

Imaging at 3 Tesla – luxury item or standard clinical tool? First experiences with MAGNETOM Spectra

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1 The Radiology Practice is located in the 'Sportpark' next to stables and open fields, creating a vacation-like feel to a high tech radiology facility, thereby making the patient feel relaxed and at ease.

Introduction

Background information on our department

The 'Gemeinschaftspraxis Radiologie und Nuklearmedizin' was founded by Dr. A. Halbsguth and B. Lochner in Frankfurt almost 30 years ago and has grown continuously since then, now serving 10 facilities in the greater Rhein-Main-Taunus area. Started as a classical outpatient practice, it acquired the first MRI scanner in Frankfurt in 1984. The group's 20 staff and partner radiologists today perform around 150,000 exams annually. The opening of the latest facility in

Bad Nauheim in January 2011 reflects a decades-long collaboration with the Sportklinik Bad Nauheim, a renowned medical center for orthopedic and trauma surgery, as well as cardiology and rehabilitation under its founder Dr. Johannes Peil. It creates a strong demand for MR imaging, since sports injuries are a major focus of its work. The Sportklinik attracts world-class athletes of many different disciplines, including Michael Schumacher and Timo Boll. Over the years, imaging was performed in Frankfurt, just 30 km away. However, with traffic situation worsen-

ing and the imaging demand ever increasing the decision was taken to move to Bad Nauheim (Fig. 1).

Where do we stand and what do we need?

The new practice next to Sportklinik was opened with the 1.5T MAGNETOM Area in January 2011. It immediately became fully booked and the need for increased capacity was apparent within weeks. The decision to go for a second magnet was made by the never ending influx of patients.

Pros and cons of investing in 3T

When deciding on the new magnet, a 3T system was not a first line priority. Of course 3T MR imaging is offered in many radiological services and proved its advantages, however there are some drawbacks associated with it. The higher magnetic field strength changes a number of physical effects as compared to 1.5T systems and, over the years, ultra-high field magnetic resonance tomography (3 Tesla) proved to be especially advantageous for examinations in the area of neuro-radiology or orthopedics. While the signal-to-noise ratio (SNR) increases with a higher magnetic field resulting in better image quality many other physical property are changed, such as the resonance frequency or the T1 and T2* relaxation times. Similarly, the dielectric resonance frequencies are changed and this may have a negative effect on image quality if not used properly. Another factor was the considerably higher cost of both

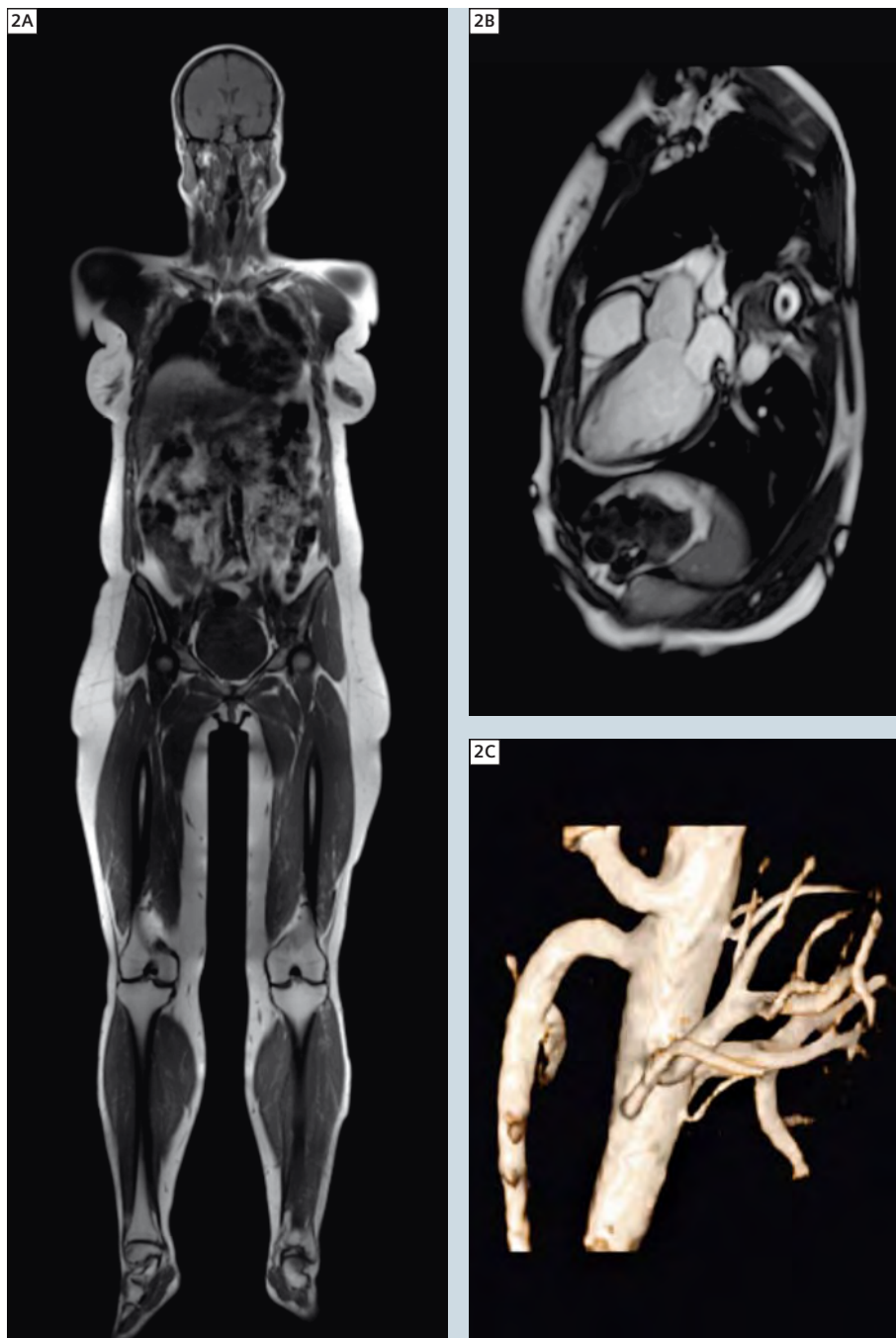
procuring and operating the system due to its higher energy and cooling requirements and higher servicing costs. We concluded that a 3T magnet could be a valuable addition for our patients if the problems described could be overcome.

Cost was a significant issue since the reimbursement for medical imaging has declined steadily over the past years. With an average of 60 € per patient reimbursed for an MRI examination with statutory health care in Germany, the investment in a 3T system seemed impossible.

Installation of the MAGNETOM Spectra

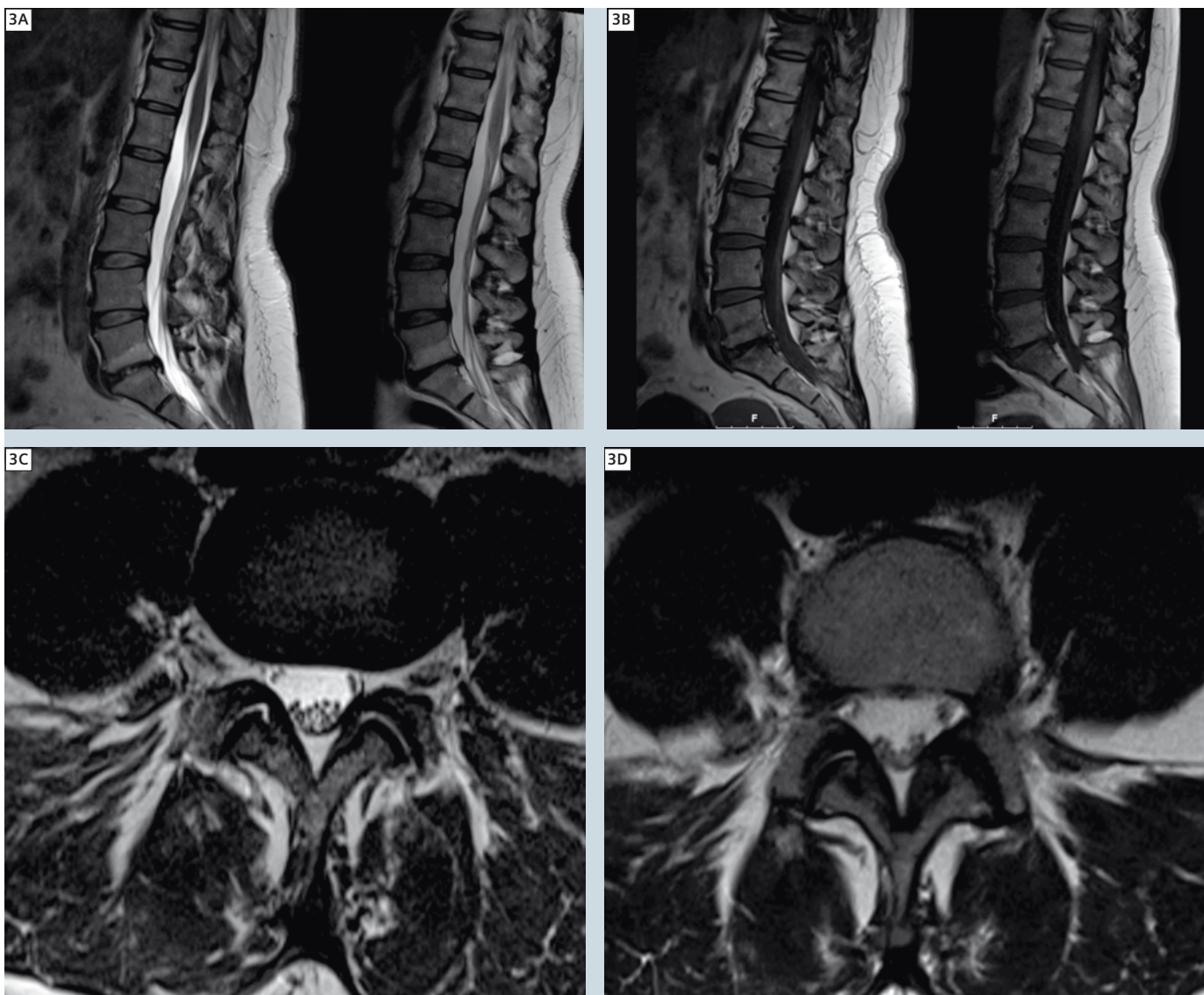
In June 2011, only 5 months after the opening of the facility in Bad Nauheim, the team around the managing partner Dr. Thomas Maier was asked by Siemens Healthcare whether it would like to become the first customer for the new 3T MAGNETOM Spectra*. The offer almost seemed too good to be true: not only did the technical advantages of the system seem ideal for our patient base, but the cost structure was such that an investment in a 3T MRI system could be feasible (Fig. 2). Soon it became clear that given our organizational structure we could also conduct the required studies for clinical approval (CE labeling) for the system.

After preparing the existing RF-room ("3T fits in the footprint of 1.5T"), the system was delivered in the second half of November 2011 and ready on December 6th. The installation time took only a few days and went without a hitch. This was especially surprising since it was the first prototype to be installed worldwide. The easy-to-use and cross-scanner available user platform *syngo*, together with a very welcome multifaceted sequence spectrum with its software preinstalled by Siemens allowed direct system implementation without large changes to the



2 Throughout the history of medical technology, our maxim has been further, better, higher and – unfortunately – more expensive. Due to cost, many technological developments do not reach the public, especially in the realm of statutory health care. The new MAGNETOM Spectra manages to break that law by delivering high class 3T imaging quality at an affordable price.

*This product is still under development and not yet commercially available. Its future availability cannot be ensured.



3 This lumbar spine comparative exam demonstrates how a high-quality 3T exam delivers a better image quality that does not necessarily translate into better patient care. The gain in image quality makes no difference to clinical decision making. **(3C–D)** shows that the gain in SNR can be used, however, to speed up exam time and thus make medical imaging more economical.

measurement sequences into a clinical (testing) setting. The measurements corresponded in principle to the known sequences of our 1.5T MAGNETOM Aera. In parallel to the diagnostics, only the protocols needed to be fine-tuned in the coming weeks and months according to the special requirements of our institute.

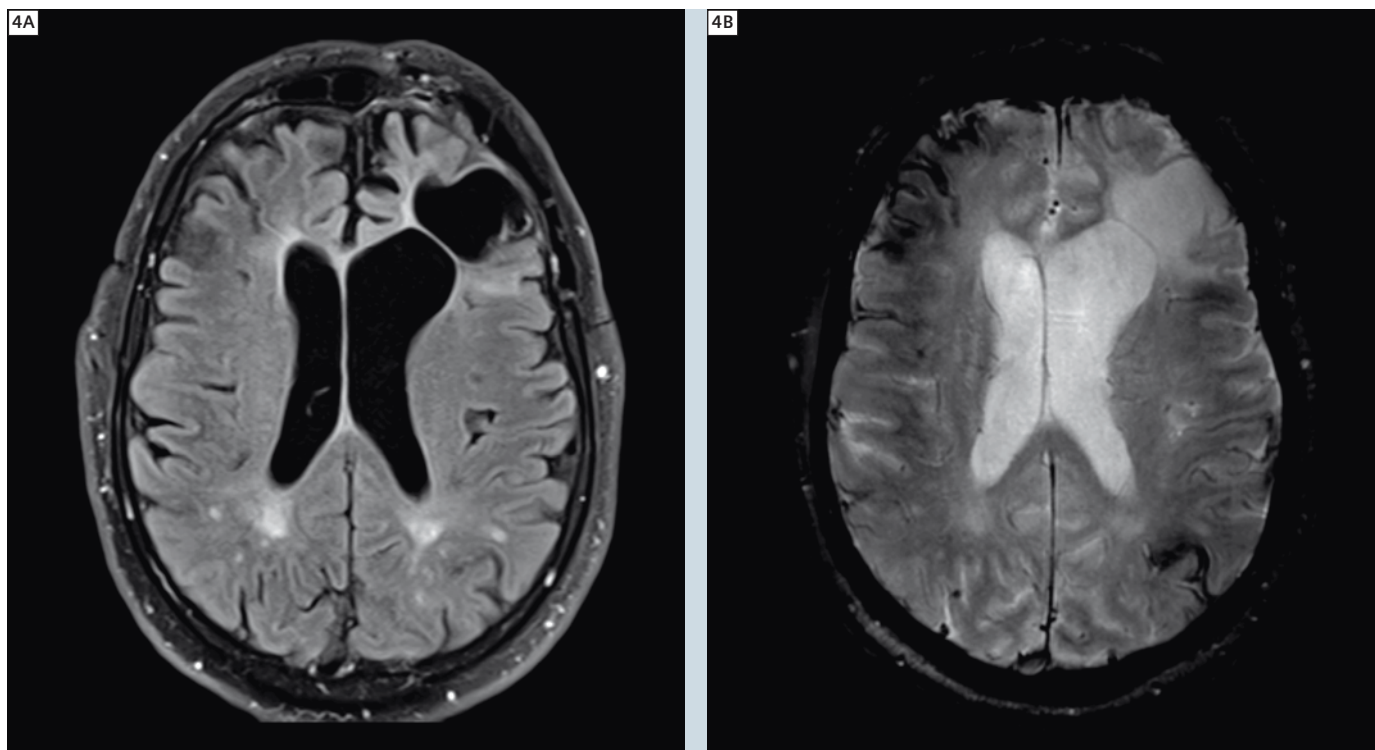
Technical advantages of 3T MAGNETOM Spectra

MAGNETOM Spectra is a magnet with zero helium boil-off, which reduces the

life-cycle costs. Given the ever increasing helium shortage of the past years and thus the rising price, this is almost a *conditio sine qua non*.

The magnetic field strength of twice that of 1.5T systems increases the signal, essentially doubling the SNR. However, the higher magnetic field strength changes the relaxation times and makes for stronger susceptibility effects so that, depending on their influence, the real signal gain does not correspond to 100% for all measurements. The increase in

SNR can be used to shorten the acquisition time as compared to 1.5T with the same spatial resolution or vice versa, to increase spatial resolution at the same acquisition time, that is, to improve the quality of the examination, for example, through improved detail display, higher resolution, thinner slices, or a higher matrix. During routine examinations we usually use both effects, i.e. sequence protocols with higher resolution and tolerable acquisition times when highest image quality is needed. Another strat-



4 This shows the superior image quality in this dark fluid inversion recovery sequence. The liquored zone of the left frontal lobe after a serious road traffic accident is extremely clear. In the hemosusceptibility sequence the residual ferritin deposits are well assessed.

egy is to reduce the acquisition time when imaging speed is required and highest resolution is not a focus of the exam, resulting in higher diagnostic safety, higher patient comfort, and consequently higher system acceptance in combination with acceptable costs under the given conditions of statutory healthcare (Fig. 3).

The optimally linked magnet design, the RF pulses, the gradients and the examination sequences resulted in the application of 3T technology and thus MAGNETOM Spectra in clinical routine diagnostics where it is readily tolerated by patients. SAR warnings did not appear at all in our examinations. Another considerable advantage in routine examination is the Tim 4G (Total imaging matrix) technology which we already use on our other 1.5T systems. The multi-coil concept and parallel imaging in combination with technical improvements, such as 'scan@center', 'AutoCoilSelect', 'Inline composing' or even 'syngo Tim CT', provide for consid-

erably easier examination planning with almost no changes in patient positioning and coils. In addition, any combination of multi-station exam up to whole-body examination is possible. Furthermore, the workflow was largely improved by facilitating planning of larger examination volumes or so-called multi-station examinations in different table positions as well as by providing easy to operate 'Set-and-Go' protocols.

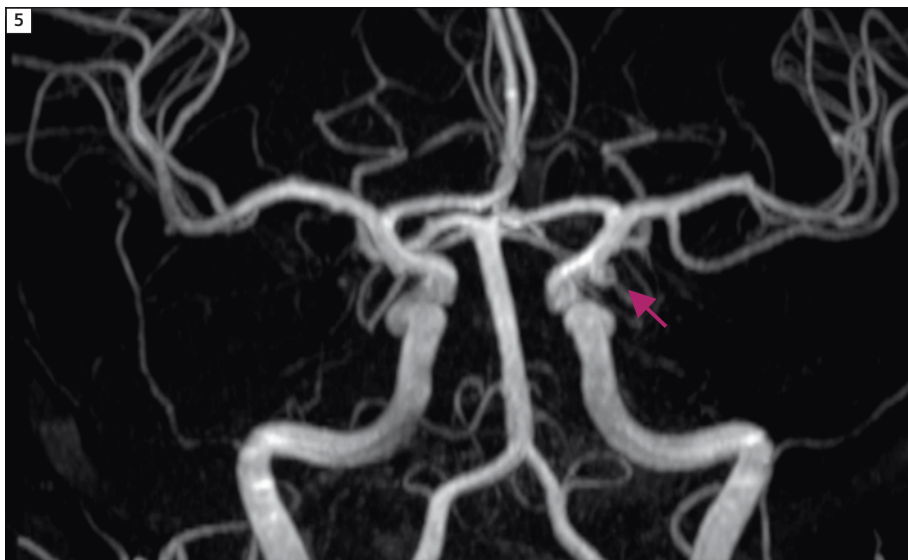
Tim and syngo workflow

Technologists performing examinations at the MAGNETOM Spectra find the workflow largely simplified and improved. Tim technology allows easy planning, especially for whole-body examinations, angiography or examinations of the entire spine. For these multi-station examinations, the localizers of the different stations are already combined via Inline composing. This means that the technologists can use the composed localizers and plan as well as perform the remaining course of the exami-

nation, making patient repositioning or coil changes unnecessary. To ensure the best possible magnetic field homogeneity, the existing 'scan@center' technology guarantees that the measurement volume to be examined is always positioned in the magnet's isocenter. At the same time, the necessary coils are detected and selected with 'AutoCoilSelect' which avoids any kind of error. To make things even better, the new dedicated hand coil can be even used out of isocenter, making uncomfortable patient positioning unnecessary. The workflow is further improved by the ease of use of the "Set-and-Go" protocols, also leading to shorter examination times.

The Dot engine concept

Our practice employs over 60 radiographers and technicians to work in various facilities in rotation. While this concept assures that every radiographer sees all various different examination techniques and stays on top, this concept may be challenging when introducing



5 One of the biggest advantages of 3T in clinical routine is the time-of-flight angiography since no contrast medium is needed and even the smallest aneurysms can be detected with ease using either MIP imaging or a conventional 2D imaging plane.

new scanners, especially when 3T imaging was not part of the daily routine. This is where the Dot concept assures a constant high quality. In this examination strategy the workflow is preset and the radiographers only have to tell the system which examination is required, e.g. left knee. The software then automatically performs all necessary tasks on its own. Even the localizers and the scan range are automatically detected. All scanning sequences are pre-programmed, so that not even the examination sequence for each individual exam has to be selected. Also no adaptation to a chosen sequence is necessary. This means that radiographers with little or almost no MRI experience can perform exams of high quality standard without mistakes.

Neuro imaging

All neuro applications used with 1.5T systems can be implemented using the 3T MAGNETOM Spectra leading to significant quality improvements because the improved SNR which can be usefully applied in a variety of ways (Fig. 4). The extension of the longitudinal relaxation rate of static tissue as compared to blood is advantageous for MR angiog-

raphy at 3T. Due to saturation effects, greater suppression of the static tissue is obtained, thus Time-of-flight (TOF) angiographies can be performed with much higher resolutions, using the same or reduced examination times. As a result, intracranial arteries can be evaluated far into the periphery. A dramatic effect can be seen in the detection or exclusion of small intracranial aneurysms. The detailed image quality allows for 3D interpretation of images. Sometimes small aberrant vessels suggest the presence of a possible aneurysm which can be better visualized at 3T than at 1.5T. For patients this is of utmost clinical importance since a suspected aneurysm in an MRI exam has to be excluded via conventional intracerebral angiography, an exam that carries a non-negligible procedural risk (Figs. 5, 6).

Furthermore, the *syngo* SWI sequences (susceptibility-weighted imaging) implemented with, e.g., blood diagnostics are more sensitive with MAGNETOM Spectra than with 1.5T systems due to higher susceptibility sensitivities that help detect the smallest blood deposits or calcifications.

The quality of the *syngo* SPACE sequence was also greatly improved for our profile

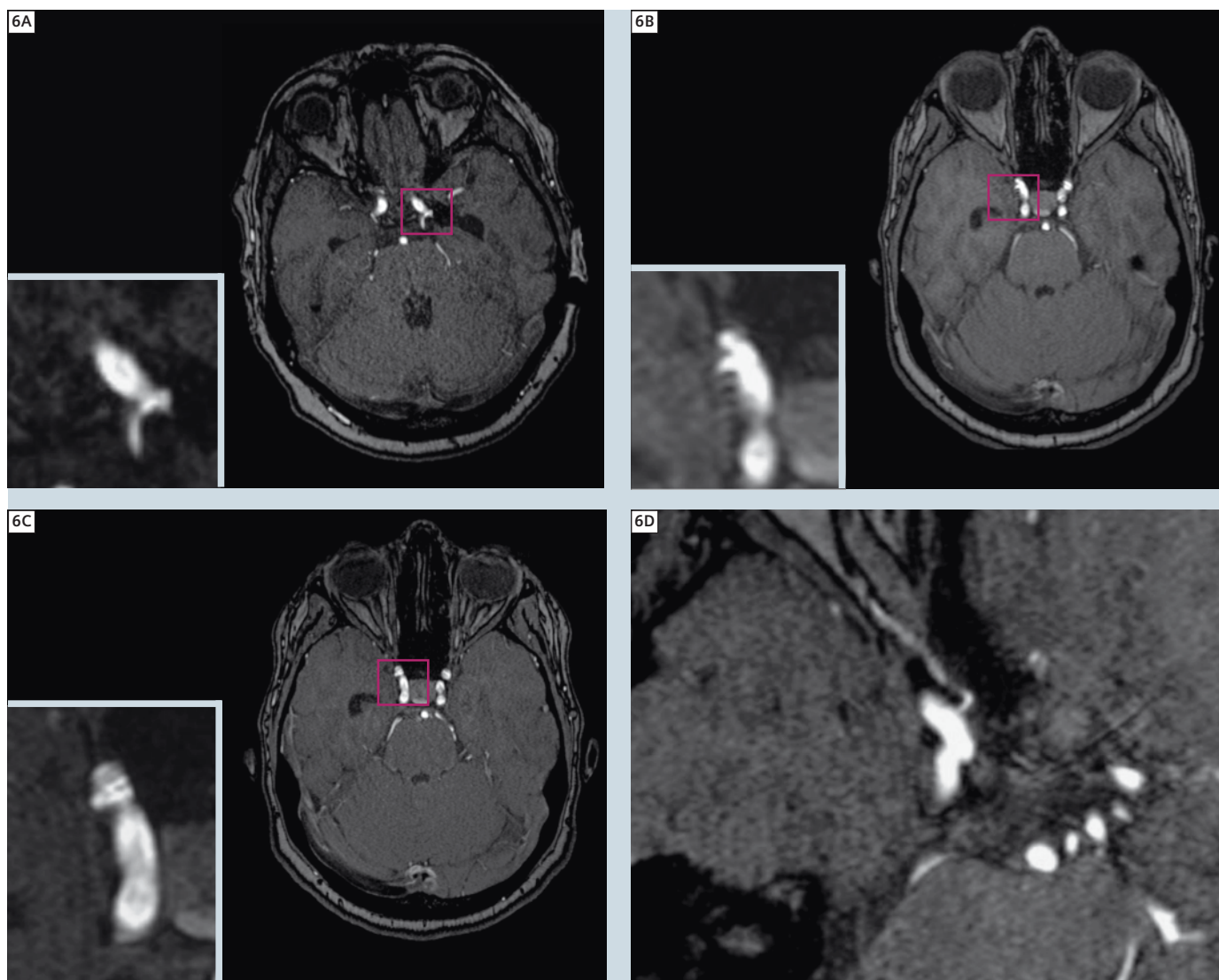
by using 3T technology in clinically feasible examination times. Examinations with isotropic voxels, even in the sub-millimeter range, are possible, resulting in largely improved reconstructions in all planes. This facilitates a more rapid and more confident assessment of small intracerebral lesions such as MS plaques. While for the primary diagnosis the presence of the typical lesions is enough to establish the differential diagnosis of a possible neurodegenerative disorder, the follow-up is often a chore. All lesions have to be compared to the previous exam, so that the application of 3D sequences helps to assure that all the lesions are compared to the corresponding ones in the previous exam.

Tim Planning Suite allows, for example, the examination of the entire spine in a simple workflow. The individually acquired images in the different stages are automatically combined via Inline composing.

Another advantage of the higher spectral resolution of 3T imaging vs. 1.5T imaging is the application of sequences such as the Dixon fat saturation technique. Not only is the Dixon sequence less susceptible for artifacts when compared to STIR or TIRM sequences, but it also allows for reduced examination times. In spine imaging usually a T2 and T1-weighted sequence in sagittal orientation is used as base sequence. To rule out fresh fractures, spondylodiscites or activated osteochondrosis, an additional inversion recovery such as STIR or TIRM is used to visualize bone edema. Due to imaging properties of the Dixon sequence a single acquisition allows the read out of a fat image and a water image. These images correspond very well to a conventional STIR sequence (water image) as well as to the T1 sequence (fat image), thus a single acquisition sequence can replace two individual imaging sequences and thus save time (Fig. 7).

Orthopedic imaging

Compared to examinations with systems of lower field strengths, the improved quality of examinations with a 3T system is undisputed. In contrast to 1.5T sys-



6 Figures **6A** and **6B** display a suspected aneurysm at 1.5T. Figures **6C** and **6D** show the same patient at 3T. One can clearly see that the suspected aneurysm is an aberrant vessel, giving the impression of a pseudo aneurysm. The 3D double oblique angulated MPR image (**6D**) displays the vessel nicely.

tems, spatial resolution can be increased at comparable examination times, allowing for examinations with unseen resolution at 1.5T whereas images with an examination quality comparable to a 1.5T system are generated at considerably shorter acquisition times. A routine knee examination can be performed in 8 minutes. We usually combine the increase in resolution and the time savings according to the purpose of the examination or the patient. Special coils, such as the 18-channel knee coil (Fig. 8) or the 16-channel hand/wrist coil (Fig. 9) enable the use of parallel imaging with

higher PAT factors. Again, these result in shorter measurement times and higher resolution (Fig. 10).

In the Bad Nauheim facility high-quality orthopedic imaging is of particularly vital importance since about 60% are MSK exams.

The advantage of high-quality cartilage imaging is evident. Many of our patients suffer from sports-induced injuries and require surgical treatment and follow-up exams. The exquisite detail of cartilage injury allows for dedicated treatment decisions that simply cannot be achieved using 1.5T imaging.

Also the use of the dedicated whole-hand/wrist coil allows for unprecedented image quality. The new coil allows for a comfortable hand positioning next to the body, making the 'superman' position in isocenter unnecessary. Motion artifacts related to an uncomfortable position during a lengthy exam are readily less frequent.



7 Using the 3T advantage to better differentiate between the spectral resonance frequencies of fat and water, the Dixon sequence not only delivers superior image quality (left images 3T, right images same patient at 1.5T), but also help to save acquisition time. While at 1.5T both a T1-weighted and a STIR sequence were necessary, at 3T a single Dixon T2-weighted sequence is sufficient to produce a dual read out of the fat image and the water image and to obtain the same medical information.

Cardiac imaging

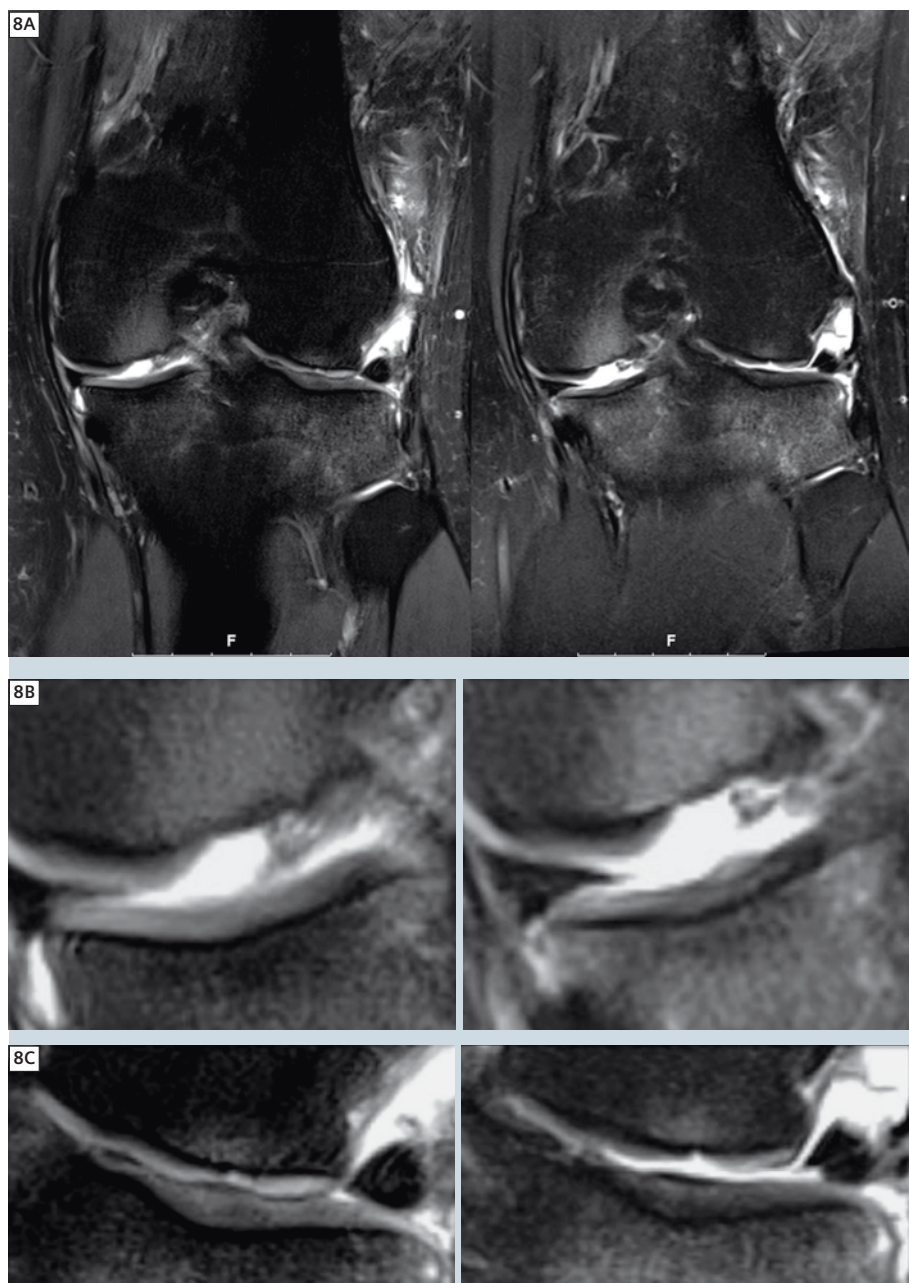
In the last decade MR imaging of the heart has been introduced to clinical routine. However, the widespread use of this formidable examination technique outside dedicated cardiac centers was hampered by the inadequate reimbursement of the statutory health system as well as the fact that only highly-trained and skilled technologists were able to perform a cardiac exam with sufficient image quality. In our institution there are only 5 technologists out of 60 that are experienced enough to carry out an exam without the radiologist's constant presence. While a general examination strategy can be preset, finding the correct standard cardiac angulations such as the short axis or the 2, 3, and 4-chamber view can be challenging for non-experts. Also due to physical conditions, the sequences have to be in part adjusted to avoid 3T-specific artifacts. These include susceptibility effects that increase at 3T, or off-resonance artifacts that reduce image quality as low-signal bands or ghosting artifacts. For frequency adjustments, an additional 'frequency scout' has to be measured to determine the frequency where banding artifacts are not present. In the subsequent function measurement, the frequency determined is changed automatically, reducing the artifacts. The cardiac Dot engine is able to fully automatically find all cardiac axes and carry out the exam with minimal user interaction including the suppression of 3T specific artifacts. A complete cardiac study including late enhancement is now possible under 30 minutes even for a non-experienced technologist. Another advantage is the integrated, fully automated Inline left ventricular function assessment. In the past, the dataset had to be transferred to specific post processing consoles and semi-automatically evaluated by either a technologist or a radiologist. Although this process took only 10 or 15 minutes per case, this was too long considering that a new patient is usually scheduled every 20–30 minutes. With the new Dot engine the evaluation of the left ventric-

ular function occurs instantaneously at the end of the data acquisition without any user interaction at all on the image acquisition console and is automatically transferred to the PACS, so that image reading can be done like any other exam. The Dot engine allows for the first time cardiac examination with reliable image quality under the condition of statutory healthcare in a general outpatient practice (Fig. 11).

Abdominal imaging

Whilst there is no dispute that 3T imaging delivers superior image quality in MSK and neuro imaging the advantages of abdominal imaging are less apparent. As in cardio-vascular diagnostics, abdominal imaging is negatively affected by the physiological respiratory motion and pulsation artifacts of abdominal vessels. Added to these are motion artifacts caused by gut mobility and increased susceptibility effects resulting from air in intestinal loops. To date, implementation of 3T systems for routine abdominal imaging has been limited due to B₁ inhomogeneities caused by dielectric effects. Additionally, the specific absorption rate (SAR) limits were reached early on, especially in the first days of 3T imaging – often examinations had to be performed by increasing slice thickness or reducing the number of slices, thus losing spatial resolution. These limited the implementation of routine diagnostics. MAGNETOM Spectra has a 60 cm bore and concern was raised whether patients with normal western European body habitus or overweight patients could be examined. We were also unclear at this time-point whether a 'budget' magnet would deliver all physical properties needed to acquire high quality exams.

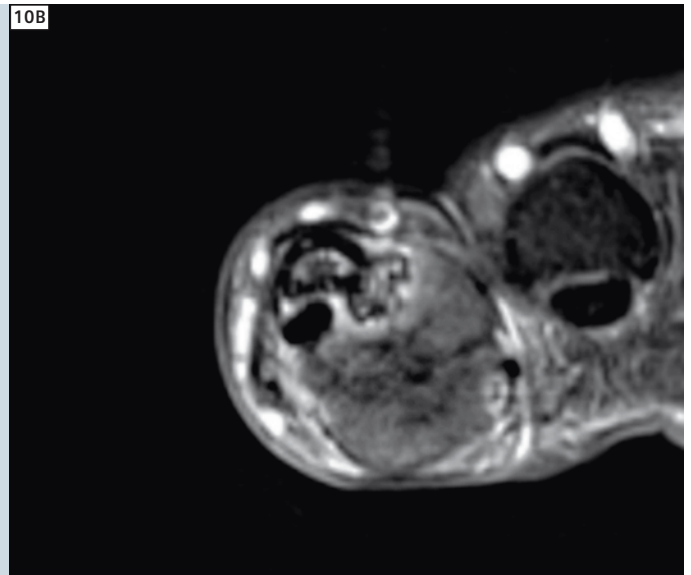
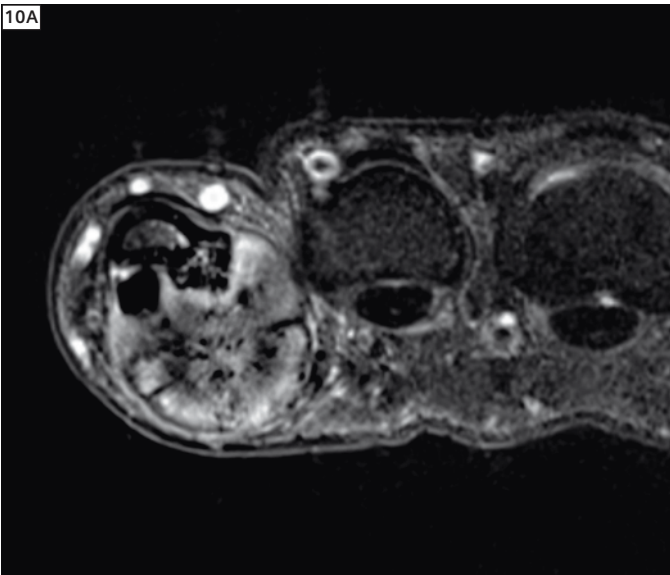
Exceeding our expectations, the optimally linked magnet design, the RF pulses, the gradients, and the examination sequences resulted in more than acceptable image quality. Even at the off-center regions of the magnetic field, a fully diagnostic image quality even in heavier patients could be acquired. Fat-suppressed sequences often stricken by



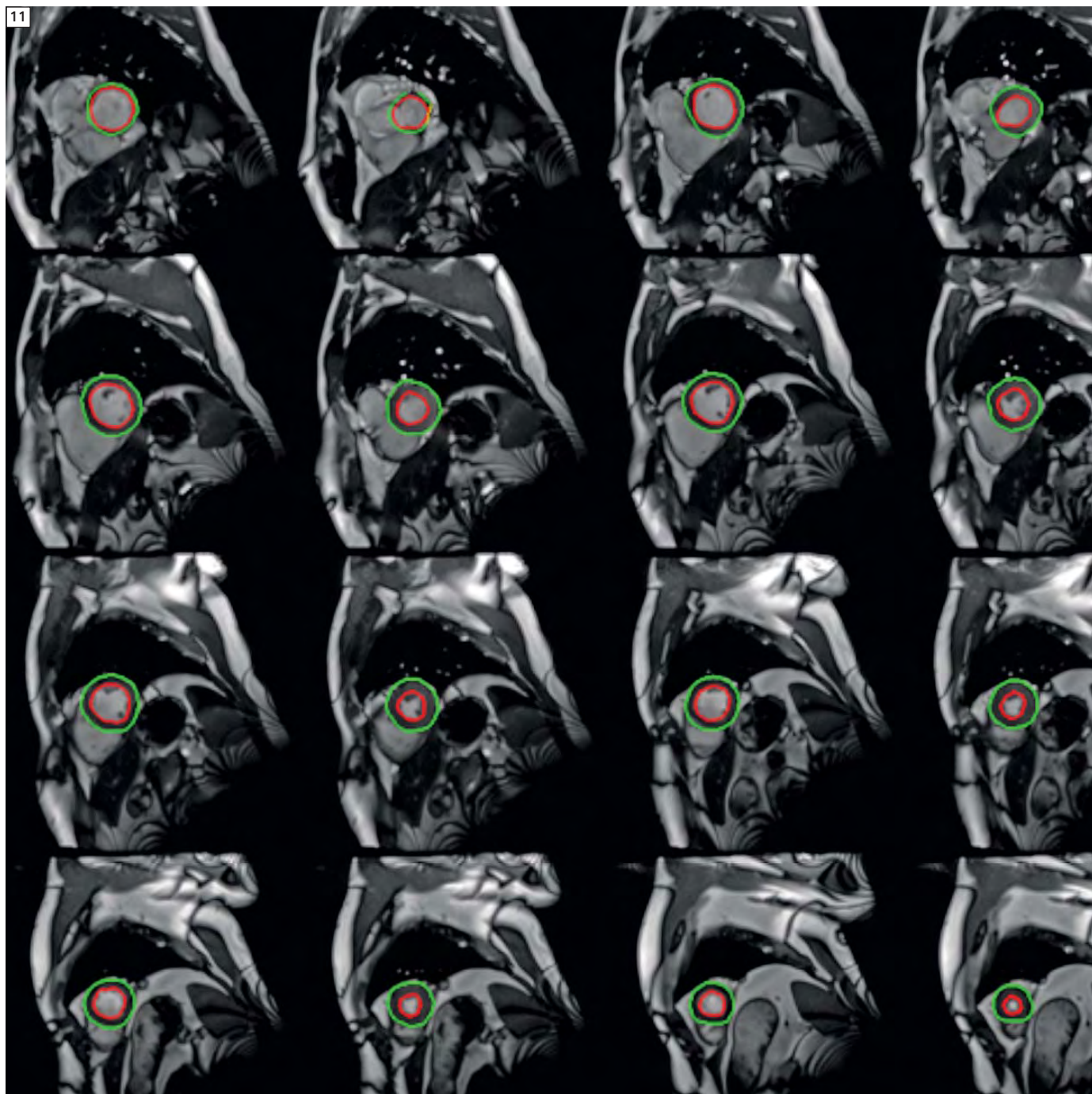
8 Advantages of cartilage knee imaging at 3T: 3T imaging (left side) compared to 1.5T imaging (right side). While the 4th grade cartilage injury of the medial condyle is apparent in both sequences, the cartilage damage of the lateral condyle is much more subtle. 3T images the damage much more realistically and enables a better assessment. The PD fat sat sequence at 1.5T exaggerates the damage and indicates a 4th grade damage, while in reality there is only a 3rd grade injury.



9 The new 16-channel whole-hand coil delivers extraordinary image quality that clearly surpasses that of 1.5T.



10 The SNR gain is dramatically seen in small volume imaging such as finger imaging. The comparative study of this cartilaginous exostosis demonstrates the higher detail resolution and the superior diagnostic information.



11 Cardiac imaging: One of the most impressive features of the MAGNETOM Spectra Cardiac Dot engine is the fully automated user-independent Inline left ventricular analysis. The software instantaneously delivers all functional parameters without a single mouse click directly after the last acquisition of the cine sequences. This technology enables a complete functional assessment of the heart with all qualitative and quantitative parameters within a timescale of just 14 minutes!

artifacts resulting from field inhomogeneity were of full diagnostic image quality. Small structures, vital for a full assessment of the abdomen such as the pancreatic duct, could be visualized with

such detail that even smaller side ducts were assessable. Of all body regions the abdomen was certainly the one where our initial expectations based on the known challenges were exceeded by far.

In our experience 3T abdominal imaging is absolutely possible in a clinical routine workflow with the implemented technologies in the MAGNETOM Spectra (Fig. 12).



MAGNETOM Spectra (left) is the newest addition to the Siemens 3T imaging portfolio. The system is the key to a new level of usability and diagnostic confidence. And it provides access to a new realm of opportunities - regarding patient care and business.

The ACUSON S1000 ultrasound system is a new member of the ACUSON S Family of premium solutions. This entry-level system encompasses state-of-the-art ultrasound technology, stellar imaging performance, and versatile applications at an exceptional cost of ownership.

Accessible Innovations

Across the globe, economic pressure on healthcare systems and its providers is eminent. Industrialized countries are challenged with an aging population and growing demand for healthcare services. Emerging markets and their growing healthcare systems are increasingly in demand of access to premium patient care and imaging capabilities. As a result, reimbursement policies across the globe are being adapted towards increasing accountability for quality and cost across the entire care continuum. Providers must demonstrate lower hospital re-admissions, high-quality outcomes, and low operational costs to stay competitive. With *Accessible Innovations* Siemens offers sensible solutions to meet these demands in the field of medical imaging.

Emerging countries are dedicated to building accessible healthcare systems that ensure high quality patient care. At the same time, developed countries are driving towards making healthcare more efficient, more applicable and more personalized for all parties involved. All across the globe, the amount of people in need for health services is rising and the financial range has limits.

It is no surprise that Total Cost of Ownership (TCO) is an important factor influencing the international

healthcare environment. Determining the economic value of an investment is important for all healthcare providers – regardless of their circumstances. Assessing total cost of acquisition, operating costs and investment protection highly contributes to profitability over time. Profitability may by no means be confused with our responsibility to provide high level imaging standards that benefit the patient in the end. Within this context and to serve common goals among the global healthcare landscape, Siemens is introducing a new range of imaging systems. With *Accessible Innovations* we are equally improving the availability, quality and efficiency

of healthcare by combining state-of-the-art diagnostic capabilities with a highly sensible TCO argumentation for our customers. Quantifying the financial impact of deploying a healthcare product over its lifecycle goes hand in hand with making healthcare more accessible for more people all over the world. SOMATOM Perspective, ACUSON S1000 and MAGNETOM Spectra are the first products that prove we are taking our responsibility seriously – the responsibility to innovate and invest in cost-efficient, premium imaging standards.

www.siemens.com/the-key-to-3T
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SOMATOM Perspective is the first high-end CT scanner to facilitate CT business without compromising clinical results. The business class scanner can help manage financial performance while focusing on patient needs and easing your daily routine.



12 Although 3T is not considered to be the best imaging modality for the abdomen, MAGNETOM Spectra delivers undisputable image quality. The example here is of a patient with multiple enlarged side ducts of the pancreas, a typical condition of suspected IPMN. The cross-sectional image using a fat saturation technique proves that larger patients can also be imaged and that the MAGNETOM Spectra magnet delivers a very homogenous B_0 and B_1 field for uncompromised abdominal image quality.

Summary

After only a short experience with the 3T MAGNETOM Spectra, we can already recommend the system for routine performance for all organs. This especially applies to the user interface and system operation which is largely the same as that for 1.5 Tesla systems and indeed considerably easier when using Dot engines. The sequence spectrum already included in the delivered software allows MAGNETOM Spectra to be immediately put into clinical operation. The benefit of the higher signal-to-noise ratio available by doubling the field strength also allows for a considerably improved image quality even when comparing it to high-end 1.5 T systems. This applies in particular to neurological examinations as well as joint diagnostics. The higher signal can be used to increase spatial resolution or to accelerate the examination as such (a combination of both under ideal circumstances).

In conclusion, MAGNETOM Spectra is an MR system that has the potential of a workhorse in the private radiology practice especially under the harsh economic conditions of statutory healthcare. As a result, 3T technology is no longer reserved just for scientific or university based centers. For us the upcoming challenge will be to explain to patients and referring physicians why not every medical question needs to be answered by a 3T MRI.

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