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EDITORIAL

Recent advances in medical physics

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Abstract Some of the major interests in medical physics over the last few years have concerned the technical advances in Computed Tomography and high field Magnetic Resonance Imaging. This review discusses the introduction of Dual Source CT and explains how it can not only offer faster data acquisition but also operate with lower radiation doses. This provides enormous benefits for all patients, but for cardiac and pediatric examinations in particular. The advances in MRI at 7 T esla are also impressive, with better signal to noise; cardiac and musculoskeletal applications are discussed; technical improvements are work-in-progress for other applications.

Keywords Dual source computed tomography · Radiation dose · Highfield MRI · 7-Tesla MRI · Cardiac applications

Diagnostic imaging is a field of research and development which has strongly grown in importance over the last decades in general but in particular also for medical physics. While x-ray imaging and related dose issues were the traditional issues for medical physics for nearly a century, the focus now is on modern three-dimensional imaging. This trend, well reflected in *European Radiology*, has little to do with basic or pure medical physics. It mostly concerned work regarding the physical principles, related technologies, the testing of new approaches and apparatus in cooperation with radiologists. X-ray computed tomography (CT) and magnetic resonance imaging (MRI) dominated as topics. Below we will refer to high-pitch dual-source CT and to 7 T MRI as examples which both offer challenges to medical physics and radiology and are of great interest with respect to their potential for clinical radiology.

"What are the limits of 'scan' speed in CT?" This question was not in fashion 20 years ago; at that time the assumption prevailed that CT was "dead" and that it would, in time, be substituted largely by MRI. The introduction of multi-slice spiral CT changed the situation completely as was covered well over the years by original articles in *European Radiology*. High-pitch dual-source CT which emerged around 2008, was also first presented in *European Radiology*. What has come from that promise?

Dual-source CT (DSCT) was introduced to clinical radiology around 2005 [1, 2]. The principal innovation may appear trivial: Instead of one, a DSCT system simply houses two x-ray tubes and two detectors under its cover. To get DSCT to work was, above all, an engineering effort, but image quality issues mostly due to scattered radiation originating from two sources proved to be a major additional challenge. But now there are many hundreds of clinical DSCT installations worldwide that work reliably and have set a new standard for high-speed CT.

A primary motivation for DSCT was to provide shorter CT data acquisition times for cardiac imaging and at the same time to provide the necessary x-ray power. The solution provided is straightforward: the effective CT data acquisition time is cut in half since two acquisition systems work in parallel; the x-ray power is doubled because there are two x-ray tubes. DSCT has proven to offer superior diagnostic results in numerous cardiac studies [3, 4]. Effective CT data acquisition times of below 100 ms per image are now standard for cardiac CT. The next challenge was to reduce the total examination time.

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Pitch is defined as the ratio of table feed per rotation to the detector coverage: $p = d/NT$. Whenever pitch is increased for a spiral CT examination, the total CT data acquisition is reduced accordingly. In single-slice CT a maximum pitch=2 is possible; for multi-slice CT this value is reduced to typically 1.5. DSCT allows pitch can be doubled to about 3. If a slightly reduced field of measurement is acceptable, as for example in cardiac or pediatric CT, values up to typically 3.4 are allowed. For 64-slice CT systems with a rotation time of 0.3 s or less, table feed values of 40 cm/s or slightly higher result. Of course, there initially is the concern if this technique has possible limitations with respect to image quality. Ertel, Lell et al. were able to show by phantom experiments supported by motion robots that the two critical parameters temporal resolution and spatial resolution were unimpaired [5]. Tacelli, Remy-Jardin et al. confirmed these results by clinical studies [6]. Both these studies have meanwhile been confirmed numerous times.

What does this mean for clinical practice and for the future of CT? The practical advantages are considerable, in particular with respect to ease of operation and patient comfort. The complete body trunk can be examined in about two seconds making motion artifacts truly rare. The complete heart is covered in about one quarter of a second, i.e. during a single heart beat. Pediatric CT data acquisition takes less than a second, obviating the need for sedation in many cases. And all this without an increase in dose. On the contrary, sub-mSv CT has become a new term and is entirely related to the advent of DSCT [7, 8]; an example is shown in Fig. 1. CT seems set to continue to prosper further.

"What is 7 T MR on humans good for?" This question motivates an ever-growing number of researchers worldwide to explore and to further expand the limits of highfield MR.

Since around the year 2006 the number of worldwide installations of 7 T esla (7 T) highfield MR systems for human whole-body examination is steadily increasing. The driving motivation behind this trend clearly is the gain in signal-to-noise-ratio (SNR) associated with higher field strength that can be considered "the

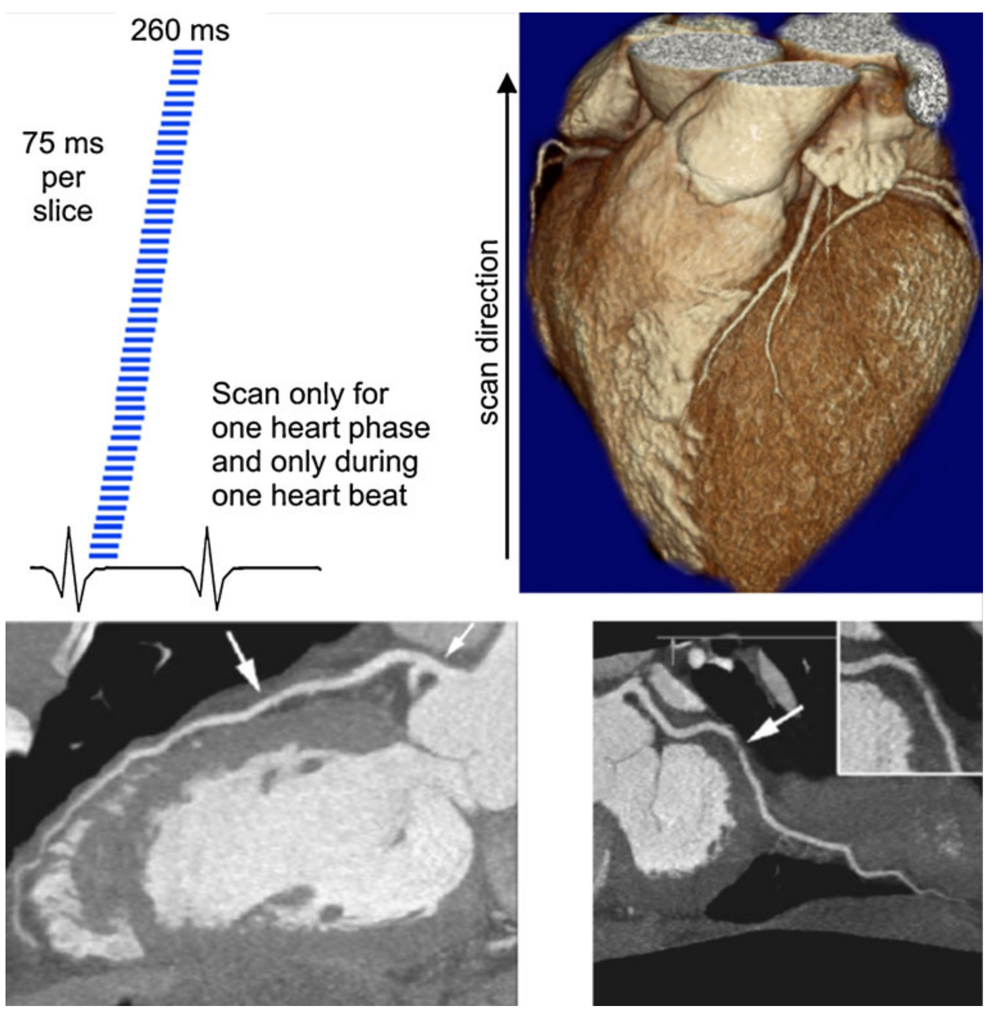

Fig. 1 High-pitch dual source spiral CT. 0.26 s scan of the coronary arteries at pitch 3.2 and an effective dose of 0.8 mSv. The temporal acquisition scheme is illustrated in the top left quadrant, a 3D and multi-planar views in quadrants two to four. (Images are a courtesy of S. Achenbach, Erlangen, Germany) [8]

currency" of MR. High SNR potentially can be traded in improved spatial and/or temporal resolution for detailed image quality and rapid image acquisition times. Also a number of physical effects such as changing tissue relaxation times, increased magnetic susceptibility, and increased chemical shift-to name only a few-provide the basis for dramatically further improving the inherently excellent soft tissue contrast of MR with high field strength.

The continuously rising number of installed 7 T high-field MR systems is also reflected in the significant number of scientific papers dedicated to 7 T highfield MR, that have been published in European Radiology in the years 2009 and 2010. All of these papers show early clinical applications of this field strength. Due to the enormous physical and technical challenges of MR imaging at 7 T, that are associated with a short radio-frequency (RF) excitation wavelength, the initial application of human 7 T MR often stays limited to "bits and pieces" and imaging of body parts small enough to fit into the vendor provided RF head coils. Against this backdrop, we have recently seen examples of early 7 T Neuro applications [9–11], 7 T Musculoskeletal applications [12], as well as high resolution 7 T highfield MR of ex vivo specimen of axillary lymph nodes [13] in European Radiology.

Exploring 7 T highfield MR beyond Neuroradiological and Musculoskeletal applications requires the fundamental development of novel RF signal excitation and reception strategies featuring multiple independent RF transmit/receive channels. This is a technical precondition required before finally overcoming the limitations such as the heterogeneous B1-field distribution and the prevention of local increases in the specific absorption rate (SAR), all necessary for the safe application of highfield MR. The endeavours towards body and cardiac MR at 7 T are currently under way at selected highfield institutions. Figure 2 shows a first example of 7 T in vivo human cardiac MRI. Among the first reports about the general challenges of whole-body MR at 7 T are the papers by Niendorf et al. and by von Knobelsdorff-Brenkenhoff et al. that can be found in most recent issues of European Radiology [14, 15]. We are current eyewitnesses towards the first clinical applications of cardiac MR at 7 T. Keep your eyes open on the progress still to come in this exciting (high) field!

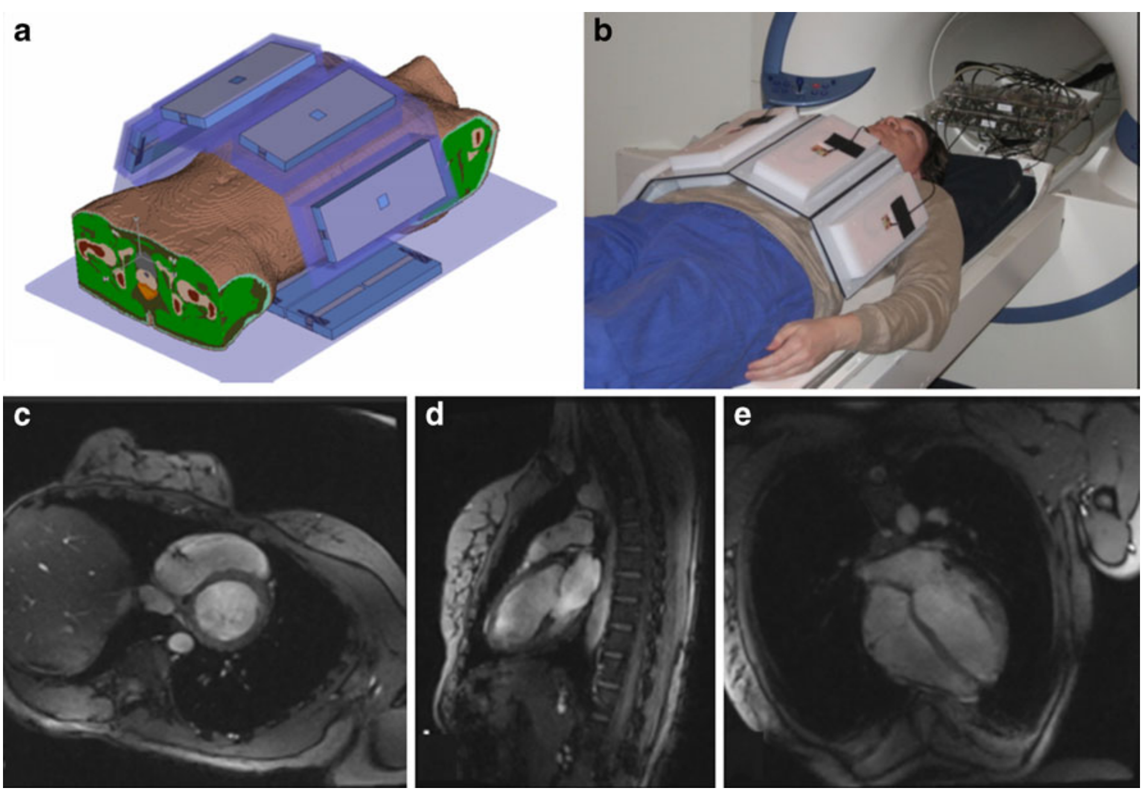

Fig. 2 Custom-built 8-channel radiofrequency (RF) transmit/receive body coil for 7 T cardiac imaging. Image **a** shows numeric simulations on an anatomic body model. **b** Photograph of the realized body coil prototype. **c**–**e** First 7 T in vivo human cardiac images acquired on a healthy volunteer, showing short axis (**c**), two-chamber view (**d**), and four-chamber view (**e**). Imaging parameters were: FLASH 2D cine sequence, flip angle 40°, FOV 340×306 mm, resolution 1.4×1.4×4.0 mm^3, GRAPPA R=2, 20 phases per RR interval, acquisition time 11 s/20 phases. (All images courtesy of Erwin L. Hahn Institute for MRI, University of Duisburg-Essen, Essen, Germany.)

References

1. Flohr TG, McCollough CH, Bruder H et al (2006) First Performance Evaluation of a Dual-Source CT (DSCT) System. Eur Radiol 16:256–268
2. Johnson TRC, Nikolaou K, Wintersperger BJ et al (2006) Dual-source CT cardiac imaging: initial experience. Eur Radiol 16:1409–1415
3. Rist C, Johnson TR, Becker CR, Reiser MF, Nikolaou K (2007) New applications for noninvasive cardiac imaging: dual-source computed tomography. Eur Radiol 17(suppl 6):F16–25
4. Achenbach S, Anders K, Kalender WA (2008) Dual-source cardiac computed tomography: image quality and dose considerations. Eur Radiol 18:1188–1198
5. Ertel D, Lell MM, Harig F, Flohr T, Schmidt B, Kalender WA (2009) Cardiac spiral dual-source CT with high pitch: a feasibility study. Eur Radiol 19:2357–2362
6. Tacelli N, Remy-Jardin M, Flohr T et al (2010) Dual-source chest CT angiography with high temporal resolution and high pitch modes: evaluation of image quality in 140 patients. Eur Radiol 20:1188–1196
7. Achenbach S, Marwan M, Ropers D et al (2010) Coronary computed tomography with a consistent dose below 1 mSv using prospectively electrocardiogram-triggered high-pitch spiral acquisition. Eur Heart J 31:340–346
8. Kalender WA (2011) Computed tomography. Fundamentals, system technology, image quality, applications, ed 3nd. Publicis, Erlangen
9. Moenninghoff C, Maderwald S, Theysohn JM, Kraff O, Ladd ME, El Hindy N, van de Nes J, Forsting M, Wanke I (2010) Imaging of adult astrocytic brain tumours with 7 T MRI: preliminary results. Eur Radiol 20:704–13
10. Conijn MM, Hendrikse J, Zwanenburg JJ, Takahara T, Geerlings MI, Mali WP, Luijten PR (2009) Perforating arteries originating from the posterior communicating artery: a 7.0-Tesla MRI study. Eur Radiol 19:2986–2992
11. Zwanenburg JJ, Hendrikse J, Visser F, Takahara T, Luijten PR (2010) Fluid attenuated inversion recovery (FLAIR) MRI at 7.0 Tesla: comparison with 1.5 and 3.0 Tesla. Eur Radiol 20:915–22
12. Chang G, Wang L, Schweitzer ME, Regatte RR (2010) 3D 23Na MRI of human skeletal muscle at 7 Tesla: initial experience. Eur Radiol 20:2039–2046
13. Korteweg MA, Zwanenburg JJ, van Diest PJ, van den Bosch MA, Luijten PR, van Hillegersberg R, Mali WP, Veldhuis WB (2010) Characterization of ex vivo healthy human axillary lymph nodes with high resolution 7 Tesla MRI. Eur Radiol. doi:10.1007/s00330-010-1915-3
14. von Knobelsdorff-Brenkenhoff F, Frauenrath T, Prothmann M, Dieringer MA, Hezel F, Renz W, Kretschel K, Niendorf T, Schulz-Menger J (2010) Cardiac chamber quantification using magnetic resonance imaging at 7 Tesla-a pilot study. Eur Radiol 20:2844–52, Epub 2010 Jul 17
15. Niendorf T, Sodickson DK, Krombach GA, Schulz-Menger J (2010) Toward cardiovascular MRI at 7 T: clinical needs, technical solutions and research promises. Eur Radiol 20:2806–16, Epub 2010 Jul 31