MAGNETOM Prisma – Abdominal Applications

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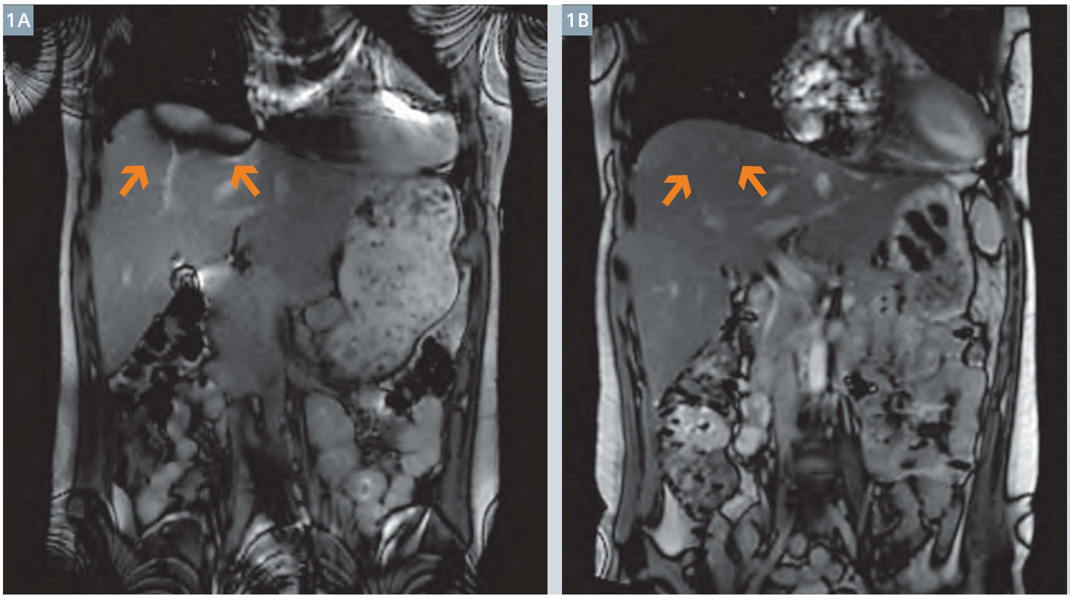
Introduction

In 2002, the first 3 Tesla (T) magnetic resonance imaging (MRI) scanner was approved for clinical use by the Food and Drug Administration. The increase in magnetic field strength technology promised new opportunities in MRI diagnosis and improvement of already established MRI procedures [1–3]. 3T MRI offers a higher signal-to-noise ratio (SNR) compared with lower field strength MRI, which leads to a higher spatial resolution or improved signal exploitation allowing for shorter acquisition times while keeping spatial resolution constant [4, 5]. With the implementation of parallel imaging techniques, imaging acceleration can be performed with a higher acceleration factor compared to lower field strength MRI [6]. Due to slight differences in magnetization characteristics at 3T compared to 1.5T, contrast-to-noise ratio (CNR) is also increased, resulting in improved lesion conspicuity in contrast-enhanced imaging, more sufficient background signal suppression and better fat/water separation [7, 8].

The experience from the clinical routine shows that imaging of the brain and the musculoskeletal system achieved better results with 3T MRI compared with lower field strength. In brain imaging for example, 3T MRI scanners were sufficiently able to detect very small contrast enhancing lesions in the diagnosis of multiple sclerosis [1]. In musculoskeletal imaging the advantages can either lead to depicting fine details of small joints or to a significant reduction in scan time. Theoretically, these advantages could also be used for abdominal imaging, but particular challenges of this body region may increase the risk for artifacts.

In abdominal imaging, especially, increasing the field strength not only provides opportunities for improving image quality and acquisition speed, but also results in more demanding technical challenges. Higher field strength causes an increase in main magnetic field (B_0) inhomogeneity, radiofrequency field (B_1) inhomogeneity, increase the amount of radiofrequency (RF) energy deposition in tissue, and cause an increase in chemical shift and susceptibility artifacts [7, 8]. Suboptimal fat suppression may pose an additional diagnostic issue. The use of parallel imaging techniques can be negatively affected by noise bands through the image plane which occur more often in examinations with a large field-of-view (FOV). Therefore, a simple transfer of imaging protocols from 1.5T to 3T is not applicable.

However, the technical development in the new generation of MR scanners enables the issues in abdominal imaging listed above to be addressed. In this article we will briefly discuss the advan-



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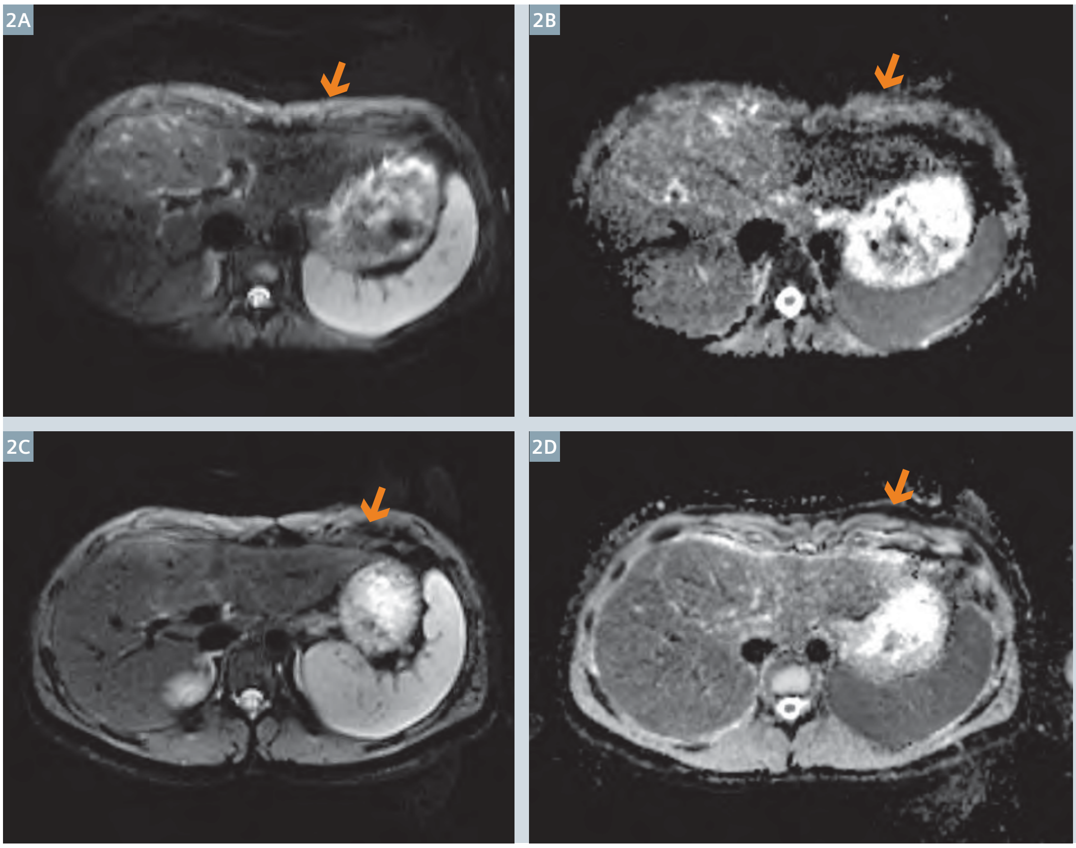
Comparison of TrueFISP in the same volunteer performed on a standard 3T MR scanner **(1A)** and on MAGNETOM Prisma **(1B)**. Distortion artifacts are markedly reduced. (Sequence details 1A, 1B: Slice thickness (ST) 10 mm; TR 289 s; TE 1.14 ms; Matrix 156 × 116; Field-of-view (FOV) 40 × 40 cm).



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DWI and ADC maps of the liver in the same volunteer performed on a standard 3T MR scanner **(2A, B)** and on the MAGNETOM Prisma **(2C, D)**. The homogeneous B_0 and B_1 fields provide improved image quality at MAGNETOM Prisma, especially of the left liver lobe. (Sequence details 2A–D: ST 5 mm; TR 6.6 s; TE 63 ms; Matrix 192 × 156; FOV 41 × 33 cm; b = 800 s/mm²).

tages and challenges of 3T abdominal imaging and demonstrate how the next generation MR scanner, the MAGNETOM Prisma, performs in this context.

Advantages of 3T MRI in abdominal imaging

Many clinical studies over recent years have shown that abdominal MRI examinations can benefit from 3T MRI due to the available increase in SNR and CNR [7, 8]. With higher SNR, higher spatial resolution can be achieved, resulting in an improved image quality offering the possibility to detect smaller lesions and to delineate finer anatomic structures. Increased CNR is a consequence of longer T1 times, as well as improved background suppression and precise fat/water separation [11, 12].

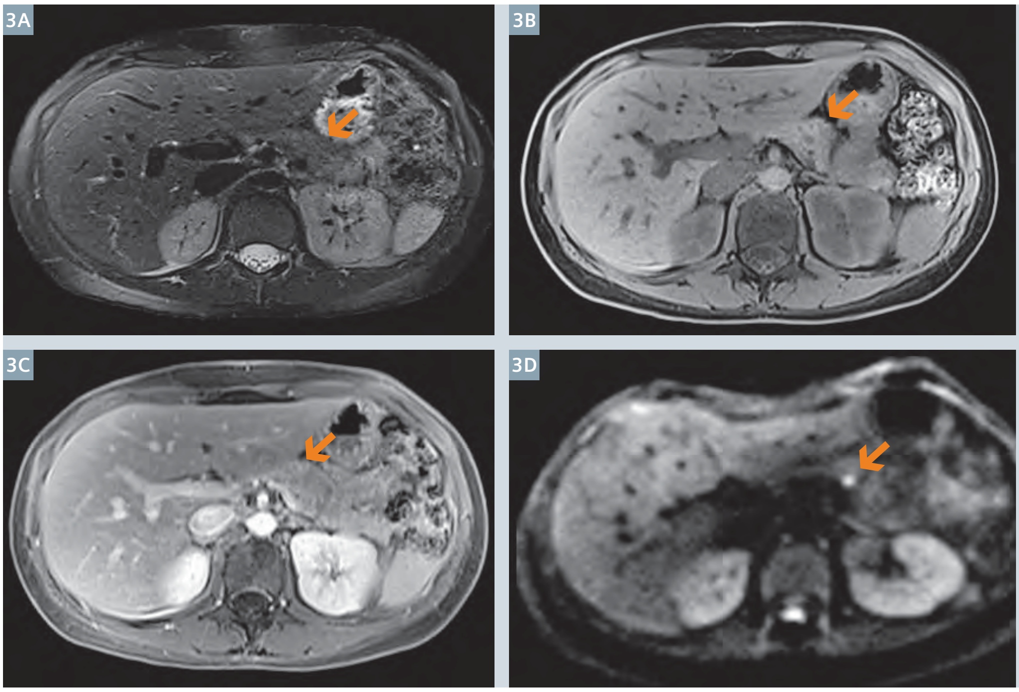
The high signal in 3T MRI allows for improvement and acceleration of parallel imaging techniques, (e.g. generalized autocalibrating partially parallel acquisition, GRAPPA) [6]. The scan time is thereby significantly reduced with the help of multiple coils, subsequent reconstruction methods and by subsampling the *k*-space. With the use of GRAPPA technique, diagnostic examinations of the abdomen can be performed in patients with impaired or poor breath-holding capabilities. The CAIPIRINHA (controlled aliasing in parallel imaging results in higher acceleration) technique benefits markedly from the improved signal in 3T MRI [9]. This technique can be used in liver imaging to acquire multi-arterial phase acquisitions, which are especially helpful in the diagnosis of hepatocellular carcinoma by obtaining adequately-timed arterial phase images [10].

Challenges of 3T MRI in abdominal imaging and how MAGNETOM Prisma performs in these conditions

Whilst there are clear advantages to 3T MRI, there are still some challenges that need to be met, particularly in abdominal imaging.

The recently-introduced next generation 3T MR scanner, MAGNETOM Prisma, is longer and slimmer in size compared to standard 3T MR scanners. With a combination of high gradient strength (80 m/T) and fast gradient slew rates (200 m/T/s), the homogeneity of the magnetic field is improved. The new system provides up to 204 coils elements with up to 128 integrated receive channels and uses the 4th generation coil architecture, total imaging matrix (Tim 4G).

In order to establish a correct spatial resolution for avoiding artifacts in MRI (e.g. distortion), the spatial linearity of the gradient has to be matched with the volume of consideration. The gradient coils are surrounded by conductive structures where eddy currents are generated by the time-varying magnetic field. At higher field strength these eddy currents effects are higher, resulting in the disruption of B_0 homogeneity, and are reflected by distortion artifacts. MAGNETOM Prisma counteracts this effect with a higher gradient strength coupled with advanced shimming solutions that allow for finer and more effective compensation of patient-induced disturbances. Figure 1 illustrates how the MAGNETOM Prisma performs in true fast abdominal



3

Insulinoma (**3A**: T2-weighted, **3B**: T1-weighted without contrast, **3C**: T1-weighted with contrast, **3D**: DWI). Excellent image quality resulting in good lesion conspicuity allows for detecting a small lesion in the pancreas tail. (Sequence details 3A: ST 4.8 mm; TR 1.6 s; TE 117 ms; Matrix 320 × 170; 3B: ST 2.5 mm; TR 3.92 s; TE 1.24 ms; Matrix 288 × 187; 3C: ST 2.5 mm; TR 4.16 s; TE 2.01 ms; Matrix 320 × 147; 3D: ST 4 mm; TR 6.6 s; TE 63 ms; Matrix 192 × 156; b = 800 s/mm²).

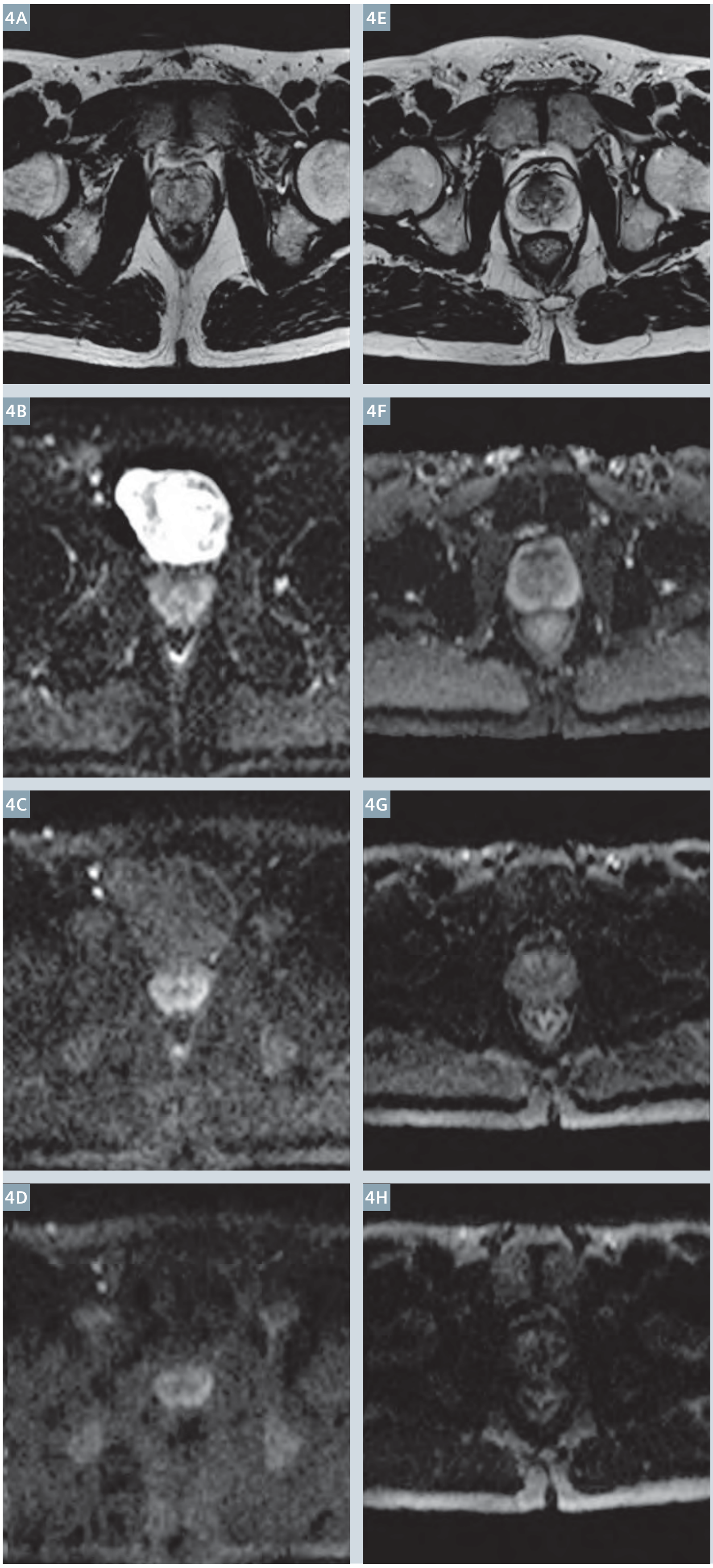
imaging with steady state free precession (TrueFISP) imaging compared to a standard 3T MRI scanner. Image quality is significantly improved and distortions are reduced especially in the periphery.

As mentioned above, higher field strengths result in pronounced image artifacts from B_1 inhomogeneities in comparison to lower field strengths [13]. The frequency required to excite the magnetization increases linearly with the field strength. Human body tissues have a high dielectric constant reducing the wavelength of the RF field significantly which results in standing wave artifacts. These images have regions of increased and decreased magnitudes which produce bright areas away from the receiver coils or dark areas near the receiver coils [4, 14, 15]. Thus, the result of B_1 inhomogeneities can be loss of image contrast. This problem plays an important role in abdominal imaging due to the large FOV further amplifying B_1 inhomogeneities.

Liver MRI is a well-established clinical application for the characterization of focal hepatic lesions, but it remains a complex technique requiring optimal patient compliance and technical conditions to obtain diagnostic images [16]. Due to B_0 and B_1 imperfections, a homogeneous large field-of-view image is more difficult to acquire at 3T. Diffusion-weighted imaging (DWI) of the liver can assess microstructural cell characteristics such as cellularity. In figure 2 an example of DWI of the liver is depicted as a comparison between a standard 3T MR scanner and the MAGNETOM Prisma. With improved homogeneity of the technical setup, the entire liver parenchyma is homogeneously imaged and previously problematic areas, such as the left liver lobe, have an evenly distributed signal similar to the right liver lobe.

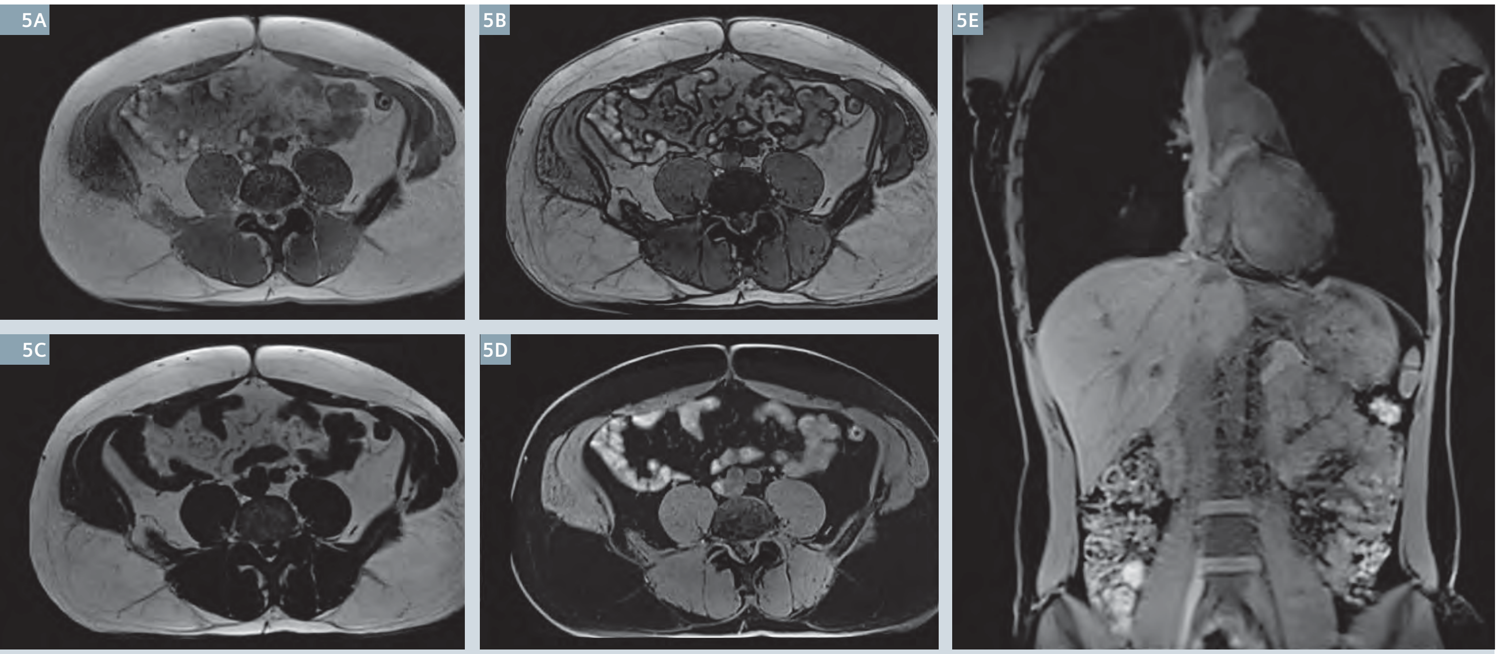
The detection of very small lesions in abdominal organs remains challenging in MR imaging. In particular, the examination of the pancreas requires adequate diagnostic images to detect and characterize small lesions. Figure 3 shows an example of an insulinoma measuring 6 × 4 mm clearly detectable in the pancreatic tail.

Imaging at 3T has the advantage of increased signal, but has to cope with disadvantages including increased chemical shift, increased susceptibility and motion artifacts [17]. Chemical shift artifacts are caused by different resonant frequencies of water and fat resulting in a chemical shift misregistration of water/fat spins which precess at the same frequency along the frequency encoding axis. At 3T MRI the chemical shift between fat and water spins increases by a factor of two occurring for instance around the kidneys potentially mimicking a subcapsular hematoma [18]. As a result of static microscopic gradients or variations in the magnetic field, susceptibility artifacts occur near tissue interfaces with different magnetic susceptibilities [14]. In abdominal imaging a multitude of boundaries between air and soft tissue are present, (e.g. adjacent to the stomach, bowel or near the diaphragm) which may increase the risk for susceptibility artifacts. At high field strength, susceptibility artifacts are more pronounced and can obscure anatomical details or important findings [14, 15, 18, 19]. Figure 4 shows T2 and DWI of the prostate of the same healthy volunteer with a standard 3T MRI scanner and with the MAGNETOM Prisma. Artifacts are significantly reduced on images acquired with the MAGNETOM Prisma. The high gradient slew rates



4

Comparison of prostate imaging performed with a standard 3T MRI scanner **(4A–D)** and with the MAGNETOM Prisma **(4E–F)**, T2-weighted and DWI with b-values of 0, 1000 and 2000 s/mm². In DWI acquired on the MAGNETOM Prisma platform the signal is higher and less noisy also at high b-values.
(Sequence details 4A: ST 3 mm; TR 5.15 s, TE 143 ms; Matrix 448 × 254; FOV 23 cm²; 4B–D: ST 2.5 mm, TR: 3.9 s; TE 72 ms; Matrix 100; FOV 25 cm²; 4E: ST 3.5 mm; TR 7.5 s, TE 101 ms; Matrix 320; FOV 23 cm²; 4F–H: ST 2.5 mm, TR: 3.7 s; TE 50 ms; Matrix 100 × 10; FOV; 25 cm²).



5 Dixon with in-phase, out-of-phase, water and fat only **(5A–D)** images performed at MAGNETOM Prisma. Additionally, demonstration of optimal image homogeneity on coronal orientation **(5E)**. (Sequence details 5A–D: ST 3 mm; TR 3.9 s; TE 1.23 ms / 2.46 ms; Matrix 288 × 187; FOV 40 × 29 cm; 5E: ST 1.6 mm; TR 4.12 s; TE 1.3 ms / 2.6 ms; Matrix 288 × 209; FOV 45 × 36 cm).

of 80 mT/m of MAGNETOM Prisma allow for shorter echo times (TE) and can be reduced to 50 ms in DWI. Thus, more signal can be detected allowing for improved, less noisy images even at high b-values.

In abdominal imaging motion artifacts may be present due to the intrinsic properties and function of abdominal organs (e.g. bowel peristalsis or cardiac motion). Particularly sequences with long acquisition times are prone to motion artifacts. Utilizing parallel imaging techniques, scan times can be reduced if sufficient image quality is maintained. MAGNETOM Prisma uses a new technology, TimTX True Shape, which offers an intelligent interaction of multiple, independent transmit channels. Thus, several high-frequency pulses can be sent in parallel resulting in better image quality and shorter scan times.

Figure 5 gives an example for excellent high-resolution imaging and image quality acquired in a single breath-hold scan with advanced parallel imaging techniques (CAIPRINHA), which benefit from the technical advantages of the MAGNETOM Prisma. Fast parallel imaging in breath-hold technique results in a reduction of motion artifacts and simultaneously in a reduction in the specific absorption rate (SAR). The SAR is a measure for RF energy deposition to the human body. Doubling the field strength to 3T results in quadrupling the RF energy deposition potentially limiting imaging thus any reduction of SAR at 3T is beneficial [14, 18].

In almost all abdominal MR imaging applications a sufficient fat saturation is paramount, especially in contrast-enhanced examinations. Nevertheless, spectral fat saturation techniques may not work well in inhomogeneous tissue volumes due to changes in the precessional frequencies. In abdominal imaging inhomogeneous or insufficient fat saturation often occurs at tissue boundaries or adjacent moving structures. The faster, stronger gradients of the MAGNETOM Prisma in combination with its more homogeneous B_0 field translate into a more homogenous and adequate fat saturation.

Summary

Due to their high SNR and CNR, 3T MRI systems have been established for clinical brain and musculoskeletal imaging over the last years. With respect to abdominal applications, 3T imaging remains challenging given the more difficult conditions associated with the large FOV and amplified image artifacts. Under these circumstances, the disadvantages of standard 3T MRI may outweigh potential advantages.

The new generation MAGNETOM Prisma copes with the said challenges by offering a new system design, and several technical methods to reduce sources of image noise and to optimize image acquisition. With high gradient field strengths and fast slew rates, existing techniques like parallel imaging can be optimally utilized and acquisition time further reduced without a significant loss in signal strength. This further leads to a reduction in motion artifacts and SAR. The increased homogeneities of the B_0 and B_1 fields contribute to a significantly improved image quality and more effective reduction of image noise.

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MAGNETOM Prisma is not commercially available in all countries. Due to regulatory reasons its future availability cannot be guaranteed.