Plane	Sagittal	Sagittal	Sagittal	Axial	Axial	Coronal
Sequence type	FRFSE	FSE	FSE-IR	FRFSE	FSE	FSE
TE	85	MinFull	42	102	MinFull	MinFull
TR	3,140	640	3,400	3,460	720	760
ETL	27	3	12	25	3	3
BW	41.67	31.2	31.25	31.2	31.2	41.67
Slice thickness	4	4	4	5	5	4
Slice spacing	0.5	0.5	0.5	1.5	1.5	1.0
FOV	24	24	24	14	15	22
Matrix	352 × 224	320 × 224	288 × 224	256 × 256	256 × 256	352 × 256
NEX/NSA	4	4	4	2	2	2
Freq Direction	A-P	A-P	A-P	A-P	A-P	S-I
SAT band	A	A	A		R-L	S-I
TI/b value/FA			TI: 145			

Graphical Prescription

Sagittal planning for metastases patients is same as routine cervical spine imaging. Axial planning is shown in Fig. 7.25 and coronal planning is shown below.

Cervical Scoliosis

Sample Imaging Protocols

The spinal structure of cervical scoliosis patients is quite different than the normal patients. Therefore, it is recommended to image at least two or three different planes/orientations. For better graphical prescription, three-plane localizer or scout imaging should be acquired with larger slice spacing and 5–10 slices. In addition, actual scanning should start with coronal plane, so that the following sagittal and axial images can be prescribed more accurately.

The sample protocol for cervical scoliosis patients is given in Table 7.34.

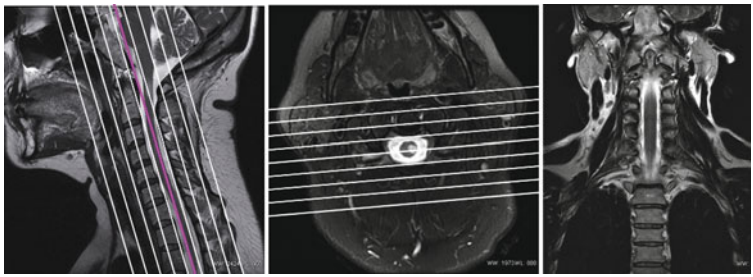

Figure 7.25 Coronal slice prescription from sagittal and axial slices is shown.

Table 7.34 A sample cervical scoliosis protocol is given.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5–10 slices in each plane	
Coronal T2	Plan from the sagittal images a straight coronal images with 3 mm thickness	A-P
Sagittal T2	Plan 3 mm sagittal slices over coronal image where you can see the spinal cord to cover the whole spinal canal	R-L
Sagittal T1	Same as above	R-L
Axial T2*GRE	Plan from the sagittal images a continuous block of 4 mm slices from cervical C1 to T1	S-I
Axial T2	Plan from the sagittal images a continuous block of 4 mm slices from cervical C1 to T1	S-I

Sample Imaging Parameters for 1.5 T

The imaging parameters for kinematic neck exam are same as routine c-spine exam. Please refer to the c-spine parameter table given before.

Graphical Prescription

Graphical prescriptions for cervical scoliosis imaging are shown in Figs. 7.26–7.28.

Cervical Myelography

Sample Imaging Protocols

Even though cervical myelography request is quite uncommon, in some cases you may prescribe cervical myelography for better visualization of spinal cord

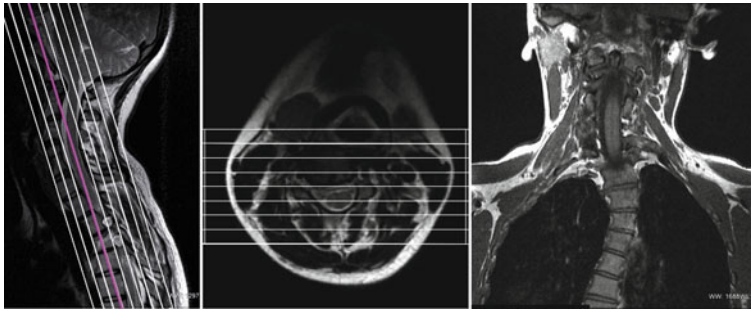

Figure 7.26 Coronal slice prescription from sagittal and axial slices is shown.

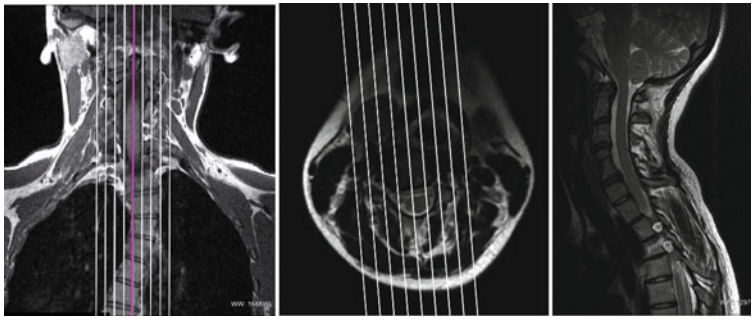

Figure 7.27 Sagittal slice prescription from coronal and axial slices is shown.

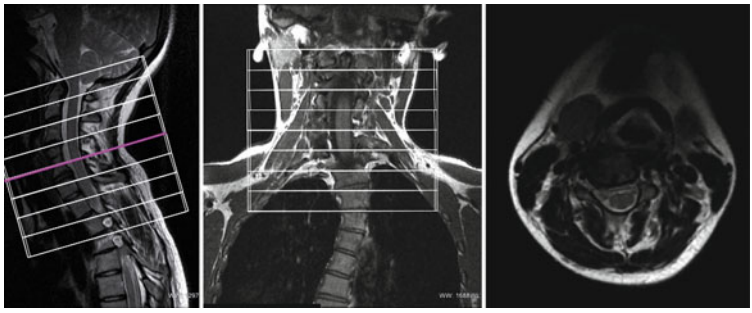

Figure 7.28 Axial slice prescription from sagittal and coronal slices is shown.

Table 7.35 Cervical myelo protocols.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5 slices in each plane	
Sagittal T2	Plan 3 mm sagittal slices over coronal image where you can see the spinal cord to cover the whole spinal canal	R-L
Sagittal T1	Same as above	R-L
Axial T2*GRE/MERGE	Plan 3 mm oblique axial slices from sagittal plane. The slices should be crossing vertebral junctions	S-I
Coronal SSFSE Heavy T2	Plan from the sagittal images parallel to spinal to cord to cover vertebra	A-P
Radial SSFSE myelo	Plan from axial and check from sagittal as radial prescription	
Coronal 3D fiesta	Plan from the sagittal images parallel to spinal to cord to be limited to spinal cord only	A-P

and/or canale. For patient's referent for myelography, additional myelography sequences are prescribed using radial SSFSE/HASTE sequence and 3D Fiesta/TrueFISP sequence (Table 7.35).

Sample Imaging Parameters for 1.5 T

See Table 7.36

Graphical Prescription

Routine sequence planning for metastases patients is same as routine cervical spine imaging. Myelography sequences planning are shown in Figs. 7.29 and 7.30.

Table 7.36 Imaging parameters for an eight channel spine coil is shown.

	T2	T1	T2*	Heavy T2 thick slab	T2 radial	3D fiesta/ CISS	3D cosmic
Plan	Sagittal	Sagittal	Axial	Coronal	Radial	Coronal	Coronal
Sequence type	FRFSE	FSE	MERGE	SSFSE	SSFSE	Balance	Balance
TE	85	MinFull	Auto	Min	Min	Min	Min
TR	3,140	640	500	Min	Min	Auto	Auto
ETL	27	3	Auto	264	264		
BW	41.67	31.2	31.25	31.25	31.25	83.33	50.0
Slice thickness	4	4	3.5	20	20–25	1.6	1.6
Slice spacing	0.5	0.5	0.5	–15		–0.8	0.8
FOV	24	24	19	24	24	26	26
Matrix	352 × 224	320 × 224	320 × 192	320 × 224	320 × 224	320 × 320	352 × 352
NEX/NSA	4	4	2	0.75	0.75	2	2
Freq Direction	A-P	A-P	R-L	S-I	S-I	R-L	R-L
SAT band	A	A	A				
TI/FA			FA: 20			FA: 65	

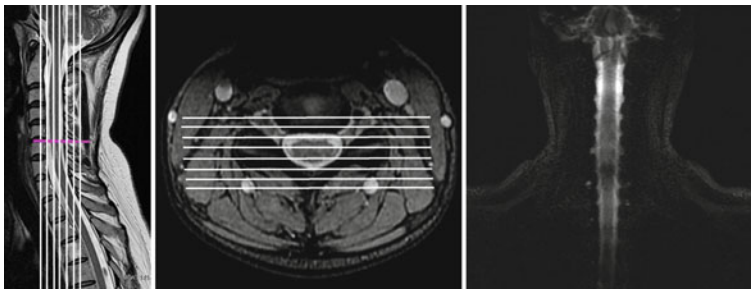

Figure 7.29 Coronal SSFSE thick slab prescription from sagittal and axial slices is shown.

Kinematic Cervical Exams

The purpose of kinematic spinal exams is to better visualize the cord compression under different positions. This way, it may be possible to better diagnose the problems. For kinematic exams, even though there are specific tools available for extension and flexion, these tools are not commonly available in most

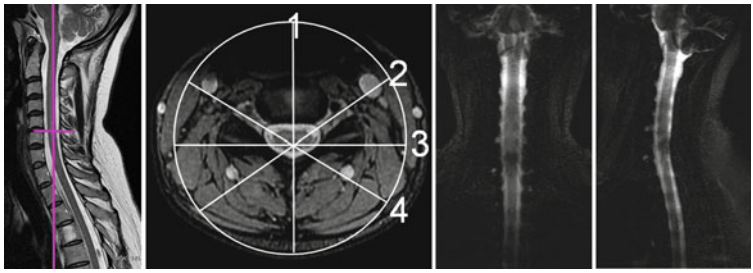

Figure 7.30 SSFSE thick slab radial prescription from sagittal and axial slices is shown.

Table 7.37 A sample kinematic cervical protocols.

Sequences	Comments	Slice order
Three plane or scout	Acquire 5 slices in each plane	
Sagittal T2	Normal position	R-L
Sagittal T2	Hyperextansion	R-L
Sagittal T2	Hyperflexion	R-L
Sagittal T1	Normal position	R-L
Axial T2*GRE	Normal position covering from C2 to C7	S-I

sites. Therefore, each site has its own way of creating kinematic exams, which may cause inconsistency. In your site, if you do not have any MR compatible kinematic tools, you should spend an additional 10 min with each patient to instruct them exactly what they are supposed to do.

For kinematic exams, a sagittal T2 sequence is applied in normal, hyperflexion, and hyperextension position. After that, routine c-spine imaging protocol is applied.

Sample Imaging Protocols

A sample kinematic exam protocol is given in Table 7.37.

Sample Imaging Parameters for 1.5 T

The imaging parameters for kinematic neck exam are same as routine c-spine exam. Please refer to the c-spine parameter table given before.

Graphical Prescription

The graphical plannings are same as routine c-spine imaging.

Nasopharynx and Maxillofacial

Patient Preparation and Positioning

Patient Preparation: Same as neck imaging patient preparation.

Patient Positioning: An eight channel brain or neurovascular coil will be appropriate for these exams in general. The patient cheekbones should be at the center of the coil for best image quality (Figs. 7.31 and 7.32).

Figure 7.31 Patient positioning on an eight CH brain coil for nasopharynx or maxillofacial MRI.

Figure 7.32 Patient positioning on an eight CH neurovascular coil for nasopharynx or maxillofacial MRI.

Sample Imaging Protocols

For nasopharynx exams, depending on the patient teeth filings and sinus cavity, chemical fat sat may not work perfectly. To eliminate any fat sat–related artifacts, we recommend STIR or the recently developed Dixon-based techniques. Dixon method is a 2D or 3D echo technique used to separate fat and water using their inherent resonant frequency differences. The recent interest in Dixon-based methods resulted in a very much improved and stable sequence, which can be used for whole body imaging. Again, we urge our readers to utilize the recently developed techniques to improve their image quality if their system has the capability.

The sample protocol for nasopharynx and maxillofacial MRI is given in Table 7.38.

Sample Imaging Parameters for 1.5 T

See Table 7.39

Graphical Prescription

Graphical prescription details are shown in Figs. 7.33–7.35.

Table 7.38 The sample protocol for nasopharynx and maxillofacial MRI.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5 slices in each plane	
Sagittal STIR	Plan 4–5 mm sagittal slices over coronal image	R-L
Axial T2	The coverage is specific to the lesion or anatomical location	S-I
Axial T1	The coverage is specific to the lesion or anatomical location	S-I
Coronal T2 or T2 fat sat/STIR	Plan from sagittal and axial images and cover the region of interest	A-P
Postcontrast	***If the contrast injection is decided***	
Axial T1	Same as above	S-I
Axial T1 fat sat	Same as above	S-I
Coronal T1 fat sat	Plan same as coronal T2	A-P
Sagittal T1	Similar to STIR prescription as above	R-L

Table 7.39 Imaging parameters for an eight channel neurovascular coil is shown.

	STIR	T2	T1	T2	T1	STIR	T1FS
Plan	Sagittal	Axial	Axial	Coronal	Coronal	Coronal	Axial
Sequence type	FSE-IR	FRFSE	FSE	FRFSE	FSE	FSE-IR	FSE
TE	35	85	MinFull	85	MinFull	35	MinFull
TR	4,925	5,520	620	3,360	760	4,925	780
ETL	12	15	3	18	3	12	3
BW	41.67	31.25	31.25	41.67	41.67	41.67	20.83
Slice thickness	5	5.0	5.0	4.0	4.0	4.0	5.0
Slice spacing	1.0	1.0	1.0	1.0	1.0	1.0	1.0
FOV	26	22	22	24	24	24	22
Matrix	288 × 224	352 × 352	352 × 352	352 × 352	352 × 352	288 × 224	288 × 224
NEX/NSA	2	2	2	2	2	2	2
Freq Direction	S-I	A-P	A-P	S-I	S-I	S-I	A-P
TI/FA	145					145	

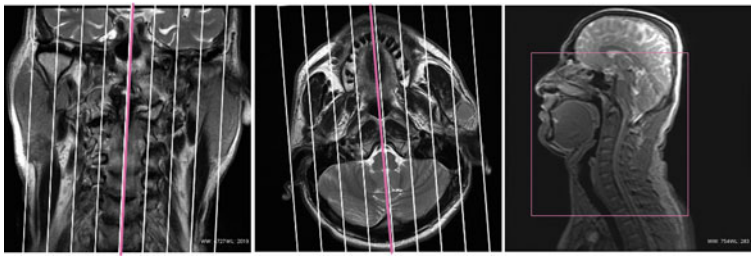

Figure 7.33 Sagittal slice prescription from coronal and axial slices is shown.

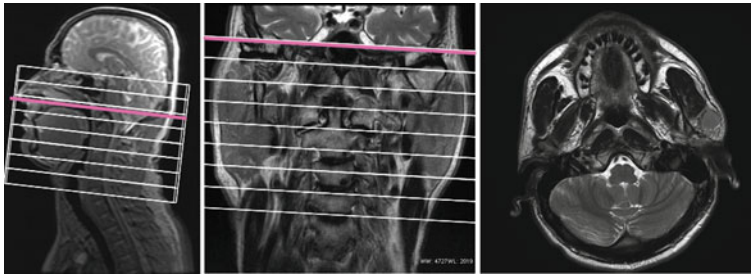

Figure 7.34 Axial slice prescription from sagittal and coronal slices is shown.

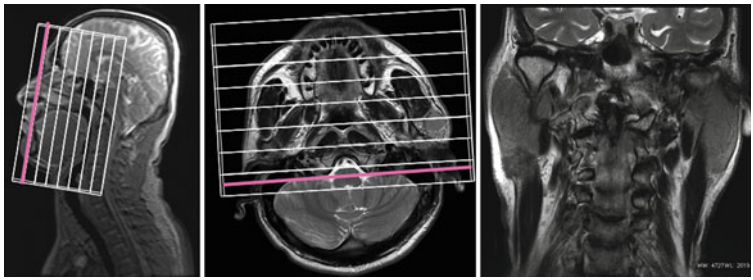

Figure 7.35 Coronal slice prescription from sagittal and axial slices is shown.

Parotid Glands

Patient Preparation and Positioning

Patient Preparation: Same as nasopharynx exam above.
Patient Positioning: Same as nasopharynx exam above.

Sample Imaging Protocols

Sagittal image acquisition is usually not needed for parotid glands if dedicated loop coils are not used. If your radiologist prefer, you can also do a T1 perfusion imaging to see the contrast uptake curves. In this case, you acquire a few phases' precontrast and continue with postcontrast exams for 4–5 min. For perfusion exams, it is recommended to inject single dose contrast agent at 4–5 cc/s injection rate.

Diffusion sequences are also applicable for parotid glands with multiple b values for differential diagnosis.

The sample protocols for the patient referred to MRI for parotid glands exam are shown in Table 7.40.

Sample Imaging Parameters for 1.5 T

See Table 7.41

Graphical Prescription

Graphical prescription details are shown in Figs. 7.36 and 7.37.

Table 7.40 The sample protocol for parotid glands.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5 slices in each plane	
Coronal STIR	Plan 4–5 mm coronal slices over axial and sagittal images	A-P
Coronal T2	Plan same as coronal STIR	A-P
Axial T2	The coverage is specific to the lesion location	S-I
Axial T1	The coverage is specific to the lesion location	S-I
T1 perfusion	*Choose a 2D or 3D T1 sequence and continuously acquire multiphases around 4–5 min starting 10 s before the injection*! (*only dedicated to lesion area*)	S-I
Axial T1	Same as precontrast axial T1	S-I
Axial T1 fat sat	Copy from axial precontrast sequences	S-I
Coronal T1 fat sat	Copy from coronal sequences	A-P

Table 7.41 Imaging parameters for an eight channel neurovascular coil is shown.

	STIR	T2	T2	T2FS	T1	T1	Diff	Perfusion
Plan	Coronal	Coronal	Axial	Axial	Axial	Coronal	Axial	Axial
Sequence type	FSE-IR	FRFSE	FRFSE	FRFSE	FSE	FSE	EPI	SPGR
TE	35	85	85	85	MinFull	MinFull	62.5	Min
TR	5,125	3,180	3,120	3,460	640	720	4,000	Auto
ETL	12	18	18	16	3	3		
BW	41.67	41.67	41.7	31.25	41.67	41.67	250	35.71
Slice thickness	4.0	4.0	4.0	4.0	4.0	4.0	4.0	6
Slice spacing	1.0	1.0	1.0	1.0	1.0	1.0	1.0	–3.0
FOV	20	22	22	22	22	22	22	24
Matrix	256 × 224	352 × 352	288 × 256	224 × 224	288 × 256	352 × 256	128 × 128	224 × 128
NEX/NSA	2	4	4	4	2	4	4	1
Freq Direction	S-I	S-I	A-P	A-P	A-P	S-I	R-L	A-P
Options	FC, Z512							Zip2, Zip512
TI/FA	145			Zip512				TI: Auto/ FA: 12

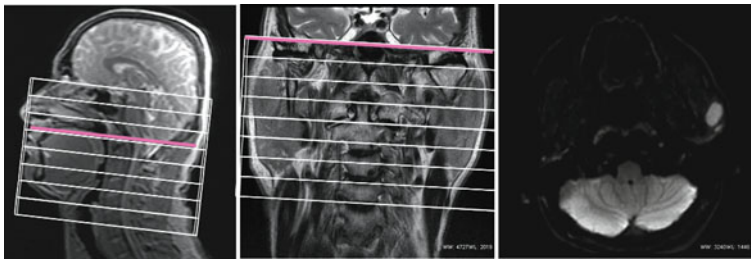

Figure 7.36 Axial slice prescription from sagittal and coronal images is shown.

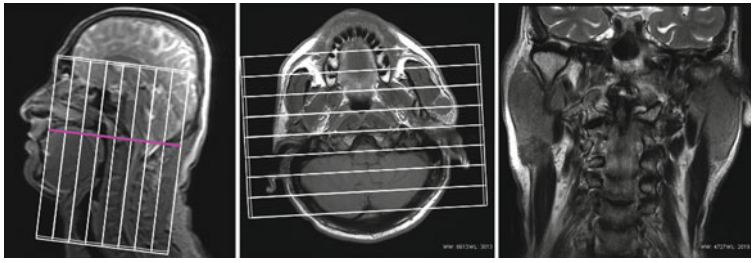

Figure 7.37 Coronal slice prescription from sagittal and axial images is shown.

Soft Tissue Neck

Sample Imaging Protocols

Similar to nasopharynx or maxillofacial MRI, chemical fat saturation may fail for neck soft tissue imaging due to special anatomical structure of the neck. To eliminate any fat sat–related artifacts, we recommend to start imaging with STIR or the recently developed Dixon-based techniques. With STIR-like sequences, traumatic tissue damage, metastases can be visualized in better contrast and help us to prescribe the following sequences specifically for the region of interest.

The sample protocols for the patient referred to MRI for neck soft tissue exam are shown in Table 7.42.

Sample Imaging Parameters for 1.5 T

See Table 7.43

Table 7.42 The sample protocol for soft tissue neck imaging.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5 slices in each plane	
Sagittal STIR	Plan 4–5 mm sagittal slices over axial and coronal images and cover complete neck region	R-L
Axial T2	The coverage is specific to the lesion location	S-I
Axial T1	The coverage is specific to the lesion location	S-I
Coronal T2	Plan from sagittal STIR to cover the complete neck region	A-P
Postinjection	*Inject if needed and scan at least two different planes*	
Axial T1	Same as above	S-I
Axial T1 fat sat	Same as above	S-I
Coronal T1 fat sat	Same as above coronal T2	A-P
Sagittal T1	Same as STIR with 4–5 mm slice thickness	R-L

Table 7.43 Imaging parameters for an eight channel neurovascular coil is shown.

	STIR	T2	T1	T2	T1	STIR	T1FS
Plan	Sagittal	Axial	Axial	Coronal	Coronal	Coronal	Axial
Sequence type	FSE-IR	FRFSE	FSE	FRFSE	FSE	FSE-IR	FSE
TE	35	85	MinFull	85	MinFull	35	MinFull
TR	4,925	5,520	620	3,360	760	4,925	780
ETL	12	15	3	18	3	12	3
BW	41.67	31.25	31.25	41.67	41.67	41.67	20.83
Slice thickness	5	6	6	4	4	4	6
Slice spacing	1.5	1.5	1.5	1	1	1	1.5
FOV	26	22	22	24	24	24	22
Matrix	288 × 224	352 × 352	352 × 20	352 × 352	352 × 352	288 × 224	288 × 224
NEX/NSA	2	2	2	2	2	2	2
Freq Direction	S-I	A-P	A-P	S-I	S-I	S-I	A-P
TI	145					145	

Graphical Prescription

Graphical prescription details are shown in Figs. 7.38–7.40.

Brachial Plexus

Patient preparation and positioning is same as routine neck imaging (Figs. 7.41 and 7.42).

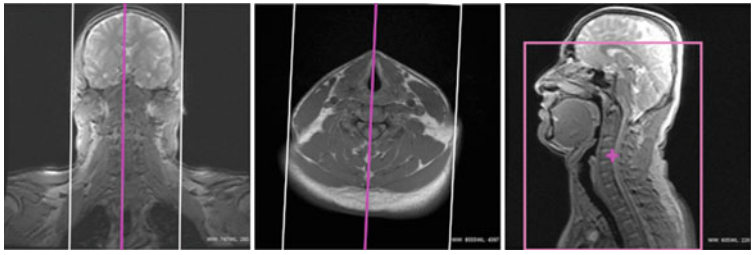

Figure 7.38 Sagittal slice prescription from coronal and axial images is shown.

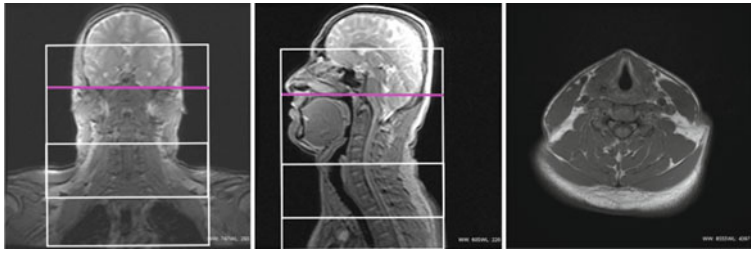

Figure 7.39 Axial slice prescription from coronal and sagittal images is shown.

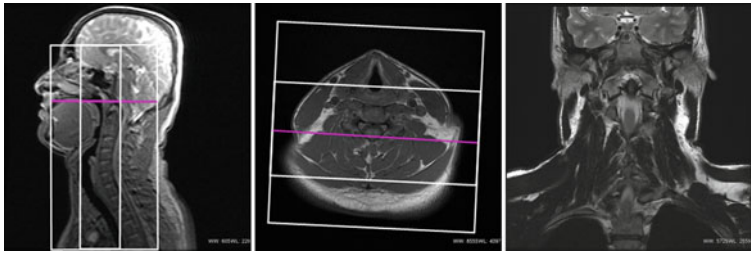

Figure 7.40 Coronal slice prescription from sagittal and axial images is shown.

Figure 7.41 Patient positioning on an eight CH neurovascular coil for brachial plexus is shown.

Figure 7.42 Patient positioning on an eight CH spine (CTL) coil for brachial plexus is shown.

Sample Imaging Protocols

The sample protocols for the patient referred to MRI for brachial plexus exam is shown in Table 7.44.

Sample Imaging Parameters for 1.5 T

See Table 7.45

Graphical Prescription

Graphical prescription details are shown in Figs. 7.43–7.45.

Table 7.44 A standard brachial plexus protocol.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5 slices in each plane	
Coronal STIR	Plan from sagittal and axial slices with 3–4 mm slice thickness	A-P
Coronal T2	Copy from coronal STIR sequence	A-P
Coronal T1	Copy from coronal STIR sequence	A-P
Axial T2	Plan from coronal and sagittal images from C3 to aortic arch or axillary region using 4 mm slice thickness	S-I
Axial T1	Copy from axial T2	S-I
Sagittal T2	Plan from coronal STIR with a 3-mm slice thickness	R-L
Postinjection	*If you decide to inject*	
Axial 3DT1 FS	Same axial plan coverage as precontrast sequence. You can use LAVA.VIBE type sequences as well	S-I
Coronal T1	Same as above	A-P

Table 7.45 Imaging parameters for an eight channel neurovascular coil is shown.

	T1	T2	STIR	T2	T1	T2
Plan	Coronal	Coronal	Coronal	Axial	Axial	Sagittal
Sequence type	FSE	FRFSE	FSE-IR	FRFSE	FSE	FRFSE
TE	MinFull	85	38	100	MinFull	85
TR	540	3,600	5,000	5,180	500	4,200
ETL	3	18	12	17	3	24
BW	41.7	41.7	41.7	41.7	41.7	41.7
Slice thickness	4	4	4	4	4	5
Slice spacing	0.4	0.4	0.4	0.4	0.4	0.5
FOV	28	28	28	28	28	24
Matrix	352 × 352	352 × 352	320 × 224	352 × 320	352 × 320	352 × 352
NEX/NSA	2	2	2	2	2	4
Freq Direction	S-I	S-I	S-I	R-L	R-L	S-I
SAT band						I
TI			145			

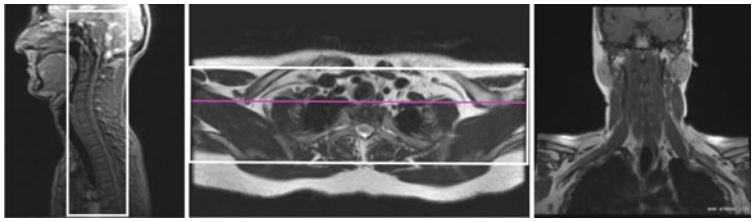

Figure 7.43 Coronal slice prescription from sagittal and axial images is shown.

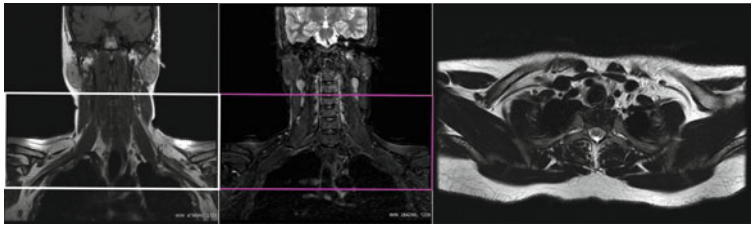

Figure 7.44 Axial slice prescription from coronal images is shown.

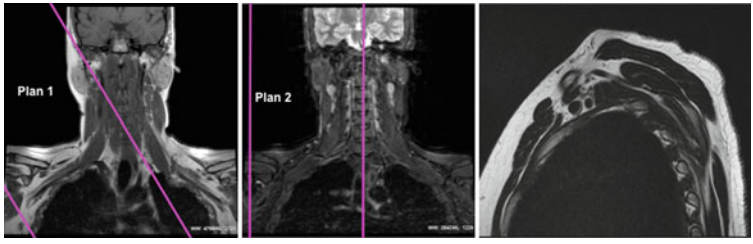

Figure 7.45 Sagittal slice prescription from coronal images is shown.

Thoracic Spine Imaging

Patient Preparation: The patient consent form should be given to the patient with a detailed explanation on the content. The form should be carefully read, all questions must be answered with clear answers such as "YES" or "NO," and additional clarifications should be written. It must be signed by the patient or legal guardians and confirmed by MR personnel. If there are any surgical implants, radiologist on duty has to make a decision based on implant type and MR compatibility. *If there is any suspicion or lack of information on the implant, do not take any risk with the patient safety and do not scan the patient*. If the form is complete with all the information, the patient should change to MR gown and remove any clothing with any metal. Please ensure that female patients remove the bra as well.

Before the MR exam, explain the nature and duration of the MR exam they will undergo. Also explain that patient motion will make a negative effect on image's quality. Make a habit of informing the patient before every sequence and communicate often to comfort the patient. It is always a good practice to remove the jewelry as well. As the last line of patient safety, it is also a good practice to scan patient with a handheld metal detector before taking the patient to MR room.

Patient Positioning: The spine coil should be centered on the table. For better patient comfort and easier breathing, leg support pads should be placed under patient knees. Patient should lie down on the coil in supine position as shown below. The center of sternum should align with the center of the coil. Additional pads should be placed around patient arms to avoid patient skin contact with the MR bore directly. Patient protection headsets and/or patient pads should be placed around the head to reduce the noise and gross patient motion. After handing the patient alarm to patient and testing it, you are ready to start the exam (Fig. 7.46).

In thoracic spine exam, one thing you will notice is increased flow-related artifacts in sagittal and axial planes. This is due to the fact that CSF flows faster in the narrow thoracic and, therefore, causes significantly more flow artifacts. These artifacts are usually magnified in sagittal plane where we use thinner slices with minimal slice spacing or no gap. They will be much less pronounced in axial plane due to thicker slices and larger slice gap. To reduce these artifacts significantly, you can apply gating devices and/or increase slice spacing up to 50%. The new motion insensitive sequences such as PROPELLER and BLADE also do a great job eliminating these artifacts.

Figure 7.46 Patient positioning on an eight CH spine (CTL) coil for thoracic exam is shown.

Table 7.46 A sample standard thoracic spine protocol.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5 slices in each plane with maximum FOV	
Sagittal FSPGR	Prescribe this sequence to count vertabra for accurate planning (counter)	R-L
Sagittal T2	Plan from coronal and sagittal counter with 3 mm slice thickness to cover the entire thoracic spine	R-L
Sagittal T1	Copy from sagittal T2	R-L
Axial T2	Acquire whole thoracic spine with one or two slice group	S-I

Standard Thoracic Spine

Sample Imaging Protocols

The sample protocols for the patient referred to MRI for routine thoracic spine are shown in Table 7.46.

Sample Imaging Parameters for 1.5 T

See Table 7.47

Graphical Prescription

Graphical prescription details are shown in Figs. 7.47 and 7.48.

Table 7.47 Imaging parameters for an eight channel spine (CTL) coil is shown.

	T2	T1	T2*	STIR	T1 flair	T2	T1
Plan	Sagittal	Sagittal	Sagittal	Sagittal	Sagittal	Axial	Axial
Sequence type	FRFSE	FSE	GRE	FSE-IR	FSE	FRFSE	FSE
TE	106	10	15	30	24	102	MinFull
TR	3,600	640	400	3,400	2,250	6,300	680
ETL	29	3	6	12	7	25	3
BW	41.7	41.7	62	25	31.25	41.7	41.7
Slice thickness	3	3	3	3	3	5	5
Slice spacing	1	1	1	1	1	2.5	2.5
FOV	30	30	30	30	30	20	20
Matrix	416 × 256	416 × 224	352 × 224	288 × 224	512 × 224	384 × 320	352 × 224
NEX/NSA	4	4	2	2	4	2	2
Freq Direction	A-P	A-P	A-P	A-P	A-P	A-P	A-P
SAT band	A	A	A	A	A	R/L	R/L
TI/FA			15	145	860		

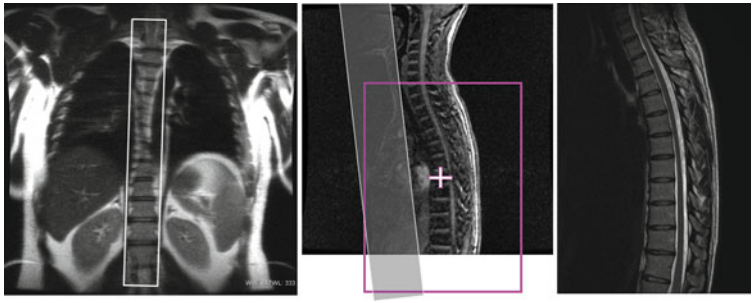

Figure 7.47 Sagittal slice prescription from coronal localizer and sagittal gradient echo counting localizer images is shown.

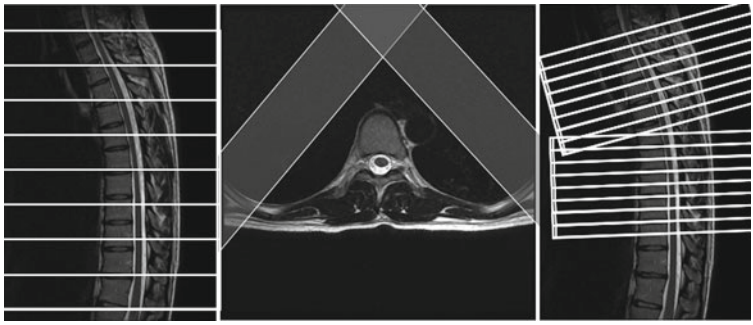

Figure 7.48 Either consecutive or multiangle multigroup axial slice prescription from sagittal slices can be prescribed as shown above. Please also make a note of the placement of saturation bands for more efficient ghosting reduction.

Table 7.48 A sample thoracic trauma protocol

Sequences	Comments	Slice order
Three plane localizer	Acquire 5 slices in each plane	
Sagittal FSPGR	Prescribe this sequence to count vertabra for accurate planning (counter)	R-L
Sagittal T2	Plan from coronal and sagittal counter with 3 mm slice thickness to cover the entire thoracic spine	R-L
Sagittal T1	Same as above	R-L
Sagittal STIR	Same as above	R-L
Coronal T2*GRE	Plan from axial localizer images with 3–4 mm slice thickness. You can use MERGE or MEDIC sequences if applicable	A-P
Axial T2	Acquire slices for region of interest only	S-I
Axial T1	Acquire slices for region of interest only	S-I

Thoracic Trauma

Sample Imaging Protocols

The sample protocols for the patient referred to MRI for thoracic trauma exam are shown in Table 7.48.

Table 7.49 Imaging parameters for an eight channel spine (CTL) coil is shown.

	T2	T1	T2*	STIR	T1 flair	T2	T1
Plan	Sagittal	Sagittal	Coronal	Sagittal	Sagittal	Axial	Axial
Sequence type	FRFSE	FSE	GRE	FSE-IR	FSE	FRFSE	FSE
TE	106	10	15	35	24	102	MinFull
TR	3,600	640	400	3,400	2,250	6,300	680
ETL	22–29	3	6	12	7	22–29	3
BW	41.7	41.7	62	25	31.25	41.7	41.7
Slice thickness	3	3	4	3	3	5	5
Slice spacing	1	1	1	1	1	2.5	2.5
FOV	30	30	33	30	30	20	20
Matrix	352 × 256	352 × 224	352 × 224	288 × 224	512 × 224	384 × 320	352 × 224
NEX/NSA	4	4	2	2	4	2	2
Freq Direction	A-P	A-P	R-L	A-P	A-P	A-P	A-P
SAT band	A	A	R-L	A	A	R/L	R/L
TI/b value/FA			15	145	860		

Sample Imaging Parameters for 1.5 T

See Table 7.49

Graphical Prescription

Sagittal and axial planning for trauma is same as routine thoracic imaging as shown above. The coronal trauma prescription is shown in Fig. 7.49.

Thoracic Metastases

Sample Imaging Protocols

The sample protocols for the patient referred to MRI for thoracic metastases exam is shown in Table 7.50.

Please note that if you start your exam with sagittal fat saturated T2 protocol, there is no additional need to prescribe STIR sequence.

Sample Imaging Parameters for 1.5 T

You can use the same imaging parameters as above.

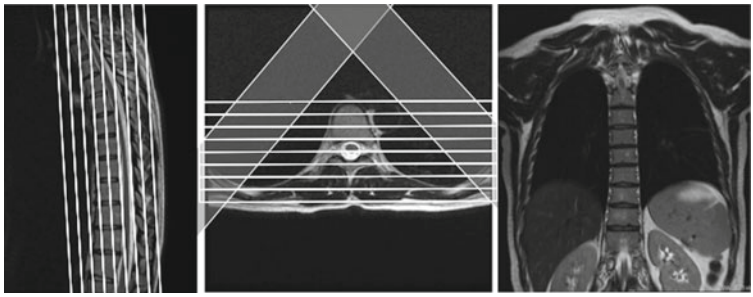

Figure 7.49 Coronal slice prescription from sagittal and axial images with two saturation bands is shown.

Table 7.50 A sample thoracic metastasis protocol.

Sequences	Comments	Slice order
Three plane	Acquire 5 slices in each plane	
Sagittal FSPGR	Prescribe this sequence to count vertabra for accurate planning (counter)	R-L
Sagittal T2	Plan from coronal slices with 3 mm slice thickness to cover the entire thoracic spine	R-L
Sagittal STIR	Same as above. You can use T2 fat sat instead of STIR as well	R-L
Sagittal T1	Same as above	R-L
Axial T2 fat sat	Acquire consecutively for whole thoracic vertabras	S-I
Axial T1	Acquire consecutively for whole thoracic vertabras	S-I
Postinjection	***If you decide to inject, scan at least in two planes***	
Axial T1	Same as above	S-I
Sagittal T1 fat sat	Copy from sagittal T1	R-L
Coronal T1 fat sat	Plan from sagittal slices with 4 mm slice thickness to cover the whole vertebras	A-P

Graphical Prescription

Sagittal and axial planning for trauma is same as routine thoracic imaging as shown above. The coronal thoracic metastases protocol is same as thoracic trauma as shown above.

Table 7.51 A sample thoracic scoliosis protocol.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5–10 slices in each plane	
Coronal T2/ T1	Plan from sagittal slices with 4–5 mm slice thickness to cover the whole vertebras	A-P
Sagittal T2	Plan from coronal and axial images with 3 mm slice thickness to cover the entire spinal canal	R-L
Sagittal T1	Copy from sagittal T2	R-L
Axial T2	Acquire with 5–7 mm slice thickness for whole thoracic vertabras either in one or two consecutive slice group	S-I

Thoracic Scoliosis

The spinal structure of thoracic scoliosis patients is quite different than the normal patients. Therefore, it is recommended to image at least two or three different planes/orientations. For better graphical prescription, localizer or scout imaging should be acquired with larger slice spacing and 5–10 slices. In addition, actual scanning should start with coronal plane, so that the following sagittal and axial images can be prescribed more accurately. If the scoliosis creates more of an S-shaped spine with two very different angulations, then you should plan two different sagittal prescriptions for each orientation.

Sample Imaging Protocols

The sample protocols for thoracic scoliosis patients are given in Table 7.51.

Sample Imaging Parameters for 1.5 T

You can use the same imaging parameters given for routine t-spine imaging.

Graphical Prescription

Graphical prescription details are shown in Figs. 7.50–7.52.

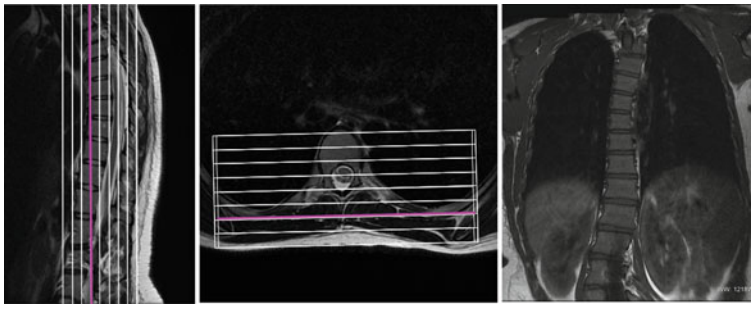

Figure 7.50 Coronal slice prescription from sagittal and axial slices is shown.

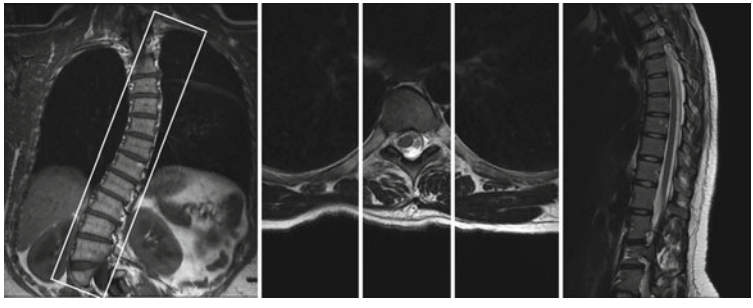

Figure 7.51 Sagittal slice prescription from coronal and axial slices is shown.

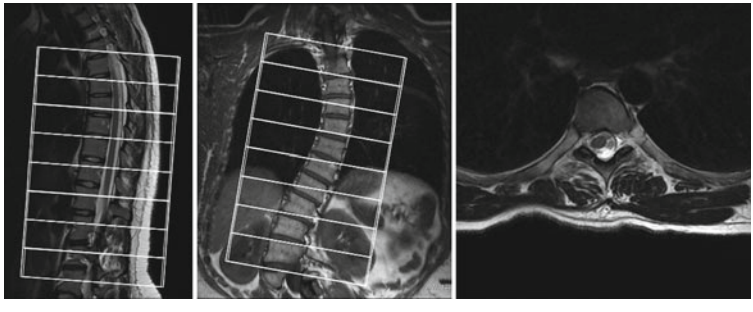

Figure 7.52 Axial slice prescription from sagittal and coronal images is shown.

Lumbar Imaging

Lumbar spine imaging is one of the most frequent MR examinations performed currently. We recommend the following protocols to make sure that lumbar exams are performed as short and simple as possible.

Patient Preparation: The patient consent form should be given to the patient with a detailed explanation on the content. The form should be carefully read, all questions must be answered with clear answers such as "YES" or "NO," and additional clarifications should be written. It must be signed by the patient or legal guardians and confirmed by MR personnel. If there are any surgical implants, radiologist on duty has to make a decision based on implant type and MR compatibility. *If there is any suspicion or lack of information on the implant, do not take any risk with the patient safety and do not scan the patient*. If the form is complete with all the information, the patient should change to MR gown and remove any clothing with any metal. Please ensure that female patients remove the bra as well. Before the MR exam, explain the nature and duration of the MR exam they will undergo. Also explain that patient motion will make a negative effect on image's quality. Make a habit of informing the patient before every sequence and communicate often to comfort the patient. It is always a good practice to remove the jewelry as well. As the last line of patient safety, it is also a good practice to scan patient with a handheld metal detector before taking the patient to MR room.

Patient Positioning: The spine coil should be centered on the table. For better patient comfort and easier breathing, leg support pads should be placed under patient knees. Patient should lie down on the coil in supine position as shown below. About 5 cm superior of iliac bones should align with the center of the coil to be used for lumbar exam. The spine coil usually has signs showing the coil coverage in each coil element. Depending on the patient height you may have a different element centered on lumbar on the patient. Therefore, you should also make a mental note where the coil center is and turn on elements before and after the center coil element. Please be aware that if you turn on more coil elements than needed, you may get an artifact called *annefact or peripheral signal artifact*. Therefore, do not turn on or select more coil elements than you need for your region of interest. However, if you have one of the systems turning on coil elements automatically depending on the FOV placed, then you do not have to worry about coil selection. Please check the localizer images for signal loss and artifacts to ensure that right coil mode and coverage are selected.

Additional MR safety pads should be placed around patient arms to avoid skin contact with the magnet bore directly. Patient protection headsets and/or

patient pads should be placed around the head to reduce the noise and gross patient motion. After handling the patient alarm to patient and testing it, you are ready to start the exam (Figs. 7.53 and 7.54).

Let us take a detailed look at the most frequently used lumbar protocols and their prescription if you are ready.

Standard Lumbar Spine

Sample Imaging Protocols

A sample routine lumbar spine protocol referred to MRI for nonspecified back and/or leg pain is given in Table 7.52.

Figure 7.53 Head-first patient positioning on an eight CH spine (CTL) coil for lumbar exam.

Figure 7.54 Feet-first patient positioning on an eight CH spine (CTL) coil for lumbar exam.

Table 7.52 A sample routine lumbar spine protocol.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5 slices in each plane with maximum FOV	
Sagittal T2	Plan from coronal slices with 3–4 mm slice thickness to cover the entire spinal canal	R-L
Sagittal T1	Copy from sagittal T2	R-L
Axial T2	Acquire from L1-S1 and place the 5 slices for each vertebral disc	S-I

Sample Imaging Parameters for 1.5 T

See Table 7.53

Graphical Prescription

Graphical prescription details are shown in Figs. 7.55 and 7.56.

Table 7.53 Imaging parameters for an eight channel spine (CTL) coil is shown.

	T2	T1	T2*	T1 flair	STIR	T2	T1
Plan	Sagittal	Sagittal	Sagittal	Sagittal	Sagittal	Axial	Axial
Sequence type	FRFSE	FSE	MERGE	FSE	FSE-IR	FRFSE	FSE
TE	102	MinFull	Min	24	42	102	MinFull
TR	4,000	720	400	2,250	3,250	5,260	420
ETL	29	3	4	9	12	27	3
BW	41.67	41.67	62.5	41.67	31.25	41.67	41.67
Slice thickness	4	4	4	4	4	4	4
Slice spacing	1	1	1	1	1	1	1
FOV	30	30	30	30	30	20	20
Matrix	512 × 256	512 × 224	352 × 224	448 × 224	320 × 224	352 × 320	352 × 224
NEX/NSA	4	4	2	4	4	4	4
Freq Direction	A-P	A-P	A-P	A-P	A-P	A-P	A-P
SAT band	A	A	A	A	A	R-L	R-L
TI/b value/FA				800	140		

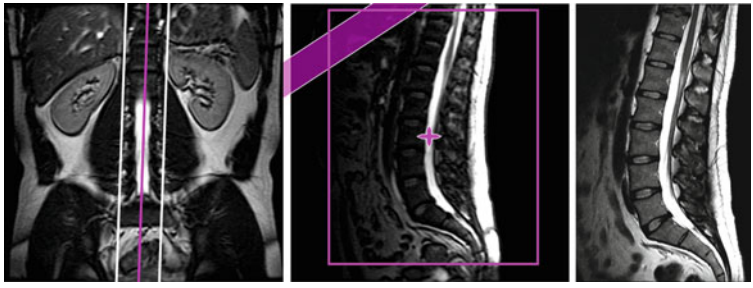

Figure 7.55 Sagittal slice prescription from coronal and sagittal images is shown. Please have a look for center of FOV and placement of saturation band.

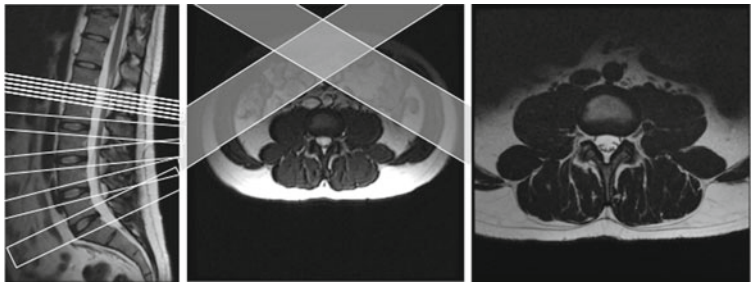

Figure 7.56 Axial slice prescription from sagittal and axial images is shown. Please note that saturation bands are planned from axial views to suppress bowel movements.

Table 7.54 A sample lumbar spine trauma protocol is shown.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5 slices in each plane	
Sagittal T2	Plan from coronal slices with 3 mm slice thickness to cover the entire spinal canal	R-L
Sagittal T1	Copy from sagittal T2	R-L
Sagittal STIR	Copy from previous sagittals	R-L
Coronal T2*GRE	Plan from axial localizer images with 3–4 mm slice thickness. You can use MERGE or MEDIC sequences if applicable	A-P
Axial T2	Acquire slices for region of interest only	S-I
Axial T1	Acquire slices for region of interest only	S-I

Lumbar Trauma

Sample Imaging Protocols

The sample protocols for the patient referred to MRI for thoracic trauma exam is shown in Table 7.54.

Sample Imaging Parameters for 1.5 T

Sample imaging parameters for trauma exam is given above in routine lumbar exam.

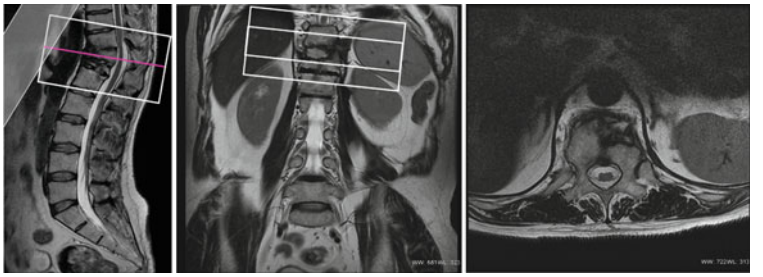

Figure 7.57 Axial slice prescription from sagittal and coronal images is shown.

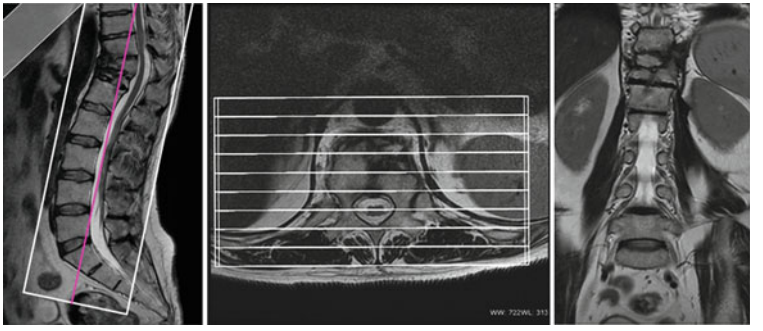

Figure 7.58 Coronal slice prescription from sagittal and axial images is shown.

Graphical Prescription

Sagittal planning for trauma is same as routine lumbar imaging as shown above. The axial coronal trauma prescriptions are shown in Figs. 7.57 and 7.58.

Lumbar Metastases

Sample Imaging Protocols

The sample protocols for the patient referred to MRI for lumbar metastases exam are shown in Table 7.55.

Table 7.55 A sample lumbar metastases protocol.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5 slices in each plane	
Sagittal T2	Plan from coronal slices with 3 mm slice thickness to cover the entire spinal canal	R-L
Sagittal T1	Copy from T2.	R-L
Sagittal STIR	Copy from sagittal T2. You can use T2 fat sat instead of STIR as well	R-L
Axial T2 fat sat	Acquire consecutively for L1-S3	S-I
Axial T1	Copy from axial T2 fat sat	S-I
Postinjection	***If you decide to inject, scan at least in two planes***	
Axial T1 fat sat	Copy from previous axials	S-I
Coronal T1 fat sat	Plan from sagittal slices with 4 mm slice thickness to cover all lumbosacral vertebras	A-P
Sagittal T1 fat sat	Copy from previous sagittal T1	R-L

Graphical Prescription

Sagittal and axial planning for trauma is same as routine Lumbar imaging as shown above. The coronal Lumbar metastases protocol is same as Lumbar trauma as shown above.

Lumbar Scoliosis

The spinal structure of Lumbar scoliosis patients is quite different than the normal patients. Therefore, it is recommended to image at least two or three different planes/orientations. For better graphical prescription, localizer or scout imaging should be acquired with larger slice spacing and 5–10 slices. In addition, actual scanning should start with coronal plane with a T1, T2, or PD weighting, so that the following sagittal and axial images can be prescribed more accurately. If the scoliosis creates more of an S-shaped spine with two very different angulations, then you should plan two different sagittal prescriptions for each orientation.

Sample Imaging Protocols

The sample protocols for lumbar scoliosis patients are given in Table 7.56.

Table 7.56 A sample lumbar scoliosis protocol.

Sequences	Comments	Slice order
Three plane localizer	Acquire 5–10 slices in each plane	
Coronal T2	Plan from sagittal slices with 4–5 mm slice thickness to cover the whole vertebras	A-P
Sagittal T2	Plan from coronal and axial images with 3 mm slice thickness to cover the entire spinal canal	R-L
Sagittal T1	Copy from sagittal T2	R-L
Axial T2	Acquire with 5–7 mm slice thickness for whole lumbosacral vertabras either in one or two consecutive slice group	S-I

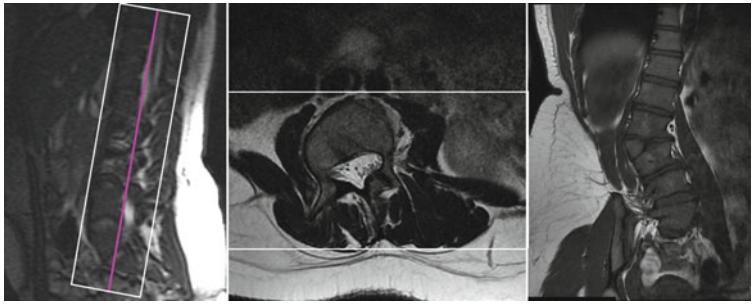

Figure 7.59 Coronal slice prescription from sagittal and axial images is shown.

Sample Imaging Parameters for 1.5 T

Sample imaging parameters for lumbar scoliosis exam can be seen from thoracic scoliosis exam.

Graphical Prescription

Graphical prescription details are shown in Figs. 7.59–7.61.

Lumbar Myelography

Sample Imaging Protocols

Even though lumbar myelography request is not quite common as the lumbar protocols we discussed above, we sometimes prescribe lumbar myelography

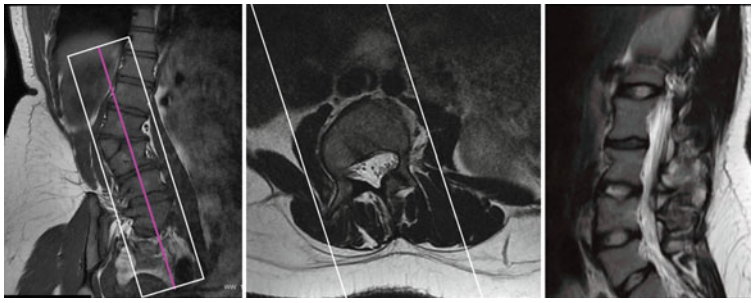

Figure 7.60 Sagittal slice prescription from coronal and axial images is shown.

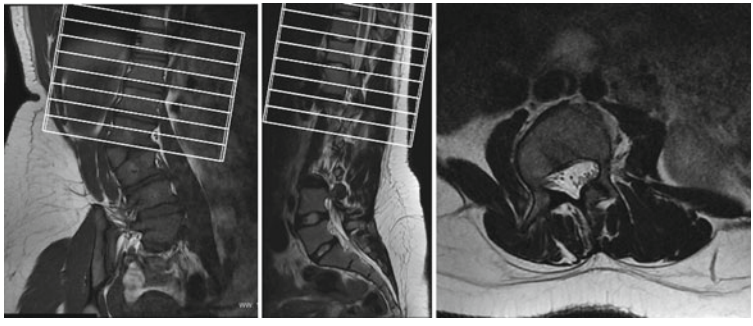

Figure 7.61 Axial slice prescription from coronal and sagittal images is shown.

for better visualization of spinal cord and/or canale. For patients referent for myelography, additional myelography sequences are prescribed using radial SSFSE/HASTE sequence, 3D FRFSE/RESTORE T2 sequence, and 3D Fiesta/TrueFISP sequence. The thin slice and high in-plane resolution capability of these sequences combined with their superb contrast (T2/T1) make lumbar myelography exams much more diagnostic.

The sample protocol for lumbar myelography patients is given in Table 7.57.

Sample Imaging Parameters for 1.5 T

Sample imaging parameters for lumbar myelography exam can be seen from cervical myelography exam.

Table 7.57 A sample for lumbar myelography protocol.

Sequences	Comments	Slice order
Three plane localizer	Acquire 3–5 slices in each plane	
Sagittal T2	Plan 3 mm sagittal slices over coronal image where you can see the spinal cord to cover the whole spinal canal	R-L
Sagittal T1	Same as above	R-L
Axial T2	Plan 3–4 mm oblique axial slices from sagittal images. The slices should be crossing vertebral junctions and cover from L1 to S1	S-I
Coronal SSFSE thickslap	Plan from the sagittal images parallel to spinal to cord to cover vertebra	A-P
Radial SSFSE myelo	Plan from axial and check from sagittal as radial prescription	S-I
Coronal 3D fiesta	Plan from the sagittal images parallel to spinal to cord to be limited to spinal cord only	S-I

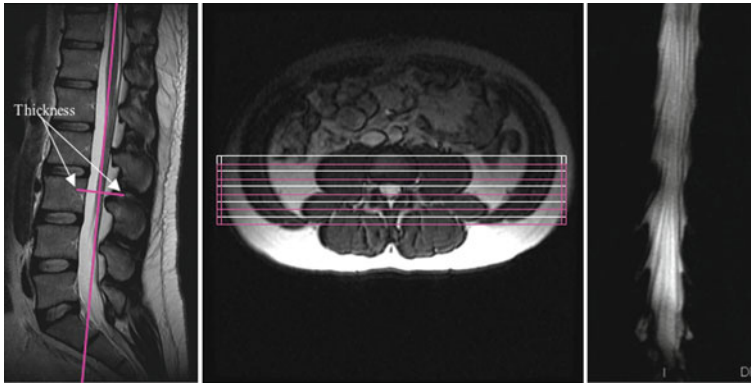

Figure 7.62 Coronal SSFSE thick slice prescription from sagittal and axial slices is shown.

Graphical Prescription

Graphical prescription details are shown in Figs. 7.62–7.64.

Lumbar Kinematic Protokolleri

The purpose of kinematic spinal exams is to better visualize the cord compression under different positions. This way, it may be possible to better diagnose the problems. For kinematic exams, even though there are specific tools

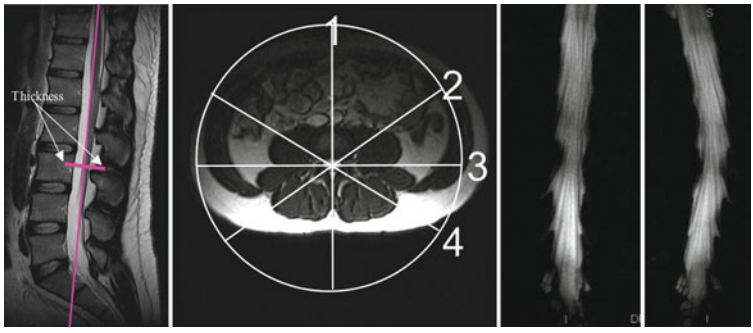

Figure 7.63 Radial planning from sagittal and axial slices is shown.

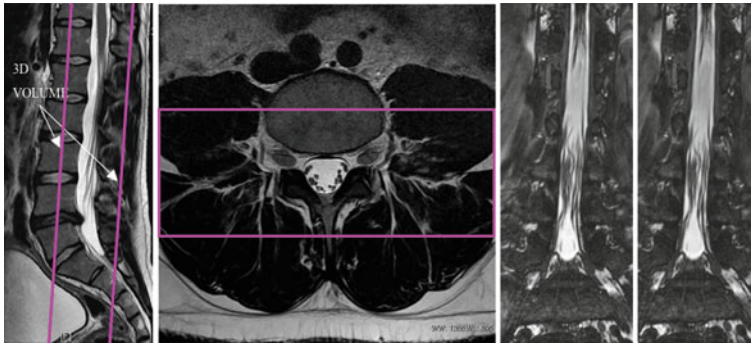

Figure 7.64 3D coronal fiesta/true FISP/b-FFE sequence slice prescription from sagittal and axial images is shown.

available for extension and flexion, these tools are not commonly available in most sites. Therefore, each site has its own way of creating kinematic exams, which may cause inconsistency. In your site, if you do not have any MR compatible kinematic tools, you should spend an additional 10 min with each patient to instruct them exactly what they are supposed to do.

For kinematic exams, a sagittal T2 sequence is applied in normal, hyperflexion, and hyperextension position. After that, routine lumbar spine imaging protocol is applied.

Sample Imaging Protocols

A sample kinematic exam protocol is given in Table 7.58.

Sample Imaging Parameters for 1.5 T

Sample imaging parameters for lumbar kinematic exam are same as routine lumbar spine exam.

Graphical Prescription

All graphical planning for kinematic exam is same as routine lumbar imaging as shown above.

Table 7.58 A sample lumbar kinematic protocol.

Sequences	Comments	Slice order
Three plane	Acquire 5 slices in each plane	
Sagittal T2	Normal position	R-L
Sagittal T2	Hyperextansion	R-L
Sagittal T2	Hyperflexion	R-L
Sagittal T1	Neutral position	R-L
Axial T2	Neutral position covering from L1 to S1 with 3 mm	S-I