BioMatrix Tuners: CoilShim

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A cervical spine or neck MRI can provide valuable diagnostic information for a wide range of different conditions. In particular, MRI's soft tissue contrast helps to detect and monitor a variety of pathologies, misalignments or injuries. It can be useful in evaluating symptoms such as pain, foreign body sensations, numbness, tingling or weakness in the arms, shoulder or neck area and can assist in detecting certain chronic diseases of the nervous system. It is also used in tumor diagnosis and in the assessment of bleeding, swelling, infections, or inflammatory conditions in the vertebrae or surrounding tissues.

In many patients, MR image quality in the neck or cervical spine region might be degraded by B_0 field distortions. These typically arise from tissue interfaces with different susceptibilities in this region, for example in the vicinity of the lung, between vertebrae, fluid-filled cavities, as well as from the body contour itself in the shoulders and neck area (Fig. 1). The low field homogeneity poses a challenge to MR imaging in this region and is often the source of image quality issues. Examples include insufficient fat saturation, spatial variations in the signal strength along the vertebrae, as well as regions showing complete signal loss.

With MAGNETOM Vida[1] a new technology platform, BioMatrix, is introduced, which combines the ability to adapt to the individual patient's biovariability and the established Tim integrated matrix coil technology. This, in particular, allows to substantially improve image quality in the neck area by utilizing CoilShim. CoilShim is one of the new BioMatrix technologies which allows for correction of patient-induced B_0 field inhomogeneities using dedicated shimming channels integrated into the Head/Neck coil.

Two new Head/Neck coils[1] support CoilShim: the BioMatrix Head/Neck 20 TCS (Tiltable, CoilShim) and the BioMatrix 64 CS (CoilShim)[1]. A first step in the compensation of patient-induced B_0 field inhomogeneities is the identification of the origin of these variations. Experiments indicate that there are two major sources of B_0 field inhomogeneities in head and neck MRI. These are the patients' shoulders on the one hand and the B_0 field distortion due to the neck on the other hand. The inhomogeneity pattern originates from the geometric shape of the human body in the head and neck area and the resulting difference in susceptibilities. Figure 1 shows a typical B_0 field inhomogeneity 'map' of the head and neck region. The map was generated from a principal component analysis performed on datasets from 19 volunteer scans. The analysis showed that only the first main component contains significant information. This suggests that the inhomogeneity pattern is likely to be the same for different body shapes and sizes and that only the magnitude of the inhomogeneity varies. To correct for B_0 field inhomogeneities in the shoulder and neck region, each of the two head and neck coils is equipped with two CoilShim channels (Fig. 2). The CoilShim channels are located in the posterior part of the Head/Neck coils,

[1] 510(k) pending. The product is still under development and not commercially available yet. Its future availability cannot be ensured.

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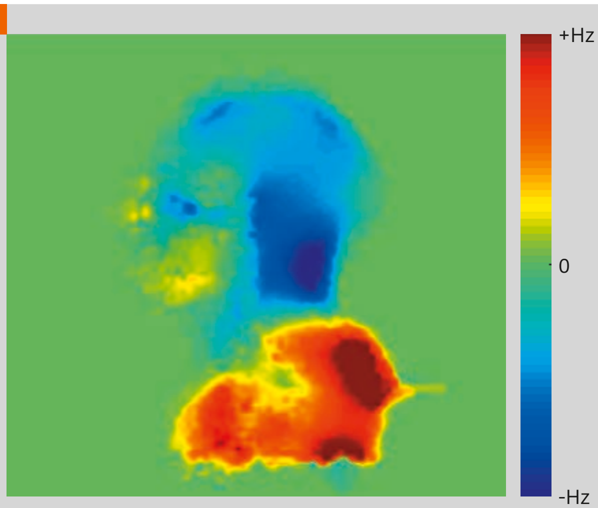

Figure 1: Typical B_0 field distortion pattern as seen in the sagittal orientation.

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Figure 2: BioMatrix Head/Neck 20 TCS coil design and the location of the CoilShim elements in the BioMatrix Head/Neck 20 TCS coil.

allowing the CoilShim technology to be used even when the anterior part of the Head/Neck coils are detached. The magnitude of the B_0 field generated by each CoilShim channel can be adjusted independently with very fine resolution. This allows for best possible B_0 homogenization for each individual patient.

In order to ensure both adequate image quality and patient safety with the new Head/Neck coils with integrated CoilShim, special measures have been taken. These measures ensure decoupling of the CoilShim elements during the transmit phase and decoupling from the gradient system during the transmit and receive phase of the MR acquisition.

Applications

The usage of CoilShim requires no dedicated patient preparation: the patient can be positioned within the Biomatrix Head/Neck coil[1] as with any other head coil. When using the 20-channel TCS coil, the tilt angle may be adapted to the patients' needs, thereby providing increased patient comfort. Tilting the coil does not interfere with the CoilShim functionality but CoilShim may improve image quality degradations resulting from tilting.

CoilShim can be used with all clinical head and neck sequences and protocols, provided that the BioMatrix Head/Neck coil is plugged and active. "CoilShim" is turned on in the user interface by switching the respective parameter, which can be found on the tabcard "System", sub tab "Adjustments" from "Off" to "Auto". The actual enabling of CoilShim technology itself is therefore controlled automatically, depending on the slice geometry and the protocol parameters.

Results

The physical effect of the CoilShim feature on the B_0 field is illustrated in Figure 3, acquired in a healthy volunteer. The images compare B_0 field maps obtained using clinical state-of-the-art standard shimming with those which result from the usage of CoilShim technology.

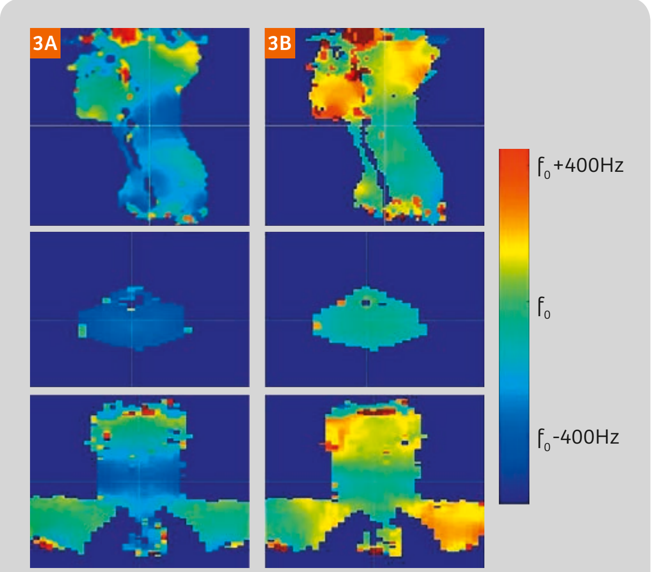

Figure 3: B_0 field map in the all three main orientations without **(3A)** and with CoilShim **(3B)**. The frequency shift relative to f_0 is shown in Hz.

The images show relative resonance frequency shifts in three orthogonal slice orientations. Once again, the two dominant sources of field inhomogeneity in the shoulder and in the neck area can be observed. In this example the frequency shift in the shoulder region is about 400 Hz and the frequency shift in the neck area is about -200 Hz. Given that the frequency shift between fat and water is 430 Hz at 3T, non-uniform fat saturation can be expected in such cases.

To further illustrate the impact of CoilShim on the quality of the shimmed region of interest, Figure 4 shows the frequency distribution of all voxels within the adjustment volume both with and without CoilShim. The spectrum of the frequencies within the adjustment volume is significantly narrowed on applying CoilShim.

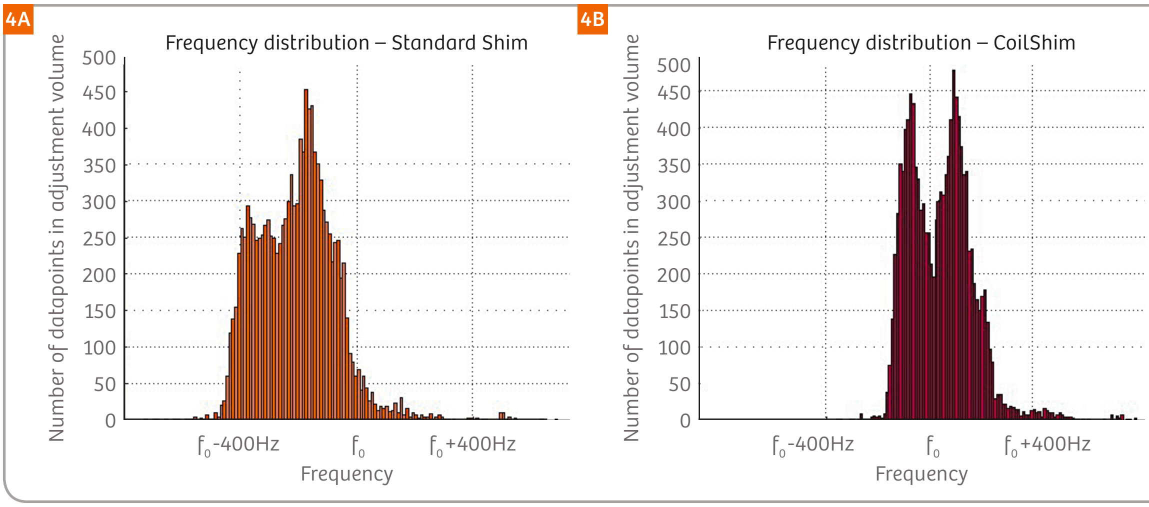

Figure 4: Histogram of frequency shift distribution relative to f_0 in Hz without **(4A)** and with CoilShim **(4B)**.

The improved field homogeneity is beneficial for all MR imaging studies in the head and neck. Applications which require a highly homogenous field, for example fat saturated or SPAIR images, or EPI-based imaging, benefit in particular from local shimming. Figures 5 and 6 show typical image examples obtained in several volunteers of different physical constitution. Figure 5 shows T1-weighted, fat saturated TSE images of the c-spine, Figure 6 illustrates the benefits of CoilShim in T2-weighted TSE images obtained with SPAIR preparation pulses. An axial T2-weighted BLADE image with SPAIR preparation pulses is shown in Figure 7. All examples show that more homogeneous fat saturation

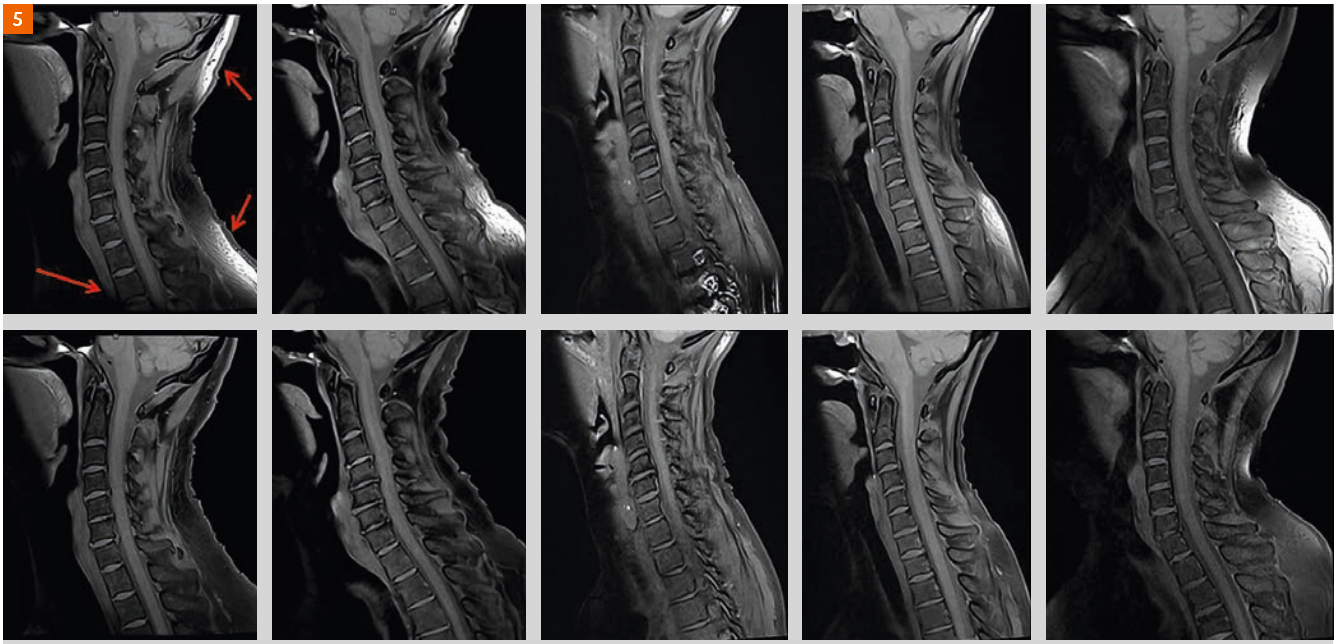

Figure 5: T1-weighted TSE images with fat saturation in five different volunteers. Using CoilShim (lower row) improved the fat saturation not only within the vertebrae but also in the posterior areas. The contrast between vertebrae and disk is also improved.

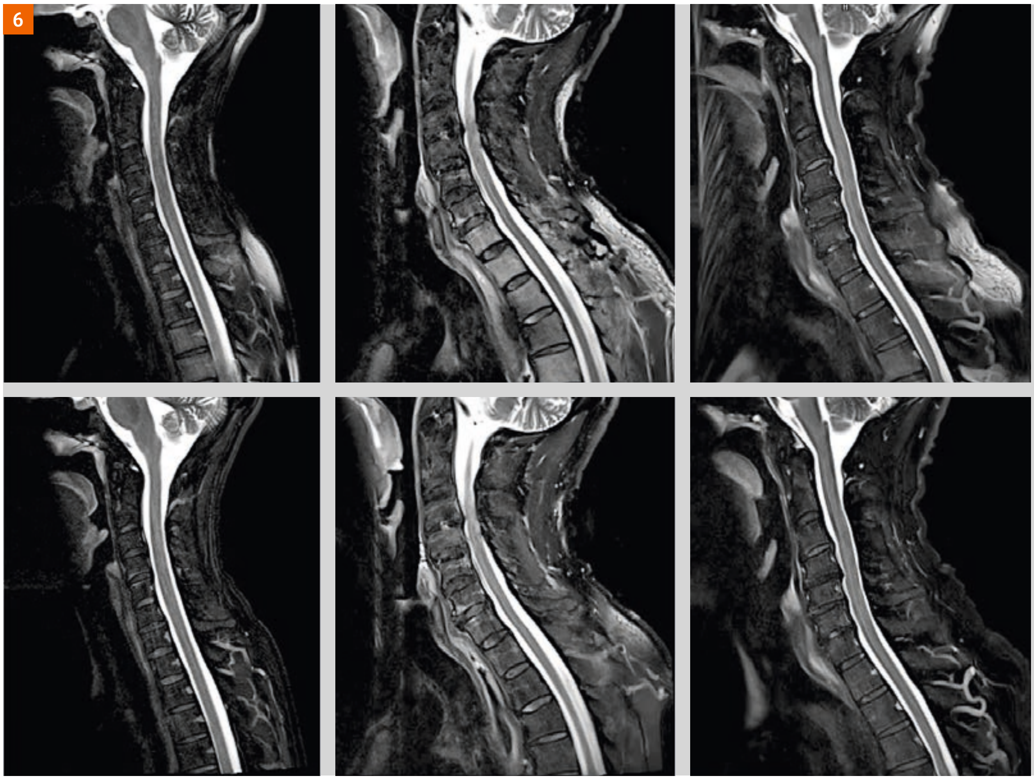

Figure 6: T2-weighted TSE images with SPAIR fat saturation in three different volunteers. Note the intensity gradient within the vertebrae without CoilShim (upper row). The image with active CoilShim on the right shows better homogeneity within the vertebrae and less contribution of un-saturated fatty tissue.

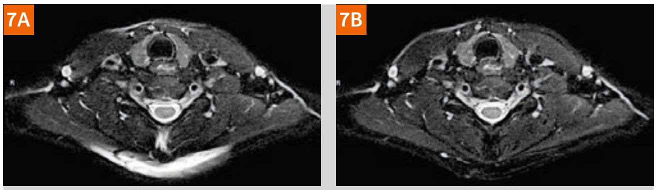

Figure 7: T2-weighted BLADE images with SPAIR fat saturation. The same imaging protocol was used with **(7A)** and without **(7B)** CoilShim. The fat saturation is more homogeneous when CoilShim is active.

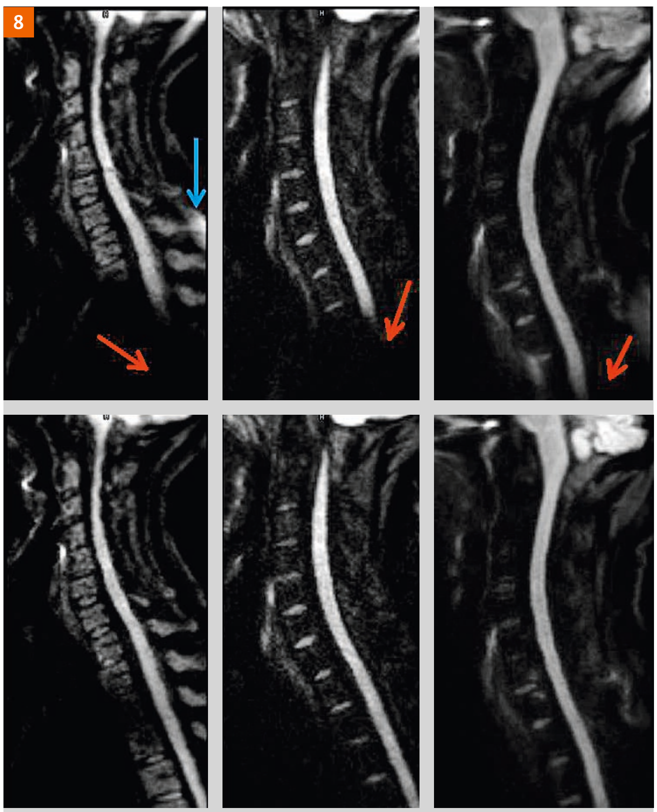

Figure 8: RESOLVE images of the c-spine with b=600 mm/s² in three volunteers. Note the lack of signal (red arrow) in the spinal canal when measured without CoilShim (upper row). Fat saturation is also more consistent (blue arrow).

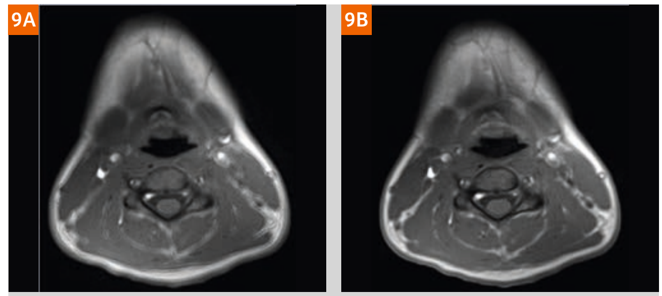

Figure 9: Radial sequences like the StarVIBE also benefit from higher field homogeneity. **(9A)** was measured without CoilShim, **(9B)** with active CoilShim. Note the increased image sharpness with CoilShim.

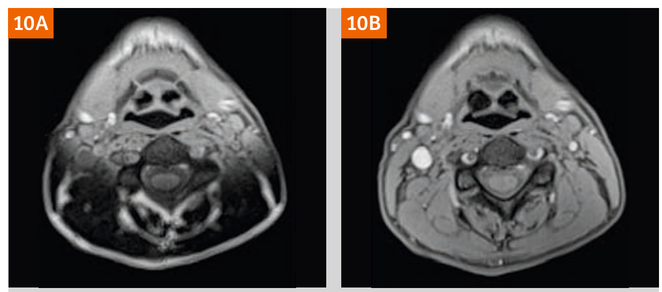

Figure 10: T1-weighted StarVibe images acquired in the neck. CoilShim **(10B),** can correct the field distortions which caused a shift in the frequency spectrum, inducing water saturation and corrupting image quality.

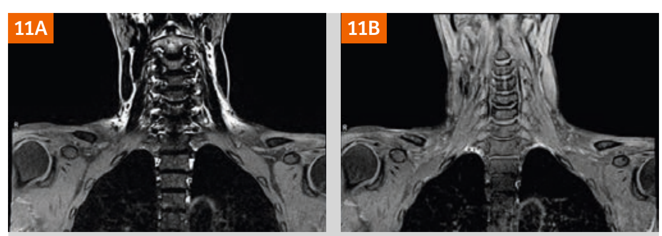

Figure 11: In rare cases, the field inhomogeneities at the border between neck and thorax are so severe, that the frequency is shifted. In these extreme examples, CoilShim **(11B)** also helps to mitigate the effects.

can be achieved with CoilShim. This in turn facilitates better lesion differentiation, in particular in the lower vertebrae.

Figure 8 shows RESOLVE diffusion-weighted images with a b-value of 600 mm/s² with and without CoilShim. Until now the display of the entire spinal canal was challenging, with CoilShim it becomes feasible to follow the spinal canal over the whole field-of-view.

Imaging methods which employ radial trajectories, for example the StarVIBE sequence, or methods such as TrueFISP, which demand a high field uniformity, also benefit from CoilShim technology and produce sharper or more homogeneous images. Figure 9 compares StarVIBE images obtained with and without CoilShim. Less homogeneous B_0 fields broaden the frequency spectra, leading to a shift in the readout direction. Since radial sequences sample *k*-space not in one, but in various directions, any off-resonance dephasing shift effect is propagated into a different direction, leading to blurred images. Larger variations in B_0 homogeneity can cause frequency shifts, which in turn lead to a degradation in image contrast, as shown in Figure 10 for a StarVIBE, and in Figure 11 for a TSE acquisition. Such issues can be avoided when using CoilShim.

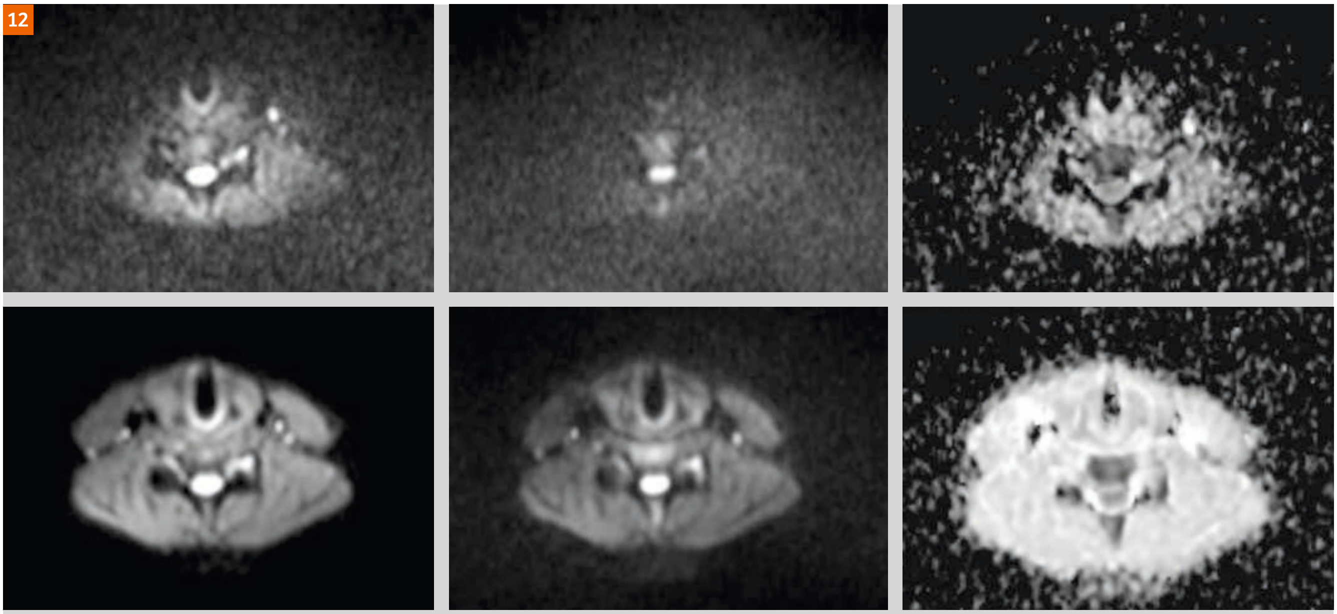

Figure 12: Combining CoilShim with SliceAdjust leads to significant image quality improvements in diffusion-weighted imaging. Less distortions and better spatial fidelity, significantly higher SNR for all b-values provides a new level of diagnostic reliability. The same slice is compared without CoilShim and SliceAdjust (upper row) and with active CoilShim and SliceAdjust (lower row). From left to right: b=50 s/mm^2, b=800 s/mm^2, ADC.

In combination with SliceAdjust, CoilShim technology allows for robust diffusion-weighted imaging (DWI) in the neck area. In the past, DWI imaging of the c-spine or neck soft tissue was challenged by distortions, low signal intensity and artefacts. On enabling the BioMatrix Tuners, the image quality can be improved significantly. Figure 12 illustrates the advantages of CoilShim and SliceAdjust when activated in a DWI image of the neck.

Practical tips

CoilShim is designed to optimize, in particular, the field homogeneity in the cervical spine. Therefore, it works best when imaging the cervical spine, especially in sagittal slice orientations. However, the whole neck area benefits when using CoilShim, although there are some physical limitations. First of all, as the CoilShim elements are located for safety reasons in the lower part of the Head/ Neck coil, the scope of the feature is regionally restricted. For this reason, a drop in B_0 field homogeneity in the vicinity of the anterior part of the neck or the chin area may be observed. This effect may be manifested, as shown in Figure 13 for example, by inhomogeneous fat saturation in the chin area due to the regional limitations of the CoilShim field. The same applies to the shoulders, since the CoilShim elements cannot cover the entire shoulder region. This is shown in Figure 14. Another occasionally-observed effect is a frequency change in the t-spine next to the lung, seen usually in coronal images. As CoilShim optimizes the c-spine and cannot reach the vertebrae of the t-spine, the B_0 field

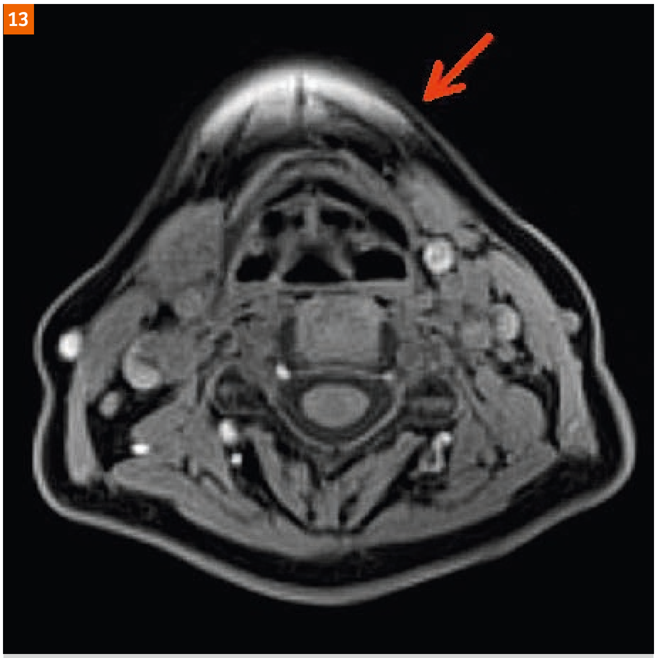

Figure 13: Anterior regions like the chin cannot be reached by CoilShim, which is located in the posterior neck coil region. Typically, in such cases, small regions with insufficient fat saturation are observed.

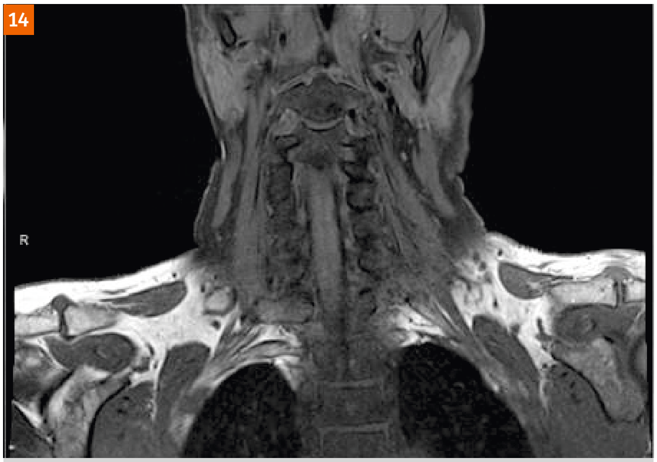

Figure 14: The local effectiveness of the CoilShim elements can lead to less efficient fat saturation in the lateral shoulder area.

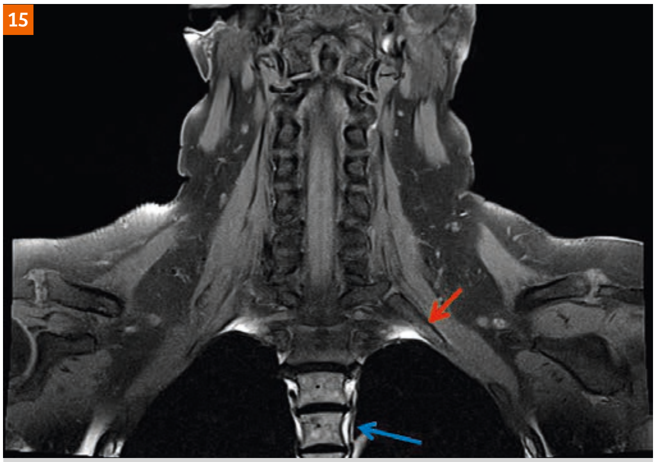

Figure 15: Typical lung-tip artefact (red arrow) and water saturation (blue arrow) in the t-spine. Note the homogeneous fat saturation in the neck/shoulder area.

is dominated by the lung, which might lead to lower field homogeneity with degradations in image quality in the t-spine as shown in Figure 15. The same image also shows the so called lung-tip artefact, which originates from local field distortions, leading to a less efficient fat saturation in a small area around the lung apex.

Summary

CoilShim addresses field disturbances within the head and neck region by local, patient-adapted shim currents. This helps to homogenize the static magnetic field in this region. Thereby the image quality can be improved. Typical benefits include more homogeneous fat saturation, less blurring in radial sequences and more signal with diffusion weighted imaging. Since CoilShim is based on new hardware and transmit pathways, it is currently only available with the BioMatrix Head/Neck coils. Nonetheless, this new technology might also be useful to improve B_0 homogeneity in other body regions in the future.

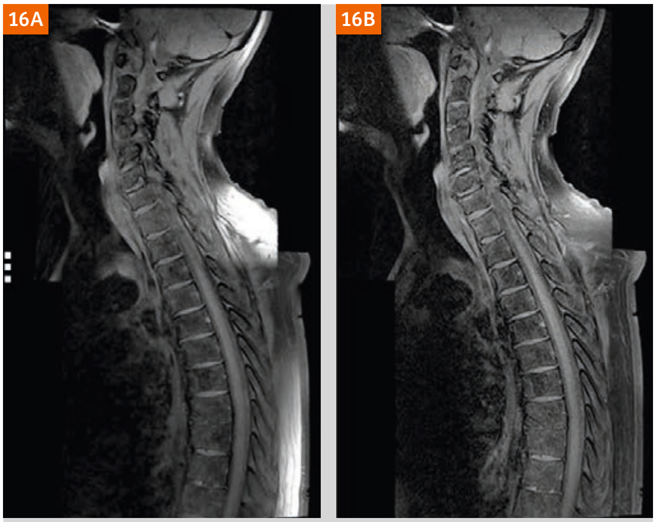

Figure 16: Composing for whole-spine representations also benefits from CoilShim **(16B)**.

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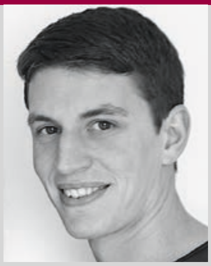

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