Whole-body MRI at 1.5T – step-by-step

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Whole-body MRI (WB-MRI) is a hot topic – you may have had enquiries from colleagues asking you if or when you might be able to offer the service. You may not know where to start or what is involved. The purpose of this article and the accompanying video tutorial is to introduce and guide you through the implementation for successful completion of a MET-RADS compliant WB-MRI protocol [1].

WB-MRI has been used as a clinical tool at Paul Strickland Scanner Centre for over 10 years. In that time over 6,500 patients have been examined using a protocol designed to enable the detection and surveillance of metastatic bone and soft tissue disease. Treatment regimens are routinely being altered based on serial qualitative and quantitative measurements produced by this technique [2].

To enable the serial analysis of quantitative ADC measurements we must reduce acquisition variables as far as practicable. Clearly it is not possible to fully control all patient variables between visits. The patient's condition may change, requiring a different coil set-up.

Adjusting scan parameters at a visit-by-visit basis adversely affects the reproducibility of both the qualitative and quantitative results. For the majority of sequences described below it is advised that the parameters are not adjusted by operators after initial protocol set-up. The sequences should be designed and saved to accommodate your largest (A>P and R>L) and tallest (H>F) patients by default, and ranges should not be reduced (e.g. phase FOV) even when this may normally prove advantageous. Those parameters which may be altered on a per-patient basis will be mentioned. Any changes made should remain constant between visits in the same patient where practicable.

Let's look at the equipment, preparation and steps required to successfully execute a WB-MRI protocol suitable for quantitative analysis.

You can find a video tutorial demonstrating the use of this protocol on the website at **www.siemens.com/wb-mri**. The video begins at the acquisition stage.

Sequence / stations	Core, comprehensive or both	TR (ms)	TE (ms)	FOV (mm)	Phase FOV (%)	Slices	Slices (mm)	Gap (%)	Matrix	Phase enc. direction	iPAT	b-values	Averages	TA (mins)
FastView	Both	3.31	2.19	480 x 1250	87.5	1	5	100	96	A>P	n/a		n/a	0:35
STIR spine sag (x2)	Both	5110	69	380	100	15	4	20	384	H>F (over-sampled)	2		2	2:30 (x2)
T1 spine sag (x2)	Both	200	9.6	380	100	15	4	20	256	H>F (over-sampled)	2		2	1:07 (x2)
T1 Dixon TimCT ax	Both	130	2.38 4.76	430 x 1015	81.3	12	5	0	256	A>P	2		1	3:45 + BHs
DWI (x4) ax	Core (Comprehensive)	7370	66	430	90.6	55	5	0	128	A>P	2	50, (600,) 900	2, (5,) 6	3:04 (4:55)
T1 Dixon CAIPI VIBE cor (x3)	Both	6.64	2.39 4.77	450	94.4	144	2	min	288	R>L (over-sampled)	5		1	0:19
T2 HASTE TimCT	Comprehensive	1000	81	430 x 1035	81.3	16	5	0	256	A>P	3		1	3:44
											Total examination time			**24:47**
											Comprehensive acquisition time			**35:55**

Table 1: Sequence parameters for MET-RADS compliant sequences for both core and comprehensive protocols at 1.5T [1].

Coil requirements

- Standard posterior spine coil
- Standard head & neck coil
- 2x anterior Body 18 coils (Fig. 1) as required for coverage to mid-thigh (3x recommended)

Number your Body coils and routinely positioning them in the same order will limit any sensitivity variability and also make coil troubleshooting much more straightforward.

It is important to note that the range required for MET-RADS compliant protocols is from vertex to mid-thigh (Fig. 2). Although not always required, access to 3x Body 18 coils is optimal and should accommodate even the tallest patients.

As such it's not necessary to use a peripheral coil for this protocol. If full imaging of the lower limbs is required it is advised to perform imaging separately and feet-first, allowing a bio-break for the patient.

As this technique will be used to generate quantitative ADC measurements it is especially important to ensure that the coils are working well. A coil QA program should be implemented with increased frequency of testing for the regularly used coils.

Product options and software compatibility

Product options used for this protocol are TimCT, Inline Composing and the Tim Planning Suite (set'n'go).

At **www.siemens.com/wb-mri** you can find a downloadable .exar1 file which was exported from an Avanto[fit] running *syngo* MR E11C software.

If you are unable to import this file, please see the full protocol in Table 1 or the full protocol .pdf file which is available on the website.
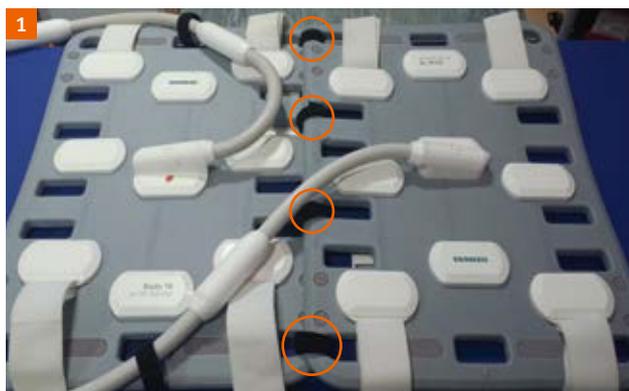
Figure 1: Improving workflow
Two Body 18 coils linked with Velcro loops (circled). This improves the reproducibility of positioning and reduces set-up time while remaining flexible.
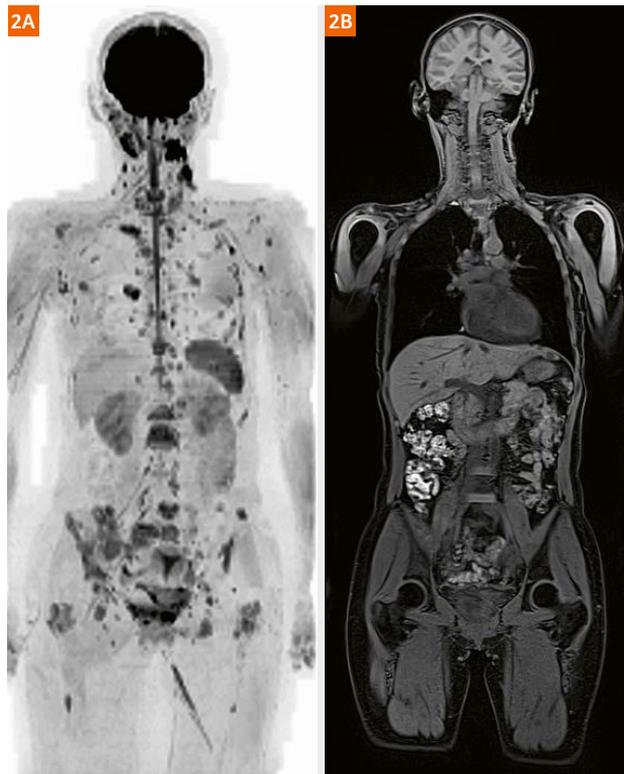
Figure 2: Range of imaging required
(2A) Coronal b900 MIP projection and **(2B)** composed coronal Dixon water images illustrating the vertex to mid-thigh range of coverage for this protocol.

Patient and equipment set-up

Patient comfort is absolutely critical to compliance with this protocol, so utilize any equipment required for comfort (e.g. extra padding, pillows, knee pad, etc.).

The patient should be advised to use the toilet where possible because the full protocol can take up to one hour.

Patients will warm up – particularly when scanning at 3T – and so the patient should wear a gown or entirely metal-free light clothing. Ensure adequate air flow to reduce the impact of heating.

Find out if the patient is able to hold their breath – if they can, use a breath-hold technique when scanning the chest and abdomen to reduce motion artifacts.

An optimal set-up includes the use of the anterior Head/Neck coil however this may not always be possible if the patient is kyphotic (Fig. 3).

Position the patient's head-first, with arms down by their side. The patient should be asked to move so that their shoulders are as close to the Head/Neck coil as possible, minimising any gap.

Place and secure anterior Body coils as required for coverage to mid-thigh. The superior margin of the first Body coil should be in line with SP1 as marked on the table-top.

As always, provide your patient with the call buzzer and adequate hearing protection.

Occasionally, due to patient body habitus, it may be necessary to place the first anterior Body coil overlapping the anterior part of the Head/Neck coil to ensure comfort.

Remember to make detailed notes of the patient set-up on their scanning record and ensure repeat visits use this set-up unless the patient's condition requires a change.

Use the positioning laser to set the start position to the inferior margin of the patient's chin – the FastView localizer will automatically move to begin acquiring at the vertex.

Form pads

Comfort and safety are key. Where possible, place foam padding between all contact points with coils, cables, the scanner and the table including elbows, sternum and knees.

Workstation

Before starting, make the following changes to the workstation options:

- Tim Planning UI active
- AutoCoilSelect ON
- Coupled graphics ON

Ready to go? It's time to scan.
Remember, you can follow along with the video from this point. Visit **www.siemens.com/wb-mri** to check it out.

Figure 3:
(3A) Optimal coil set-up. While it is important to keep the coils as close to the patient as possible, ensuring that antorior coils remain horizontal where possible, will maximize SNR.
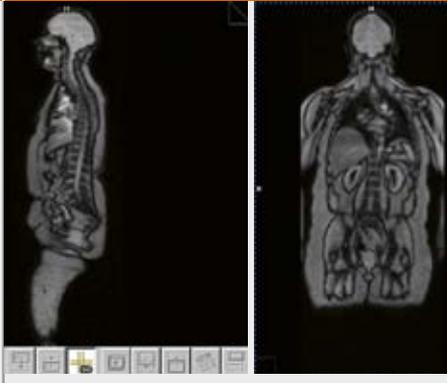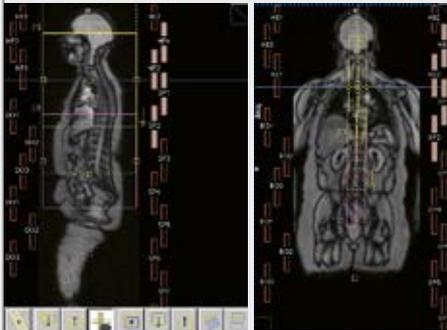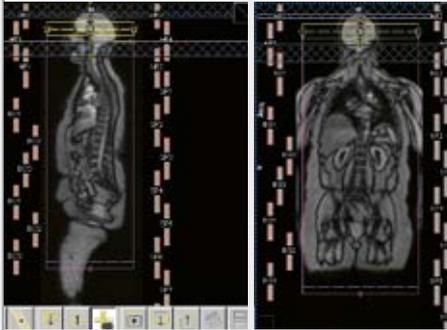
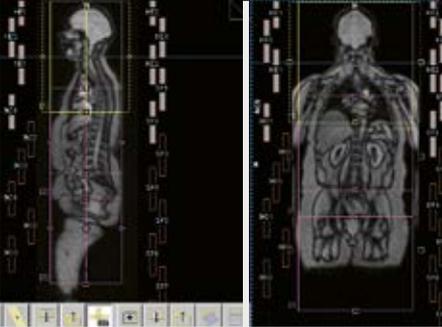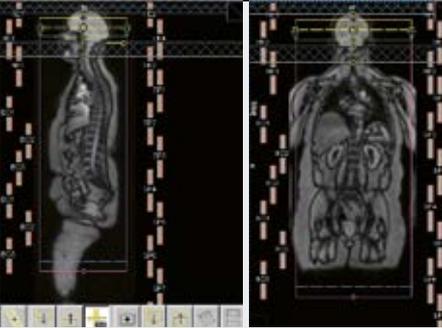Position pads under the elbows and forearms.

Ensure cables do not cross over or create loops.

Use a knee pad for patient comfort – use the same pad each time for reproducibility.

(3B) Comfort set-up. Patient comfort is increased at the cost of SNR in the head, neck and distal femurs.

Table 2: Step-by-step positioning examples and acquisition tips.

Sequence details	Positioning and ranges	Acquisition tips	Adjustable parameters	Notes
Step 1 **FastView localizer** **Range:** vertex to knees **Plane:** axial (MPRs will be generated) **Method:** TimCT		On initial set-up, set the acquisition range to as far as your table movement range will allow TimCT adjustments are enabled: this sequence will perform imaging, 3D shim and TimCT adjustments (3x movements) Where not available: utilize a set'n'go multi-planar localizer covering head to knees Once the images have been reconstructed, begin planning the spine sequences		Until this sequence has fully completed the location of the anterior coils will not display on-screen **Important: Don't proceed with planning beyond spinal imaging until the anterior coils are visible**
Step 2 **STIR and T1 spine** **Range:** whole spine **Plane:** sagittal to patient's anatomy **Method:** set'n'go		Set'n'go with automatic composing enabled H>F coverage from skull base to at least S3 Angle to cover the spine R>L – coupled graphics are **ON** so make this a best-fit To ensure anterior elements are not used during acquisition, at sequence set-up navigate to **System: Misc:** and set AutoCoilSelect **OFF** for both slice groups in both sequences once the required posterior elements are selected – save this into the protocol As all patients should always have their shoulders in the same position it is not usually necessary to change the active elements	Increase the number of slices to ensure full R>L coverage of the spine The TR may need to be increased to allow additional slices The FOV may be increased in order to include at least S3 for very tall patients	Ensure the same number of slices are used for each station AND each sequence type (both STIR and T1) Image contrast may be different between visits Record any changes Image resolution may be affected Usually this will not require matrix adjustments as long as the resolution remains constant between visits

WAIT until FastView localizer has fully completed before proceeding –
this ensures anterior coils are visible and activate correctly with AutoCoilSelect ON

Sequence details	Positioning and ranges	Acquisition tips	Adjustable parameters	Notes
Step 3 **T1 Dixon TimCT** **Range:** orbits to knees **Plane:** axial **Method:** TimCT Breath-holding where possible through the thorax and abdomen		Where TimCT is not available: utilize an axial T1 Dixon set'n'go technique Adjust the position of the volume to ensure A>P coverage, equal R>L coverage using humeral heads as a guide, and ensure the blue isocenter line lies just inferior to the skull vertex (this allows the sequence to run – it may fail to start if not positioned in this manner) The volume will therefore not cover the entire brain – other sequences are included for this purpose If performing breath-holds: utilize the manual start-stop function to perform breath-holds while imaging the thorax and liver	Extend range as required to cover to mid-thigh	Detail the range selected on the patient's record to ensure reproducibility on future visits

Sequence details	Positioning and ranges	Acquisition tips	Adjustable parameters	Notes
Step 4 **Multi-b-value DWI** **Range:** vertex to knees **Plane:** axial **Method:** set'n'go		Adjust position of the set'n'go slice groups to ensure coverage from the skull vertex superiorly to at least mid-thigh inferiorly In the rare event that this range is insufficient, add another slice group (including overlap where required) Adjust position of slice groups to ensure A>P coverage, equal R>L coverage using humeral heads as a guide Manually activate the B01 element group on the first slice group – this will increase signal in the neck region		If using a fixed-frequency technique, ensure this value is copied or noted in order that it can be applied to the subsequent slice groups, however this should NOT be recorded on the patient's record as this value will necessarily change between visits A useful tip is to save this frequency as an image comment for the slice group
Step 5 **T1 Dixon CAIPIRINHA VIBE** **Range:** vertex to knees **Plane:** coronal **Method:** set'n'go Breath-holding where possible		Adjust position of slice groups to ensure A>P coverage, equal R>L coverage using humeral heads as a guide. In the H>F direction, ensure some air is included superior to the skull vertex to ensure full coverage of this structure If performing breath-holds: utilize manual or auto-matic breath-hold instructions as required	Slices per slab: increase to ensure full A>P coverage if this is insufficient by default	Your acquisition time will increase It may be necessary to introduce some partial fourier to control this
			Partial Fourier: use to decrease acquisition time for breath-holds where required	Be conscious of the impact on SNR
Step 6 **T2 HASTE TimCT** **Range:** orbits to knees **Plane:** axial **Method:** TimCT		Where TimCT is not available: utilize an axial T2 HASTE set'n'go technique As this uses a copy reference from the T1 TimCT sequence it is not necessary to change the position of the volume, although care should be taken that the same range is acquired If the sequence fails to start, it is likely that a small 'footwards' change in the position of the slice group will allow it to run	Extend range as required to cover to mid-thigh	Detail the range selected on the patient's record to ensure repro-ducibility on future visits

Sequence selection and discussion

If you are using the downloadable .exar1 protocol you will find sequences which have been included and optimized based upon the experience of scanning around 30 whole body examinations each week.

You should expect the protocol to take anywhere between 30 to 60 minutes depending on what is included.

Please see the MET-RADS document [1] for the clinical justification of sequences included, however it may be helpful to touch briefly upon how the sequences have been optimized and how they can be used clinically.

Spine sequences (STIR and T1-weighted):
Both sequences are used to detect and characterize bone lesions. High-resolution STIR imaging can also help to differentiate between active and inactive metastases. In our experience, T2 imaging without fat suppression does not provide significant additional diagnostic data.

Whole-body sequences (T1 Dixon and T2 HASTE):
The multiple contrasts generated by a T1 Dixon sequence can be used to calculate the signal fat fraction (F%). This can be used to quantitatively assess response to treatment or disease progression. Flip angles have been selected to optimize T1 weighting; PD-weighted fat fractions may prove more accurate for F% estimates, but this comes at the expense of loss of the T1 contrast.

T2 HASTE imaging (in this case without fat suppression) facilitates the localization and characterization of pathologies. Asking patients to hold their breath during acquisition through the thorax and liver may improve detection of thoracic lesions or liver metastases; as such acquisition times have been kept to a minimum. The whole body axial T1 Dixon or T2 HASTE range can be acquired in under 4 minutes using TimCT where available.

Diffusion-weighted imaging:
Optimized for maximum signal generation, this sequence makes up the majority of the acquisition time. Depending on the capabilities of the scanner it is not unusual for each slice group to require over five minutes of acquisition time.

A STIR technique is used due to the improved fat suppression over a large FOV – although some centers have reported success using a SPAIR technique.

55 slices are acquired per slice group; any more and ADC values on end-of-group slices do tend to 'falsely'

Avanto^fit

Prisma^fit
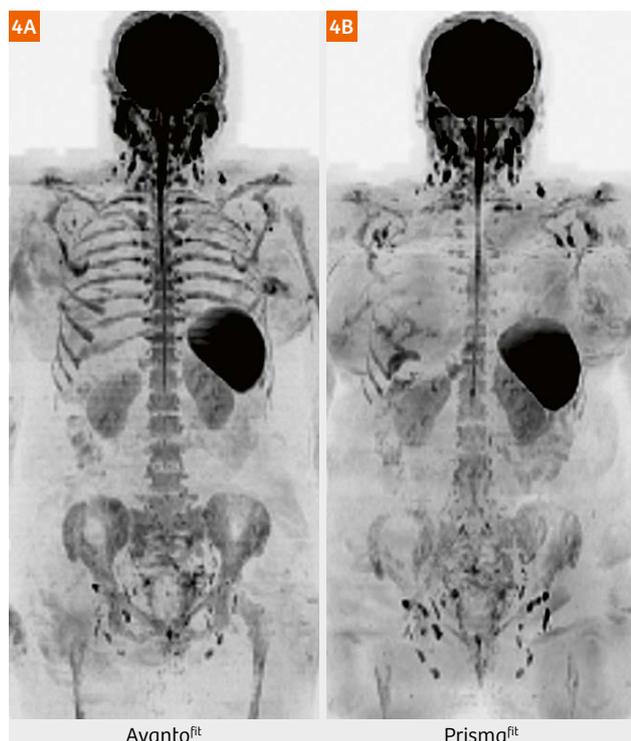
Figure 4: Coronal projections of b900 MIP with inverted greyscale
Images from a patient scanned at both **(4A)** 1.5T and **(4B)** 3T. Greater signal intensity of bone marrow is demonstrated at 1.5T due to the lower susceptibility effects of bone.
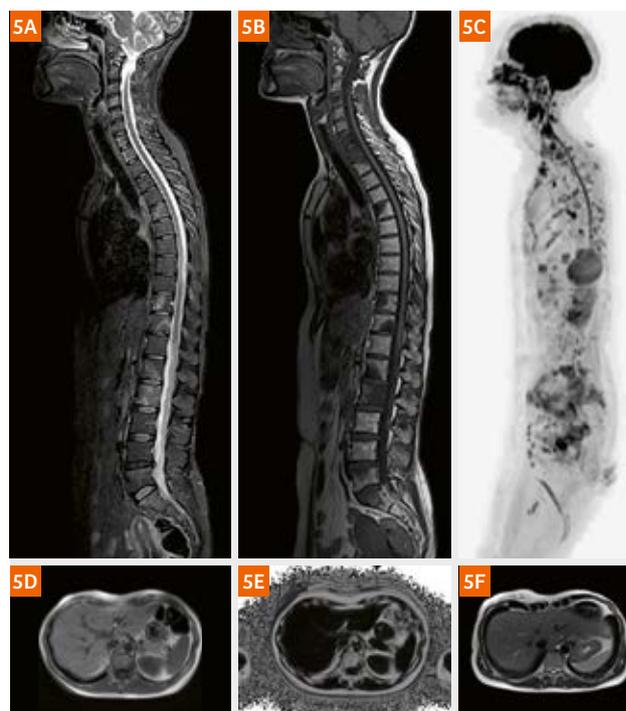
Figure 5: Example images from a completed dataset
(5A) Composed STIR and **(5B)** T1w spine images, **(5C)** sagittal projection of inverted b900 MIP, **(5D)** in-phase T1w Dixon and **(5E)** corresponding F%, **(5F)** T2w HASTE axial.

drift beyond acceptable margins [3]. An overlap can be introduced to counter this effect, although this is subject to optimization.

The optimal number of slices, and fat suppression technique, is entirely scanner-dependent and should be decided upon following rigorous testing and comparison (for example, acquiring fewer slices per station when using a shorter magnet).

Three b-values are used to optimize ADC calculation with the lowest set at b = 50 mm²/s. For the core protocol, two b-values are sufficient, thereby reducing the acquisition time (Table 1).

Asymmetric averaging is used to optimize acquisition time while ensuring sufficient SNR at higher b-values.

The **image scale correction** factor **(System: TxRx:)** is set at 3.5, optimizing the visual appearance of hypercellular lesions versus normal bone marrow on the high b-value images.

Diffusion schemes vary between imaging centers, however we have settled on a 3D diagonal, monopolar scheme for maximum signal generation with a minimal TE. Anisotropy-sensitive techniques are unnecessary.

Eddy currents and geometric distortions, while increased using this technique, are compensated for by using the newly-released SliceAdjust feature which allows for slice-specific shimming [4]. This technique is recommended where available.

Unfortunately, the downloadable .exar1 protocol does not feature this particular sequence due to licensing and compatibility issues. Manually apply the center frequency used for the first DWI station to all subsequent stations to avoid the so-called **'broken spine'** artifact [5]. The .exar1 protocol has been set-up to allow frequency-fixing and features a 3-scan trace diffusion scheme to reduce the effect of geometric distortions where SliceAdjust is not available.

Scanning patients on different scanners is not recommended – especially at different field strengths (Fig. 4).

Post-processing

T1-weighted fat fractions (F%) should be generated from both the TimCT and coronal VIBE series. Add the FAT and WATER series together, and then divide the FAT by the ADD. Using a scaling factor of 1000 it is possible to window more finely. Using a ROI it is possible to read off the percentage of fat in an area which can be used to monitor response of bone metastases and liver fat condition.

Coronal MPRs and radial MIPs, generated from the highest b-value series, can be used during reporting but often serve as a very visual means of communicating findings to clinical colleagues. Generate coronal MPRs at 5 mm thickness and the radial MIPs every 3 degrees (120 images) displayed using an inverted grey-scale.

Conclusion

The tricky part with WB-MRI is the initial set-up – don't be surprised if your first efforts don't produce the results you expect. A typical completed data set (Fig. 5) can consist of over 6,000 images depending on the sequences chosen and reconstructions performed, but once the protocol is in place it's fairly straight-forward for operators to perform. In our experience, treating each examination as an experiment rather than a scan will lead to success.

Keep up to date at **www.siemens.com/wb-mri** for the latest news, case studies and the video tutorial.

Acknowledgements

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Visit **www.siemens.com/wb-mri** to find the video tutorial.